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$PM_{2.5}$-Related Mortality and Years of Life Lost in Megacity of Ahvaz, Iran

Yusef Omidi Khaniabadi [1] | Hasan Raja Naqvi [2] | Pierre Sicard [3,4] | Pouran Moulaei Birgani [5] | Alessandra De Marco [6] | Sina Fathi Rad [7] | Khatereh Anbari [8] | Rajab Rashidi [9] | Mahsa Moradi [10]✉

1. Occupational and Environmental Health Research Center, Petroleum Industry Health Organization (PIHO), Ahvaz, Iran.
2. Department of Geography, Faculty of Sciences, Jamia Millia Islamia, New Delhi, India.
3. ACRI-ST, Route Du Pin Montard, Biot, France.
4. INCDS Marin Drăcea, 128 Eroilor Bvd, Voluntari 077030, Romania.
5. Family Health Research Center, Petroleum Industry Health Organization (PIHO), Ahvaz, Iran.
6. ENEA, Via Anguillarese, 301, Rome, Italy.
7. Department of Medicine, School of Medicine, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.
8. School of Medicine, Social Determinants of Health Research Center, Lorestan University of Medical Sciences, Khorramabad, Iran.
9. Professor of Occupational Health Engineering, Department of Occupational Health, Environmental Health Research Center, School of Health and Nutrition, Lorestan University of Medical Sciences, Khorramabad, Iran.
10. Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.

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ABSTRACT

The aims of the current study were to assess the variations in $PM_{2.5}$ concentrations in Ahvaz (Iran), and related mortality and years of life lost in 2019 and 2020. Backward wind trajectories through HYSPLIT model were obtained. The hourly in-situ data of $PM_{2.5}$ concentrations were transformed into daily averages. The integrated exposure-response function, relative risk, and baseline incidence values were used for estimation attributable mortality, years of life lost, and loss of life expectancy in Ahvaz. The aerosols variation showed that $PM_{2.5}$ reduced in post-lockdown (22 April – 21 May, 2020) compared to pre-lockdown phase and same time in 2019. The results of HYSPLIT model illustrated that dust from the Arabian Desert region especially Iraq can travel long distances and contribute to air particulate pollution in Iran. The number of premature deaths for non-accidental causes (37.5 and 31.2), M-IHD (12.4 and 10.3), M-COPD (29 and 28.2), and M-LC (16.2 and 11.25) for exposure to $PM_{2.5}$ above 10 µg m-3 in people were obtained in 2019 and 2020. The years of life lost declined by 16% in 2020, and exposure to $PM_{2.5}$ reduced the life expectancy 0.69 and 0.44 years respectively in 2019 and 2020. Previous conducted studies have provided quantitative estimates of the ability of green infrastructure to ameliorate urban air quality (e.g., $PM_{2.5}$) at city scale worldwide.

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INTRODUCTION

In the recent years, air pollution is a major environmental and health issue worldwide (Amoatey et al., 2021; Anbari et al., 2024), especially in developing countries where encountered with high levels of air pollution due to industrial activities, population, urbanization, and

*Corresponding Author Email: *moradi.m106@gmail.com*

dust events (Broomandi et al., 2023; Khaniabadi et al., 2023). The epidemiological studies have shown exposure to particulate matter (PM) as a lethal form of air pollution is reason of several health problems such as chronic and acute respiratory diseases, cardiovascular diseases, pulmonary lung functions, type 2 diabetes, and lung cancer, which threat human heath even in low concentrations (Liao et al., 2019; Yu et al., 2022). The exposure can cause activation of oxidative stress pathways, autonomic imbalance, and direct translocation into blood circulation (Basith et al., 2022), leading to atherosclerosis, coagulation, hypertension, myocardial remodeling, and thrombotic (Newby et al., 2015).

Fine inhalable particles ($PM_{2.5}$) dispersed from various sources such as industries, automobiles, cookies, and desert dust, can penetrate deep into the lungs and bloodstream leading to rising adverse health effects such as cancer, bronchitis, asthma, and hospital admissions (Chen et al., 2024; Tian et al., 2024). The American Cancer Society (ACS), reported that there is a strong correlation between long-term exposure to $PM_{2.5}$ and mortality among people ≥ 30 years-old (Pope Iii et al., 2002). In 2015 the global burden of disease (GBD) stated that the $PM_{2.5}$ has ranked been as fifth among 67 risk factor, leading 4.2% of global disability adjusted life years (DALYs), and 7.6% of total global deaths (Al-Hemoud et al., 2018; Cohen et al., 2017).

Although particulate pollution related to mortality is decreased in several high-income countries, it is still a significant concern in low-income countries, leading to higher mortality and morbidity. Many factors are contributing to this event such as climate change, urbanization, and anthropogenic activities which are the major sources of air particulate pollution (Moradi et al., 2023). To assess the relationship between $PM_{2.5}$ exposure and increase in mortality, the updated version of AirQ model, developed by the Word Health organization (WHO) is used across the world (Al-Hemoud et al., 2018; Amoatey et al., 2021; Cakaj et al., 2023; Rovira et al., 2020). Furthermore, the estimated cost of the heath effect by $PM_{2.5}$ exposure can be considered using the DALYs method to calculate of YLL and loss of life expectancy (Souza Zorzenão et al., 2024). The YLL is an indicator applied to quantify of potential time lost due to premature mortality. Indeed, it is actually an average number of years which a person can survived if not died prematurely (Leogrande, 2023), i.e., he could be saved and alive for additional years if air pollution is reduced (Sahu et al., 2021).

A deep literature review highlighted there is limited understanding about the air pollution issues and health status of the inhabitants from exposure to ambient $PM_{2.5}$ in Iran. Therefore, the main objectives of this study were to i) investigate the temporal trends in $PM_{2.5}$ concentrations, ii) satellite aerosol optical depth (AOD), iii) trajectories through HYSPLIT model for variation of atmospheric aerosols, iv) estimate the associated mortality, and (v) calculation years of life lost and loss of life expectancy during two successive years 2019 and 2020 in the megacity of Ahvaz, southwest of Iran.

MATERIALS AND METHODS

Study area

Ahvaz (31°19′N 48°40′E), the capital city of Khuzestan province with a population 1.3