Toxicology Reports 13 (2024) 101730

Contents lists available at ScienceDirect

Toxicology Reports

journal homepage: www.elsevier.com/locate/toxrep

The level, source, and health outcome of $PM_{2.5}$ exposure in Southwest Iran

Bahram Kamarehei [a], Majid Farhadi [a,b,*], Farshid Soleimani [c], Mahya Dolati [d], Arefeh Sepahvand [a,b], Marzieh Bayat [b,e], Ali Farhadi [e], Ayda Sepahvand [b,e], Mohammad Javad Mohammadi [f,g,**]

[a] Environmental Health Research Center, Lorestan University of Medical Sciences, Khorramabad, Iran
[b] Educational Development Center, Lorestan University of Medical Sciences, Khorramabad, Iran
[c] Tobacco and Health Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran
[d] Student Research Committee, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[e] Student Research Committee, Lorestan University of Medical Sciences, Khorramabad, Iran
[f] Department of Environmental Health Engineering, School of Public Health and Environmental Technologies Research Center, Medical Basic Sciences Research Institute, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[g] Air Pollution and Respiratory Diseases Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

ARTICLE INFO

Keywords:
Particulate matter
Mortality
Respiratory disorders
Cardiovascular disease
Ahvaz

ABSTRACT

Introduction: Dusty storms considerably increase airborne particles in dry and semi-dry locations, such as deserts with no plants and strong winds. Therefore, the environment and people are affected severely. Ahvaz, an important metropolis, is often polluted by neighboring nations. The present research studies the concentration, source, and calculation of these particles' effects.
Material and method: For health consequences evaluation, the WHO suggests the Air Quality Health Impact Evaluation Programmed (Air Q 2.2.3). Khuzestan Meteorology Office recorded particulate matter measurements on both hazy and clear days. The data was gathered voluminously in 2023.
Result: According to data collected from Khuzestan province's meteorology documents, 49 days in 2023 had very unsafe air quality. The most polluted months in terms of the number of dust days are as follows: January (14 days) > December (12 days) > November (11 days) > August (5 days) > May (3 days) > September (2 days) > March, February, June, July, October (1 day) > April (0 days). HYSPLIT maps indicate that Iran causes dust in March, the Great Arabian Desert in December and August, Iraq in April, September, and October, Kuwait in January, Turkey in February and July, Egypt in June and May, and Oman in November.
Conclusion: The meteorology database reveals that Ahvaz is highly polluted and that 49 days had unacceptable dust levels. Based on assessments obtained employing the Air Q+ programs, the people of Ahvaz encountered heart disease, respiratory disease, and stroke caused by their exposure to $PM_{2.5}$ particulates.

1. Introduction

Airborne Particulate matter (PMs) can be inhaled by us in various quantities. Although most of those PMs are readily eliminated by the mucociliary system[1], this $PM_{2.5}$ fraction, referred to as the lung fraction with an aerodynamic diameter of less than 2.5 μm, is kept in the lungs and makes up 96 % of the particulates seen in human respiratory parenchyma[2]. Considering fine particle aerosols, or $PM_{2.5}$, are quickly inhaled directly into the respiratory system, so is increasing worry about them. New modifications to the National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ have been implemented by the US EPA according to these problems. The modified $PM_{2.5}$ guidelines currently set the thresholds for the 24-hour average and yearly average at 35 and 15 $\mu g\ m^{-3}$, respectively[3]. PM inhalation has negative impacts on the cardiovascular and breathing systems of young and old. PM, especially $PM_{2.5}$, possesses the ability to completely enter the respiratory tract and circulation upon breathing, leading to asthma, lung cancer, heart attacks, and possibly fatal results[4]. In addition, $PM_{2.5}$ enters the gas-exchange area of the lung [5], it additionally may also penetrate the lung barrier, enter the bloodstream, and eventually move throughout

* Corresponding author at: Environmental Health Research Center, Lorestan University of Medical Sciences, Khorramabad, Iran.
** Corresponding author at: Air Pollution and Respiratory Diseases Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.
E-mail addresses: Mirmajid100farhadi@gmail.com (M. Farhadi), F.soleimani72@yahoo.com (F. Soleimani), javad.sam200@gmail.com (M.J. Mohammadi).

https://doi.org/10.1016/j.toxrep.2024.101730
Received 31 July 2024; Received in revised form 3 September 2024; Accepted 4 September 2024
Available online 6 September 2024

the entire body [6,7]. The more particular area of $PM_{2.5}$ additionally allows it to quickly bind to toxic compounds, such as transitional metals and Polycyclic aromatic hydrocarbons (PAHs)[8]. Therefore, $PM_{2.5}$ is more strongly related to adverse health impacts than big particles. WHO has proposed PM as an indicator of particulate matter pollution, which is currently a major threat to global health[9]. Several investigations indicate the detrimental health impacts of suspended PM, such as a higher incidence of adverse respiration symptoms in kids, hospital admissions, and premature death[10]. Despite numerous studies over the years on the health consequences of airborne particulates, it remains unclear what kinds of PMs are dangerous. Prior studies on the health effects of PM exposure used various measurements for PM, such as total suspended particles (TSP), coefficient of haze (COH), black smoke, British smoke, KM (a measure of particulate optical reflectance), and PM_{10} and $PM_{2.5}$. These measurements don't accurately indicate composition; instead, they represent PM mass within specific size ranges. To achieve efficient management of airborne particles, it is essential to collect data on the causes that contribute to the features of PM that pose health risks[11,12]. The adverse health impacts of $PM_{2.5}$, a PM biomarker included in the 1997 NAAQS, are becoming the subject of an increasing number of research. Due to a documented recognition of the dosage of particulates in these sizes within the pulmonary system and epidemiological information verifying the particular negative effects of $PM_{2.5}$, this indicator was incorporated in the 1997 NAAQS [13, 14]. Nevertheless, as there was very little data known about the attributes of PM in these sizes that could indicate toxicity, an extensive mass-based guideline was developed. Metals, organic substances absorbed onto particulates or building fragments themselves, biological components, sulfate (SO_4^{2-}), nitrate (NO_3^-), pH level, and surface-adsorbed reactive substances like ozone (O_3) belong to the properties of $PM_{2.5}$ that may be associated with toxicity[15,16].

The city of Ahvaz is one of the most polluted cities in the world, the reason for the pollution of this region is the association with dry and semi-desert countries. Every year, dust storms are seen in Southeast Asian countries, and a large amount of this dust first passes through Khuzestan province and is transferred to other provinces.

2. Material and method

2.1. Study area

Ahvaz, which is situated in the center of Khuzestan province and spans an area of 185 km^2, is located at 31° 19′ N, 48° 40′ E, in the southwest region of Iran, close to the Persian Gulf. Ahvaz city is among Iran's biggest cities. About 1300,000 persons reside in Ahvaz[17]. About 140 km2 of areas usually experience warm temperatures, with long, mild winters and hot summers exceeding 50°C[18]. The deputy director of Healthcare in Ahvaz City obtained $PM_{2.5}$ data from the Ministry of Environmental and Meteorology Office. Fig. 1 shows the exact geographic location of Ahvaz city, which is the area under investigation.

2.2. Air Q^+

The WHO has authorized the Air Quality Health Assessment Program (Air Q 2.2.3) as a useful method to evaluate adverse health effects. The approach, which was established by the WHO European Centre for Environment and Medicine, utilizes concentration-response equations and time-series assessment methods for evaluating the adverse effects of

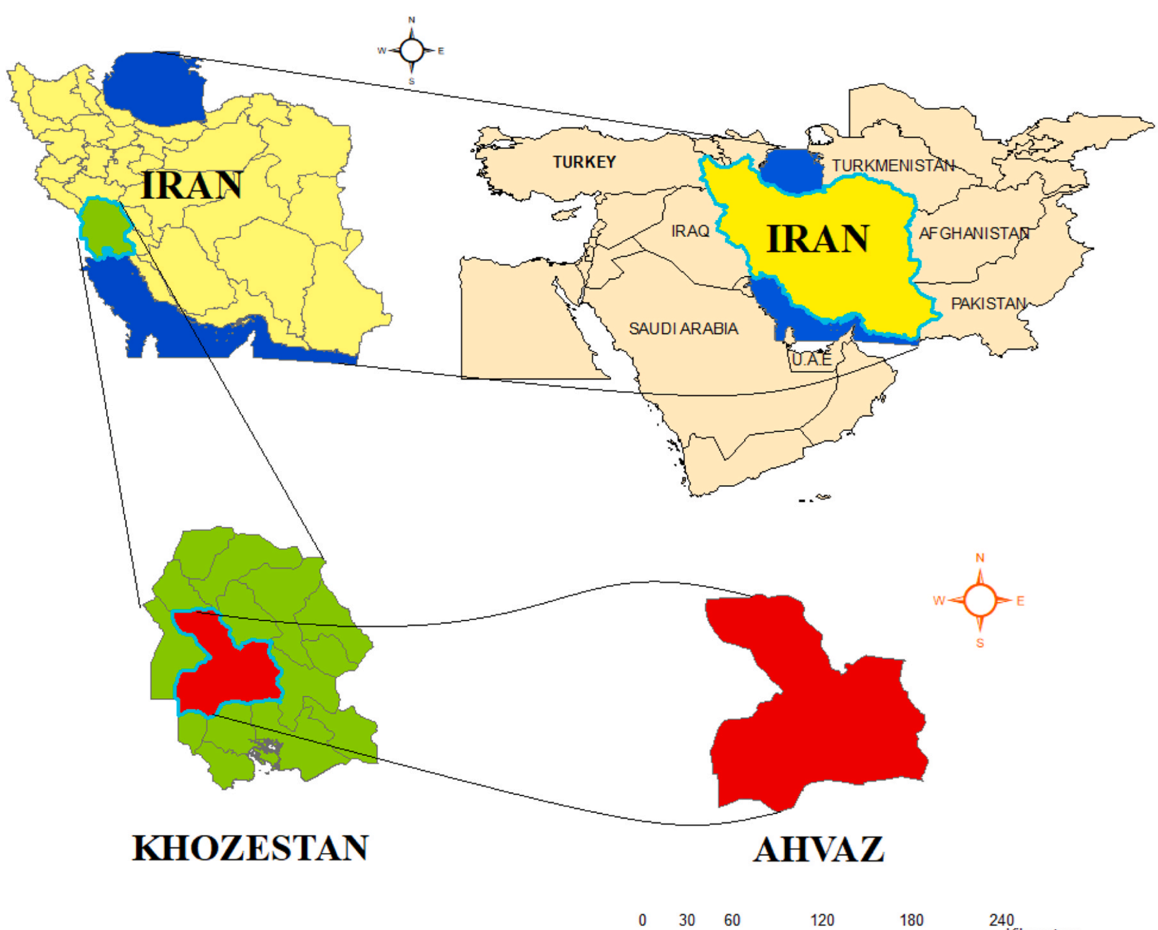

Fig. 1. Geographical location of Ahvaz city.

airborne contaminants on those living in a specific region and period. Initially, to determine the effect of $PM_{2.5}$ on death, we utilized Relative Risks (RR) established by a time-series methodology. While evaluating the impact of short exposures on health, the mean daily level—which is associated with risk categories and can be split into levels of 10 μg/m^3—is used. nevertheless, in evaluating the long-term impacts of exposure, demography has to be considered. Minimizing the adverse health consequences of exposure to airborne contaminants has been a key component of medical policy talks on air quality management. The WHO has authorized the Air Q+ program for use in ecological research. The equipment emphasizes using epidemiological data to figure out the impact of pollution on humans at a particular location and time. The tool utilizes measuring techniques and mathematical formulas[19].

2.3. Data analysis

Information on atmospheric contaminants provided by the Khuzestan Environmental Ministry was required to make sure the model ran. The Khuzestan Meteorological Office provided data on the concentrations of PM on days with and without dust. Mortality data comes from the Health Ministry and the Iranian Statistical Centre. Data for 2023 was collected in large amounts. Using the Air Q^+ approaches, we investigated the negative impact of inhaled $PM_{2.5}$ on health. $PM_{2.5}$ has been chosen as the pollutant to be evaluated with the Air Q^+ technology. An investigation was done using information regarding air quality to analyze epidemiology indicators, including Attributable Proportion (AP), Relative Risk (RR), Baseline Incidence (BI), and mortality rate per 100,000 individuals. RR estimates the probability of getting a disease as the outcome of pollution exposure. Using Air Q^+ information sets that the WHO has made accessible, the RR and BI coefficients were calculated. The Ahvaz meteorological site measured a 24-hour mean level of $PM_{2.5}$ of 56.64 μg/m^3.

3. Result and discussion

3.1. The level of particles in $PM_{2.5}$

Descriptive results from data collection are reported in Table 1. The $PM_{2.5}$ concentration was reportedly moderate on 4 days in January, including the 6th, 15th, 30^{th,} and 31st. Thirteen days of this month, the weather condition was reported as unhealthy for sensitive people. The remaining two weeks were considered unhealthy. The highest concentration was recorded on January 4 (169 μg/m^3) and the lowest was reported on the 30th (75 μg/m^3). The average monthly $PM_{2.5}$ concentration was also 135.77 μg/m^3 (SD:23.5). $PM_{2.5}$ concentration, in February, 17 moderate days were reported, 7 days of this month the air condition was reported as unhealthy for sensitive people; These days were the 3rd, 8th, 22nd, 23rd, 24th, 25th, and 26th. 1 day was considered unhealthy (2nd) (Fig. 2). The highest concentration was recorded on February 2 (160 μg/m^3) and the lowest was reported on the 10th (58 μg/m^3). The average monthly concentration of $PM_{2.5}$ was also expressed as 97.44(±25.5). The monthly average concentration of $PM_{2.5}$ in March is 92.09(±25.6), its maximum concentration is 156 μg/m^3 (6th) and its minimum concentration is 50 μg/m^3 (21st) in this month. Nine days this month had weather considered dangerous for those with sensitive, while the other twenty days had moderate conditions. The monthly average concentration of $PM_{2.5}$ in March was 69.12 μg/m^3 (±15). This month's minimum and maximum concentrations recorded were 49 μg/m^3 (2nd) and 109 μg/m^3 (30th), respectively. The only day the weather was reported as unhealthy for sensitive people was April 30; There was only one very clear day this month (2nd). 28 days of the rest of the month, the condition was reported as moderate. The air condition for May comprised three days that were regarded as unsafe (the 24th, 25th, and 28th), sixteen days that were deemed hazardous for those with sensitivity, and 10 days that were regarded as moderate. The monthly average concentration of $PM_{2.5}$ is 105.72 μg/m^3 (±27), the lowest and highest recorded concentrations are 50 μg/m^3 (2nd) and 158 μg/m^3 (24th). The minimum and maximum reported concentrations of $PM_{2.5}$ in June belonged to the 2nd (46 μg/m^3) and the 13th (151 μg/m^3). The average monthly concentration was 80.44 μg/m^3 (±26.25). In total, 30 days of recorded concentration of particles, air condition has 1 good day, 25 moderate days, 3 unhealthy days for sensitive people, and 1 completely unhealthy day. The recorded $PM_{2.5}$ concentration of unhealthy days for sensitive people on the 14th, 15th, and 19th are 104 μg/m^3, 116 μg/m^3, and 128 μg/m^3, respectively. According to the results obtained from July, 18 days were reported as moderate, 12 days as unhealthy for sensitive people, and only 1 day as unhealthy air condition. The 4th (104 μg/m^3), 5th (113 μg/m^3), 6th (126 μg/m^3), 7th (133 μg/m^3), 14th (103 μg/m^3), 15th (110 μg/m^3), 16th (103 μg/m^3), 22nd (113 μg/m^3), 23rd (105 μg/m^3), 24th (105 μg/m^3), 30th (111 μg/m^3), and 31st (143 μg/m^3) days are recorded as unhealthy days for sensitive people. The minimum, maximum, and average monthly $PM_{2.5}$ were reported as 63 μg/m^3, 155 μg/m^3, and 98.16 μg/m^3 (±23), respectively. Although 4 days of August were not reported, the 30th (60 μg/m^3) and 18th (189 μg/m^3) were recorded as the minimum and maximum $PM_{2.5}$ concentrations. The monthly average of particles was reported as 119.92 μg/m^3 (±32.25). Six days of this month were reported as moderate, 16 days as unhealthy for sensitive people, and 5 days as unhealthy. Eighteenth (189 μg/m^3), 19th (156 μg/m^3), 20th (158 μg/m^3), 22nd (168 μg/m^3) and 23rd (173 μg/m^3) are recorded as completely unhealthy. September 6 (159 μg/m^3) and 10th (156 μg/m^3) as unhealthy days; the 3rd (117 μg/m^3), 7th (138 μg/m^3), 9th (144 μg/m^3), 21st (100 μg/m^3), 29th (104 μg/m^3), and 30th (107 μg/m^3) are also reported as unhealthy days for sensitive people. The rest of the days of this month are recorded as moderate. The minimum, maximum, and average concentrations of $PM_{2.5}$ recorded for this month were 56 μg/m^3, 159 μg/m^3, and 95 μg/m^3 (±25.75), respectively. Six days of air conditioning in October were reported as unhealthy for sensitive people and 1 day as completely unhealthy (31st). The 1st, 21st, 22nd, 23rd, 24th, and 25th were the days that were reported as unhealthy air conditions for sensitive people, where the $PM_{2.5}$ concentration was 107 μg/m^3, 130 μg/m^3, 125 μg/m^3, 100 μg/m^3, 117 μg/m^3, and 116 μg/m^3, respectively. Even though 4 days in this month, $PM_{2.5}$ concentration was not reported (26th, 27th, 29th, and 30th), another 19 days were recorded as moderate. According to the results, November (with 25 days of polluted air) was the second most polluted month of 2023 in Ahvaz city. The lowest and highest concentrations of $PM_{2.5}$ recorded in Ahvaz city were reported in November 65 μg/m^3 (17th) and 180 μg/m^3 (11th). Only 5 days of this month the weather was reported as moderate; While two weeks of it were unhealthy conditions for sensitive people and 11 days were completely unhealthy air. 1st (163 μg/m^3), 2nd (161 μg/m^3), 9th (160 μg/m^3), 10th (173 μg/m^3), 11th (180 μg/m^3), 12th (163 μg/m^3), 13th (164 μg/m^3), 14th (161 μg/m^3), 15th (161 μg/m^3), 19th (159 μg/m^3), and 26th (156 μg/m^3) were completely unhealthy days in this month. It should be noted that the monthly average concentration of $PM_{2.5}$ in this month was 129.13 μg/m^3 (±28.75). December was named as the most polluted month of 2023. In this month, the average

Table 1
Monthly concentration of $PM_{2.5}$.

Month	Min	Max	Mean	SD
January	75	169	135.77	23.5
February	58	160	97.44	25.5
March	50	156	92.09	25.6
April	49	109	69.12	15
May	50	158	105.72	27
Juan	46	151	80.44	26.25
July	63	155	98.16	23
August	60	189	119.92	32.25
September	56	159	95	25.75
October	51	152	90.26	25.25
November	65	180	129.13	28.75
December	84	175	140.03	22.75

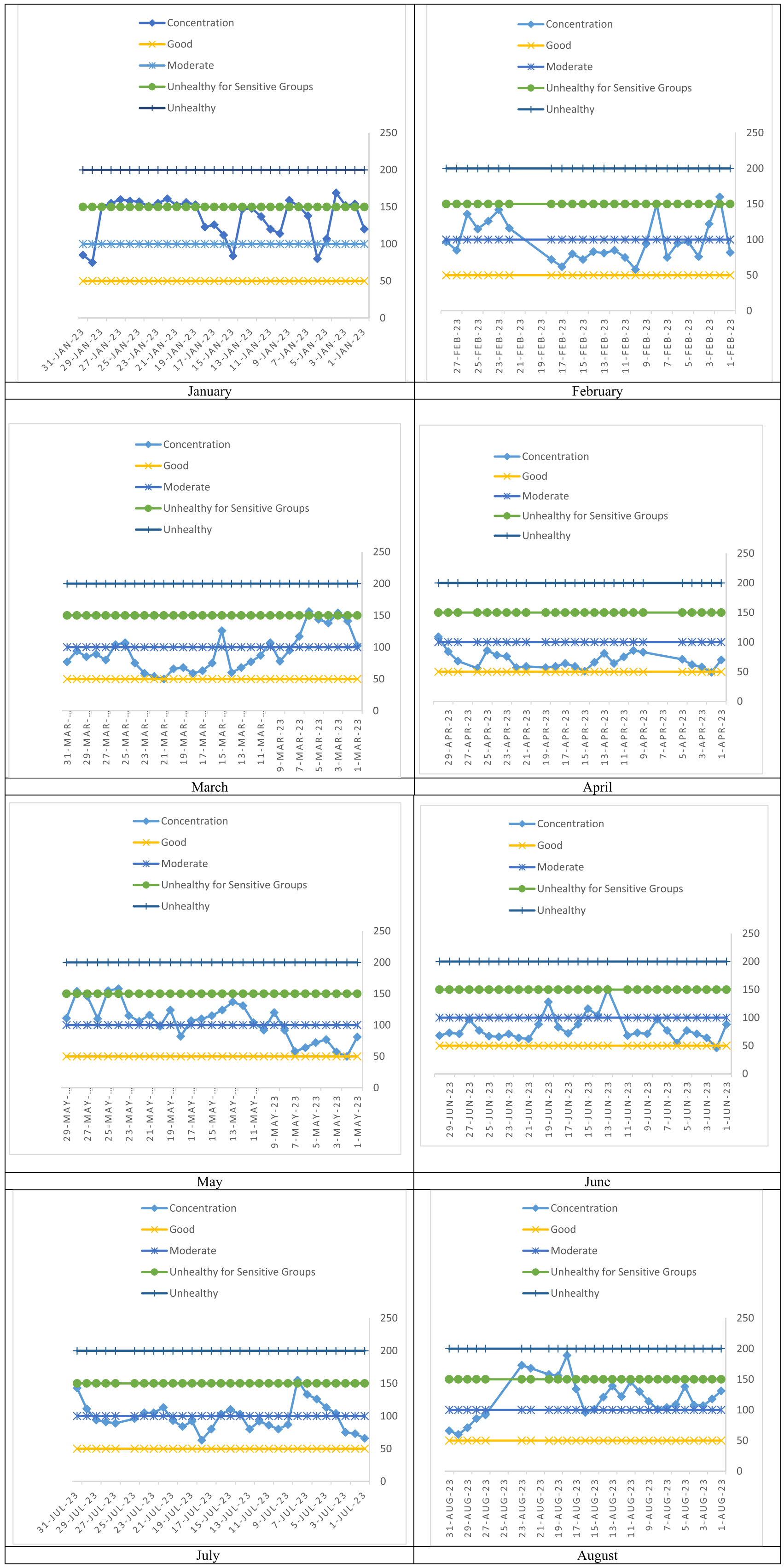

Fig. 2. Monthly concentration of $PM_{2.5}$ and its comparison with AQI.

Fig. 2. (*continued*).

concentration of particles with a diameter less than 2.5 µm was 140.03 µg/m^3 (±22.75) ؛ the lowest and highest concentrations were 84 µg/m^3 and 175 µg/m^3, respectively. Four days of this month were reported as moderate air conditioning, 10 days as unhealthy air conditioning for sensitive people, and 12 days as completely unhealthy; even though meteorological stations did not record 5 days of this month. The annual average of $PM_{2.5}$ concentrations throughout every year of Nikoonahad's study is above the guidelines set by the WHO. Consequently, average, and maximum $PM_{2.5}$ levels in 2014 and 2015 were above the WHO limit of 30 µg/m^3 by roughly 5.6 and 88 times, respectively[20,21]. In 2014, the annual mean and highest levels above the WHO guidelines were 3.35 and 24 times, respectively. Summer seasons have been indicated to have the greatest amount of PM_{10}, while winter seasons often have the lowest amounts. This discovery corresponds with the PM_{10} concentrations reported by Maleki et al. in Ahvaz City, near the region of Ilam[22]. Due to the studied area's dryness and windiness, significant particle dispersion levels occur throughout the year. The problem has been aggravated by city and business development, including the energy and petrochemical industries. Yazd, Arak, Tehran, Tabriz, Shiraz, and Ahvaz recorded average annual PM2.5 concentrations of 103 µg/m^3, 78 µg/m^3, 90 µg/m^3, 85 µg/m^3, 102 µg/m^3, and 385 µg/m^3, respectively[23–25].

3.2. Origin of $PM_{2.5}$ particles

As previously mentioned, January was the second most polluted month in terms of the average concentration of $PM_{2.5}$ (135.77 µg/m^3); Almost two weeks were unhealthy for sensitive people and two weeks were completely unhealthy. The output map from the HYSPLIT program showed that the origin of this dust was Kuwait (Fig. 3). $PM_{2.5}$ concentration, in February, 17 moderate days were reported, and 7 days of this month the air condition was reported as unhealthy for sensitive people; 1 day was considered unhealthy. The highest concentration was recorded on February 2 (160 µg/m3). The output map from the HYSPLIT program showed that the origin of the February 2 dust was Turkey. In July, during the first week of air conditioning, only one day (the 2nd) showed a concentration of $PM_{2.5}$ which was completely harmful caused by dust. Turkey was responsible for the dust throughout the initial week of July. The concentration of particles in the last decade was reported to have 7 days of unhealthy air conditioning for sensitive people and 3 days of completely unhealthy air conditioning. The minimum, maximum, and average monthly $PM_{2.5}$ were recorded as 50 µg/m^3, 158 µg/m^3, and 105.72 µg/m^3 respectively. May 24 was declared as the most polluted day of this month. Second and 23rd recorded the lowest (46 µg/m^3) and highest (151 µg/m^3) $PM_{2.5}$ concentrations recorded in June; The monthly average of particles was 80.44 µg/m^3 (±27). According to the maps extracted from the HYSPLIT program, the origin of dusty days in

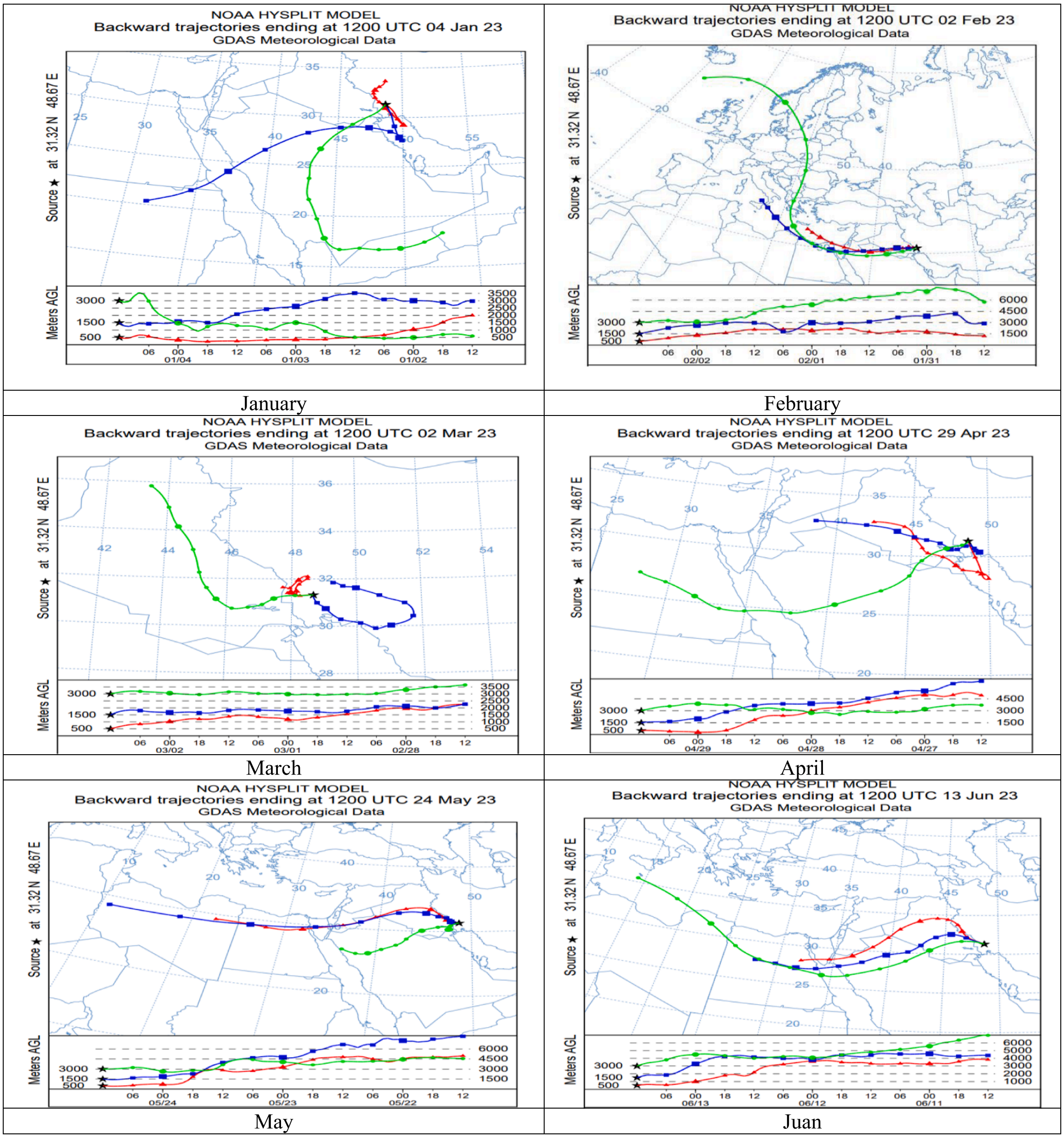

Fig. 3. The origin of monthly dust.

this month and May was Egypt. One of the most polluted months of 2023 in the city of Ahvaz belongs to November, which had 11 completely unhealthy days; The most polluted day of this month in terms of $PM_{2.5}$ concentration was the 11th (180 μg/m^3). The origin of the dust in this month was the country of Oman. The average concentration of $PM_{2.5}$ reported in this month was 129.13 μg/m^3 (±28.75). The Arabian Peninsula was a major source outside of Iran, state Najafi et al. [26]. Akbary and Farahbakhshi [27] reported that the main sources of particulates in Kermanshah were situated in southern Turkey, Syria, Iraq, northernmost Saudi Arabia, and Kuwait. By employing backward trajectory assessment, Soleimani et al. [28] showed that some dust comes from considerably further away, namely the Sahara; throughout the southern monsoon season particulates from regions in the northern part of Africa move over the eastern Arabian Sea to southern Iran[29]. Ashrafi et al. claimed that particulates from Jordanian sources may have accidentally mixed with particulates from the southern Syrian Desert [30].

April was the cleanest month since 2023 in Ahvaz city in terms of $PM_{2.5}$ concentration (69.12 μg/m^3±15); In this month, only one day (30th) the concentration of particles exceeded 100 μg/m^3, which was responsible for the dust that day according to the map extracted from the HYSPLIT program, Iraq. In September, 2 days were reported as completely unhealthy air conditions and 6 days as unhealthy air conditions for sensitive people; The concentration of $PM_{2.5}$ recorded as unhealthy air occurred in the second week of this month, which also originated from Iraq, as in April. According to the map extracted from the HYSPLIT program, the origin of dust in October is Iraq. In October, there were 6 days of unhealthy weather for sensitive people and only one day was completely unhealthy (31st). This month's monthly average of dust was reported as 90.26 μg/m^3. Both the rivers Tigris and Euphrates are significant for Iraq and Syria, as stated by Abdi et al. [31] and Sotoudeh et al. [32], especially during summertime when the area is dominated by powerful Shamal winds. the research of Cao et al. [33], dust is also produced by the swamps that divide Iran and Iraq; however,

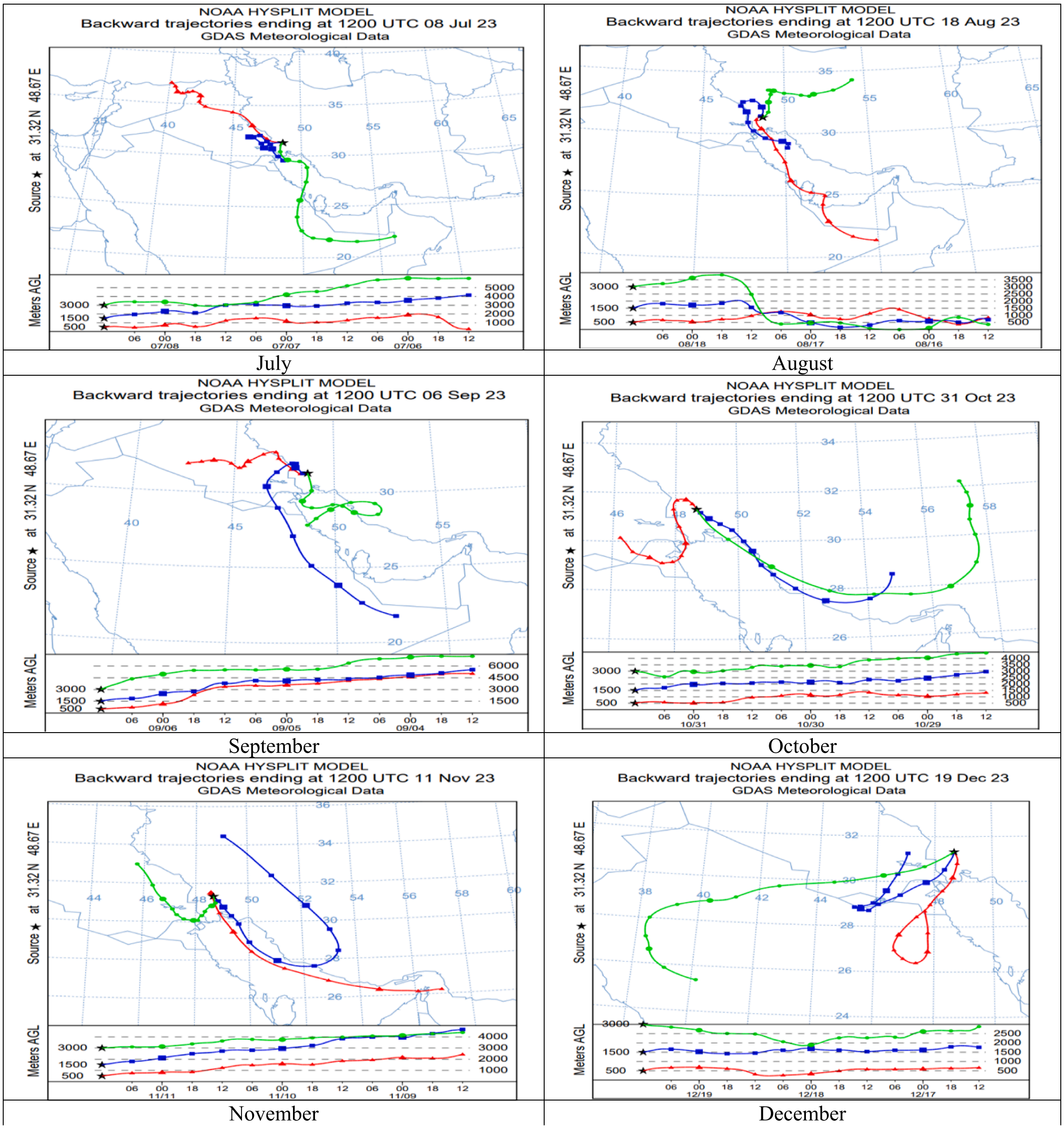

Fig. 3. (*continued*).

Givehchi et al. [34] and Farahani and Arhami [35]indicate that an important amount of dust in Tehran originates from Iraq and Syria. Although these sources are particularly active during summer, particulates from them can enter Iran at any time of the entire year[26].

December had the dustiest days; Two weeks of complete $PM_{2.5}$ concentration was reported as completely unhealthy air and two weeks as unhealthy air condition for people. The most polluted month of 2023 in Ahvaz city belongs to December, and the most polluted day of this month belongs to the 19th (140.03 μg/m^3). August had 16 (consecutive) days of unhealthy air for sensitive people and 5 days of completely unhealthy air, the highest concentration reported in one day was on the 18th (189 μg/m^3). The Great Desert of Arabia was responsible for the dust in the polluted months of December and August. The two main regions affecting the distribution of particulates in southwestern Iran are the area between the Tigris and Euphrates river's eastern and western limits, as well as the southeast region of the Arabian Peninsula[36]. As stated by Boloorani et al. [37] the Tigris/Euphrates origin's importance was affected by certain exterior attributes. Boloorani et al. [38] made a map that showed four main source regions, one of which represented the Saudi Arabian Rub-Al-Khali desert, which Salmabadi et al. [39] had already been identified. The findings of this study show an important portion of dust particles in Iran originated from the northwestern region, west, and southwest areas. The primary origin of these particulates includes the Sahara Desert, the deserts of Syria and Iraq, Saudi Arabia, Kuwait, and the Mesopotamian Plains.

During the 20 days of March, the weather condition was characterized as moderate. However, in 9 of those days, the meteorological condition was classified as unhealthy for people particularly sensitive to it. Only two days in March (the 6th and 8th), saw reports of unhealthy conditions. The origin of March dust was inside Iran (Khuzestan province). Several somewhat small particle sources are scattered around the Khuzestan area in Khuzestan Province, which is situated in southern Iran. As stated by Heidarian et al., 350,000 acres, or 9 % of the plain, are all susceptible to generating dust; however, roughly 50,000 ha of the Al-Azim marshes are situated in this susceptible region [40]. The origins of this dust are destroyed fields, abandoned rain-fed crops, irrigated land, and temporary saline lakes [41].

3.3. The health consequences of $PM_{2.5}$ exposure

The consequences of polluted air cost countries both directly and indirectly. The World Bank's research determined that in 2013, Iran's polluted air caused a significant decrease in general health and a 2.48 % decrease in GDP for the nation, causing a loss of 30.6 million USD in income[42]. It consequently is conceivable to avoid adverse effects on human health and even monetary losses by developing and enacting strategies and regulations focused on lowering pollutants. Considering that particulates from Middle Eastern countries are the main contributors to emissions in Iran, any advancements in decreasing these sandy storms could provide important benefits[43]. Table 2 shows the consequences of exposure to fine dust in Ahvaz city. The consequences are expressed in two levels: Short-term exposure and long-term exposure. In short-term exposure, they refer to hospital admission (respiratory and cardiovascular), death due to respiratory disease, death due to stroke, and all deaths caused by exposure to dust. Long-term exposure to $PM_{2.5}$ also causes mortality stroke, mortality IHD, LC, and COPD. Exposure to $PM_{2.5}$ for a short time results in a 15.55 % increase in hospital admissions. Particularly, in Ahvaz city, getting exposed to 104.87 $\mu g/m^3$ of $PM_{2.5}$ led to the hospitalization of 2269 people. In Ahvaz city, the fatality rate caused by exposure to levels of $PM_{2.5}$ is 195.9 deaths per person. Among the population with short-term exposure to $PM_{2.5}$, there was a 6.32 % mortality. From the results shown in the table, it follows that 36 people from the entire population of Ahvaz, who were exposed to the average concentration of 104.87 $\mu g/m^3$, died; 3.08 deaths per 100,000 people exposed. Lung cancer and COPD are other respiratory diseases caused by long-term exposure to fine dust. Long-term exposure to fine dust increases the attribute proportion by 46.07 %. It is estimated that 2267 of the total deaths are due to respiratory diseases due to exposure to $PM_{2.5}$. 377.7 people per 100,000 residents of Ahvaz died due to exposure to 104.87 $\mu g/m^3$ of $PM_{2.5}$. Other negative consequences of long-term exposure to dust include lung cancer. According to the results obtained from the Air Q^+ program, it is estimated that the attribute proportion of long-term exposure to $PM_{2.5}$ was 33.73 %. 23 of the residents of Ahvaz have died due to lung cancer; That is, 3.78 people per 100,000 people have developed lung cancer and died due to long-term exposure to an average concentration of 104.87 $\mu g/m^3$ of fine dust. The findings of Geravandi et al. [44]imply that predicated on the Air Q 2.2.3 scenario, PM is the cause of 4.76 % of pulmonary fatalities in Ahvaz. Nonetheless, the long-term effects of PM have been shown by a new investigation. Based on Hadei et al. [45], Ahvaz's yearly average of AP and the prevalence of death from lung cancer associated with PM2.5 were around 25 and 23 instances, respectively. Approximately 8 million instances, with a corresponding number of problems associated with air pollution, have been recorded. An analysis of the death rate among people of Tehran, Iran, about Acute Lower Respiratory Infections (ALRI) indicated a significant association between airborne pollutants and mortality؛ Particularly, might be directly caused by air pollution[46]. Increasing traffic density has been demonstrated to considerably decrease women's exhaustion volume in 1 second and the needed essential capacity[47]. A research study done in 11 US cities on hospital admissions for lung and heart diseases found that for every 10 $\mu g\ m^{-3}$ rise in PM10 levels, there has been a 2.5 % increase (with a 95 % CI of 1.8–3.3) in CVD hospitalizations[48].

Short-term and long-term exposure to $PM_{2.5}$ not only causes respiratory problems but also causes cardiovascular diseases. 7.81 % of those admitted to Ahvaz hospitals in 2023 were due to short-term exposure to fine dust; Therefore, the number of people hospitalized due to exposure to $PM_{2.5}$ was 394. It is estimated that 34.06 per 100,000 people were hospitalized. IHD is one of the diseases caused by long-term exposure of people to $PM_{2.5}$. It is estimated that the attributable portion of IHD is 56.18 %. 214 people exposed to fine dust died due to ischemia in Ahvaz city in 2023; In other words, 35.68 people per 100,000 have died due to ischemia due to exposure to $PM_{2.5}$. An investigation by Hadei et al. [49] determined that long-term exposure to $PM_{2.5}$ was related to 338 fatalities from ischemia and about 660 fatalities from IHD. The death rate from IHD was 93 per 100,000 people, while the fatality rate from stroke was 47 per 100,000 people. During 2011 and 2019, the mean yearly death rate caused by IHD primarily because of prolonged exposure to PM_{10} was 51 fatalities per 100,000 people. Compared to the findings of earlier research, this average is considerably less. Based on a research study done by Ansari and Ehrampoush [50], the death rate associated with IHD per 100,000 people as a result of polluted air in Tehran, Iran, between 2017 and 2018 was 105. By Applying the Air Q+ model to analyzing ten Iranian cities, Hadei et al. [51] observed that the mean

Table 2
The health consequences of $PM_{2.5}$ exposure.

Outcome		RR[a]	AP[b]	AC[c]	B+[C][d]	N+[C][e]
Short term	Hospital Admissions (Respiratory disease)	1.019–1.040	15.55 %	2269	195.9	2268.5
	Hospital Admissions (Cardiovascular disease)	1.009–1.016	7.81 %	394	34.06	394.37
	Mortality all causes	1.006–1.008	5.65 %	356	30.71	355.65
	Mortality (Respiratory disease)	1.007–1.011	6.32 %	36	3.08	35.72
	Mortality (Stroke)	1.007–1.013	6.24 %	46	3.96	45.87
Long term	Mortality all (natural) causes (30+)	1.08–1.09	53.63 %	2639	439.8	2638.8
	COPD[f] (For adults)	-	46.07 %	2267	377.77	2266.65
	LC[g] (For adults)	-	33.73 %	23	3.78	22.67
	Mortality stroke[h] (For adults)	-	65.01 %	248	41.28	247.68
	Mortality IHD (For adults)	-	56.18 %	214	35.68	214.06

[a] Relative Risk
[b] Attributable Proportion
[c] Attributable Cases
[d] Estimated Change of incidence (per 100,000 population at risk) at a certain category of exposure
[e] Estimated number of cases attributable to a certain level of exposure
[f] Chronic Obstructive Pulmonary Disease
[g] Lung Cancer
[h] Ischemic Heart Disease

death rate from IHD associated with dust particles was 84 per 100,000 people in all cities and towns. People with higher levels of risk may be responsible for the higher rate of fatalities reported in those previous investigations. For respiratory-related deaths, particles are the cause of 41.66 % of deaths. In towns with populations higher than our study base, Tehran showed a comparable prevalence of 23.8 CVD-related fatalities per 100,000 people in 2017–2018. According to Barzegar et al., a study done between 2006 and 2017 revealed that 24.5 % of mortality related to cardiovascular disease (CVD) in Tabriz was triggered by long-term exposure to PM. The two primary risk factors related to CVD are driving and breathing in pollution from biomass combustion[52]. In their research, Ya et al. reported an association between $PM_{2.5}$ (ER = 0.074 %) and PM_{10} (ER = 0.023 %) and non-accidental daily fatalities. Adults aged 65 or older and women were found to be particularly vulnerable to air-polluted exposure, and a study on stratification indicated that summer exposure to pollutants may be more prevalent than wintertime exposure. The elevated levels of PM2.5 and PM_{10} particles increase the risk of daily deaths from cardiovascular disease and non-accidental causes, but not from pulmonary diseases[53].

Particulate matter can affect the brain and eventually cause strokes. Strokes can occur in both short-term and long-term exposure to $PM_{2.5}$. 6.24 % attributable to stroke due to short-term exposure to dust and the estimated number of deaths due to stroke is 46 people; For every 100,000 people, 3.96 people die due to stroke (due to exposure to fine dust). The results of this research showed that due to long-term exposure to $PM_{2.5}$, the attributed proportion was 65.01 %, the estimated number of deaths due to stroke was 214 and the estimated number of deaths per 100,000 people was 35.68. According to the results, short-term and long-term exposure to $PM_{2.5}$ is responsible for 5.65 % and 53.63 % of deaths (people over 30 years old), respectively. It is estimated that short-term and long-term exposure has caused the death of 2639 and 356 residents of Ahvaz city. In Iran, pulmonary diseases caused by airborne particles contributed to about 1503 deaths in 2012, based on a Health Impact Assessment (HIA) performed by the WHO. A predicted 42,301 years were estimated to be the total number of DALY, compared with 41,601 years for YLL. Chronic exposure to $PM_{2.5}$ led to 415 instances of YLL, 9014 years of DALY, and 9014 years of fatal COPD events overall. In Iran, $PM_{2.5}$-related YLL, DALY, and IHD instances have been documented in 388,334 years, 399,301 years, and 16.989 cases, respectively [54]. According to Heli et al.'s evaluation, between 2011 and 2019, between 44 % and 53 % of instances involving PM exposure were 18 years of age or older and had been diagnosed with IHD. Additionally, strokes comprised 16–25 % of the total reported cases. In the northern Caribbean province of Columbia, there have been 25 fatalities per 100, 000 people because of sandstorms among kids under the age of 4. It makes up 12 % of the ALRI-related fatalities in the area under consideration [55].

4. Conclusion

The present study focused on the origin, concentration, and health consequences of $PM_{2.5}$ in 2023 in Ahvaz city. The results obtained from the data of the meteorological database showed that the city of Ahvaz is very polluted and the number of days in which the dust concentration is completely unhealthy air condition reached 49 days; The share of completely polluted days in December (12 days), January (12 days) and November (11 days) was more than other months. According to the maps extracted from HYSPLIT, Iran is the source of dust in March, the Great Arabian Desert is the source of dust in December and August, Iraq is responsible for dusty days in April, September, and October, Kuwait is responsible for dust in January, Turkey is the source the dust of February and July, the country of Egypt was the source of the dust of June and May, the country of Oman was also the source of the dust of November. Based on estimates done using the Air Q^{+} programs, the residents of Ahvaz suffered heart disease, lung disease, and stroke as an outcome of being exposed to $PM_{2.5}$ particulates. Policymakers need to take health precautions because the yearly average of dusty days exceeds two months. Wearing face masks, suspending schools and offices temporarily, and planting trees around dust sources are a few instances of health precautions that safeguard people's health.

Limitations

The authors of the following paper were completely provided with data concerning $PM_{2.5}$ from the Meteorology Organization of the Khuzestan region. However, there are increased potential hazards to people when PM_{10} particles are present.

CRediT authorship contribution statement

Bahram Kamarehei: Formal analysis. **Majid farhadi:** Writing – original draft, Conceptualization. **Farshid Soleimani:** Writing – original draft. **Mahya dolati:** Writing – original draft. **Arefeh Sepahvand:** Formal analysis. **Marzieh Bayat:** Investigation. **Ali Farhadi:** Methodology. **Ayda Sepahvand:** Investigation. **Mohammad javad Mohammadi:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] N. Seihei, M. Farhadi, A. Takdastan, P. Asban, F. Kiani, M.J. Mohammadi, Short-term and long-term effects of exposure to PM10, Clin. Epidemiol. Glob. Health 27 (2024) 101611.
[2] M.J. Mohammadi, M. Farhadi, S. Ghanbari, P. Asban, F. Kiani, M. Taherian, I. Mir, Ecological risk assessment of heavy metals in urban dust in Iran: a systematic review and meta-analysis, Toxicol. Rep. 11 (2023) 471–480.
[3] P. Thangavel, D. Park, Y.-C. Lee, Recent insights into particulate matter (PM2. 5)-mediated toxicity in humans: an overview, Int. J. Environ. Res. Public Health 19 (12) (2022) 7511.
[4] S. Basith, B. Manavalan, T.H. Shin, C.B. Park, W.-S. Lee, J. Kim, G. Lee, The impact of fine particulate matter 2.5 on the cardiovascular system: a review of the invisible killer, Nanomaterials 12 (15) (2022) 2656.
[5] K.E. Pinkerton, F. Green, C. Saiki, V. Vallyathan, C.G. Plopper, V. Gopal, et al., Distribution of particulate matter and tissue remodeling in the human lung, Environ. Health Perspect. 108 (11) (2000) 1063–1069.
[6] D. Xu, N. Huang, Q. Wang, H. Liu, Study of ambient PM2. 5 on the influence of the inflammation injury and the immune function of subchronic exposure rats, Wei sheng yan jiu= J. Hyg. Res. 37 (4) (2008) 423–428.
[7] G. Wang, J. Zhao, R. Jiang, W. Song, Rat lung response to ozone and fine particulate matter (PM2. 5) exposures, Environ. Toxicol. 30 (3) (2015) 343–356.
[8] P. Pandey, D. Patel, A. Khan, S. Barman, R. Murthy, G. Kisku, Temporal distribution of fine particulates (PM2. 5, PM10), potentially toxic metals, PAHs and metal-bound carcinogenic risk in the population of Lucknow City, India, J. Environ. Sci. Health, Part A 48 (7) (2013) 730–745.
[9] T. Lancet, WHO's global air-quality guidelines, Elsevier, 2006, p. 1302.
[10] C.A. Pope III, D.W. Dockery, Health effects of fine particulate air pollution: lines that connect, J. air Waste Manag. Assoc. 56 (6) (2006) 709–742.
[11] T.J. Grahame, R.B. Schlesinger, Health effects of airborne particulate matter: do we know enough to consider regulating specific particle types or sources? Inhal. Toxicol. 19 (6-7) (2007) 457–481.
[12] I. Muda, M.J. Mohammadi, A. Sepahvad, A. Farhadi, R.F. Obaid, M. Taherian, et al., Associated health risk assessment due to exposure to BTEX compounds in fuel station workers, Rev. Environ. Health (2023).
[13] F. Dominici, R.D. Peng, M.L. Bell, L. Pham, A. McDermott, S.L. Zeger, J.M. Samet, Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases, Jama 295 (10) (2006) 1127–1134.
[14] M. Franklin, A. Zeka, J. Schwartz, Association between PM2. 5 and all-cause and specific-cause mortality in 27 US communities, J. Expo. Sci. Environ. Epidemiol. 17 (3) (2007) 279–287.
[15] P.K. Hopke, K. Ito, T. Mar, W.F. Christensen, D.J. Eatough, R.C. Henry, et al., PM source apportionment and health effects: 1. Intercomparison of source apportionment results, J. Expo. Sci. Environ. Epidemiol. 16 (3) (2006) 275–286.

[16] Perspectives H. Understanding the health effects of components of the particulate matter mix: progress and next steps. Cambridge, MA: Health Effects Institute. 2002.
[17] M. Effatpanah, H. Effatpanah, S. Jalali, I. Parseh, G. Goudarzi, G. Barzegar, et al., Hospital admission of exposure to air pollution in Ahvaz megacity during 2010–2013, Clin. Epidemiol. Glob. Health 8 (2) (2020) 550–556.
[18] A.R. Yari, G. Goudarzi, S. Geravandi, S. Dobaradaran, F. Yousefi, E. Idani, et al., Study of ground-level ozone and its health risk assessment in residents in Ahvaz City, Iran during 2013, Toxin Rev. 35 (3-4) (2016) 201–206.
[19] J.D. Sacks, N. Fann, S. Gumy, I. Kim, G. Ruggeri, P. Mudu, Quantifying the public health benefits of reducing air pollution: critically assessing the features and capabilities of WHO's AirQ+ and US EPA's environmental benefits mapping and analysis program—community edition (BenMAP—CE), Atmosphere 11 (5) (2020) 516.
[20] A. Nikoonahad, R. Naserifar, V. Alipour, A. Poursafar, M. Miri, H.R. Ghafari, et al., Assessment of hospitalization and mortality from exposure to PM 10 using AirQ modeling in Ilam, Iran, Environ. Sci. Pollut. Res. 24 (2017) 21791–21796.
[21] Organization W.H. Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide: World Health Organization; 2006.
[22] H. Maleki, A. Sorooshian, G. Goudarzi, A. Nikfal, M.M. Baneshi, Temporal profile of PM10 and associated health effects in one of the most polluted cities of the world (Ahvaz, Iran) between 2009 and 2014, Aeolian Res. 22 (2016) 135–140.
[23] Fazelinia F., Khodabandehlou A.A., Rafati L., Mahvi A.H. Investigation of air quality index and PM10 and PM2. 5 in Arak. 2013.
[24] A. Gholampour, R. Nabizadeh, S. Naseri, M. Yunesian, H. Taghipour, N. Rastkari, et al., Exposure and health impacts of outdoor particulate matter in two urban and industrialized area of Tabriz, Iran, J. Environ. Health Sci. Eng. 12 (2014) 1–10.
[25] A. Shahsavani, K. Naddafi, N.J. Haghighifard, A. Mesdaghinia, M. Yunesian, R. Nabizadeh, et al., The evaluation of PM10, PM2. 5, and PM1 concentrations during the Middle Eastern Dust (MED) events in Ahvaz, Iran, from april through september 2010, J. Arid Environ. 77 (2012) 72–83.
[26] M.S. Najafi, B. Sarraf, A. Zarrin, A. Rasouli, Climatology of atmospheric circulation patterns of Arabian dust in western Iran, Environ. Monit. Assess. 189 (2017) 1–13.
[27] M. Akbary, M. Farahbakhshi, Analyzing and Tracing of Dust Hazard in Recent Years in Kermanshah Province, Int. J. Environ. Res. 9 (2015) 2.
[28] Z. Soleimani, A. Darvishi Boloorani, R. Khalifeh, D.W. Griffin, A. Mesdaghinia, Short-term effects of ambient air pollution and cardiovascular events in Shiraz, Iran, 2009 to 2015, Environ. Sci. Pollut. Res. 26 (2019) 6359–6367.
[29] V. Ramaswamy, P. Muraleedharan, C.P. Babu, Mid-troposphere transport of Middle-East dust over the Arabian Sea and its effect on rainwater composition and sensitive ecosystems over India, Sci. Rep. 7 (1) (2017) 13676.
[30] K. Ashrafi, M. Shafiepour-Motlagh, A. Aslemand, S. Ghader, Dust storm simulation over Iran using HYSPLIT, J. Environ. Health Sci. Eng. 12 (1) (2014) 9.
[31] F. Abdi Vishkaee, C. Flamant, J. Cuesta, P. Flamant, H.R. Khalesifard, Multiplatform observations of dust vertical distribution during transport over northwest Iran in the summertime, J. Geophys. Res.: Atmos. 116 (D5) (2011).
[32] S. Sotoudeheian, R. Salim, M. Arhami, Impact of Middle Eastern dust sources on PM10 in Iran: highlighting the impact of Tigris-Euphrates basin sources and Lake Urmia desiccation, J. Geophys. Res.: Atmospheres 121 (23) (2016) 14,018–14,34.
[33] H. Cao, J. Liu, G. Wang, G. Yang, L. Luo, Identification of sand and dust storm source areas in Iran, J. Arid Land 7 (2015) 567–578.
[34] R. Givehchi, M. Arhami, M. Tajrishy, Contribution of the Middle Eastern dust source areas to PM10 levels in urban receptors: Case study of Tehran, Iran, Atmos. Environ. 75 (2013) 287–295.
[35] V.J. Farahani, M. Arhami, Contribution of Iraqi and Syrian dust storms on particulate matter concentration during a dust storm episode in receptor cities: case study of Tehran, Atmos. Environ. 222 (2020) 117163.
[36] A.D. Boloorani, S. Nabavi, R. Azizi, H. Bahrami, editors. Characterization of dust storm sources in western Iran using a synthetic approach. Advances in meteorology, climatology and atmospheric physics, Springer, 2013.
[37] A.D. Boloorani, Y. Kazemi, A. Sadeghi, S.N. Shorabeh, M. Argany, Identification of dust sources using long term satellite and climatic data: a case study of Tigris and Euphrates basin, Atmos. Environ. 224 (2020) 117299.
[38] A.D. Boloorani, S.O. Nabavi, H.A. Bahrami, F. Mirzapour, M. Kavosi, E. Abasi, R. Azizi, Investigation of dust storms entering Western Iran using remotely sensed data and synoptic analysis, J. Environ. Health Sci. Eng. 12 (2014) 1–12.
[39] H. Salmabadi, R. Khalidy, M. Saeedi, Transport routes and potential source regions of the Middle Eastern dust over Ahvaz during 2005–2017, Atmos. Res. 241 (2020) 104947.
[40] P. Heidarian, A. Azhdari, M. Joudaki, J.D. Khatooni, S.F. Firoozjaei, Integrating remote sensing, GIS, and sedimentology techniques for identifying dust storm sources: a case study in Khuzestan, Iran, J. Indian Soc. Remote Sens. 46 (7) (2018) 1113–1124.
[41] A. Abyat, A. Azhdari, H. Almasi Kia, M. Joudaki, Khuzestan plain continental sabkhas, southwest Iran, Carbonates Evaporites 34 (2019) 1469–1487.
[42] C. Lucas, T. Power, Ensuring Cultural Safety for Indigenous Peoples Accessing Medicines. Encyclopedia of Evidence in Pharmaceutical Public Health and Health Services Research in Pharmacy, Springer, 2023, pp. 288–301.
[43] A. Eleftheriou, P. Mouzourides, G. Biskos, P. Yiallouros, P. Kumar, M.K.-A. Neophytou, The challenge of adopting mitigation and adaptation measures for the impacts of sand and dust storms in Eastern Mediterranean Region: a critical review, Mitig. Adapt. Strateg. Glob. Change 28 (6) (2023) 33.
[44] J. Guo, G. Chai, X. Song, X. Hui, Z. Li, X. Feng, K. Yang, Long-term exposure to particulate matter on cardiovascular and respiratory diseases in low- and middle-income countries: a systematic review and meta-analysis, Front Public Health 11 (2023) 1134341.
[45] M. Hadei, S.S. Hashemi Nazari, M. Yarahmadi, M. Kermani, M. Farhadi, A. Shahsavani, Estimation of gender-specific lung cancer deaths due to exposure to PM2.5 in 10 cities of Iran during 2013 - 2016: a modeling approach, Int J. Cancer Manag 10 (8) (2017) e10235.
[46] M. Ansari, M.H. Ehrampoush, Meteorological correlates and AirQ(+) health risk assessment of ambient fine particulate matter in Tehran, Iran. Environ. Res 170 (2019) 141–150.
[47] F.W. Ko, D.S. Hui, Air pollution and chronic obstructive pulmonary disease, Respirology 17 (3) (2012) 395–401.
[48] A. Zanobetti, J. Schwartz, D.W. Dockery, Airborne particles are a risk factor for hospital admissions for heart and lung disease, Environ. Health Perspect. 108 (11) (2000) 1071–1077.
[49] M. Hadei, S.S.H. Nazari, A. Eslami, A. Khosravi, M. Yarahmadi, Z. Naghdali, A. Shahsavani, Distribution and number of ischemic heart disease (IHD) and stroke deaths due to chronic exposure to PM2. 5 in 10 cities of Iran (2013-2015); an AirQ + modelling, J. air Pollut. Health 2 (3) (2017) 129–136.
[50] M. Ansari, M.H. Ehrampoush, Meteorological correlates and AirQ+ health risk assessment of ambient fine particulate matter in Tehran, Iran, Environ. Res. 170 (2019) 141–150.
[51] M. Hadei, S.S.H. Nazari, M. Yarahmadi, M. Kermani, M. Farhadi, A. Shahsavani, Estimation of gender-specific lung cancer deaths due to exposure to PM2. 5 in 10 cities of Iran during 2013-2016: a modeling approach, Int. J. Cancer Manag. 10 (8) (2017).
[52] V. Barzegar, P. Sarbakhsh, Ms Hassanvand, S. Faridi, A. Gholampour, Long-term trend of ambient air PM10, PM2.5, and O3 and their health effects in Tabriz city, Iran, during 2006-2017, Sustain. Cities Soc. 54 (2019) 101988.
[53] Y.K. Lu, X.L. Liu, Y.H. Liu, N. Chen, H.Y. Gao, Y.H. Jin, Y.X. Yan, The effects of short-term exposure to air pollution on mortality in Baotou, China, during 2015-2019, Environ. Geochem Health 45 (6) (2023) 3387–3404.
[54] Organization W.H. Ambient air pollution: A global assessment of exposure and burden of disease. 2016.
[55] H.A. Arregocés, R. Rojano, G. Restrepo, Health risk assessment for particulate matter: application of AirQ+ model in the northern Caribbean region of Colombia, Air Qual. Atmos. Health 16 (5) (2023) 897–912.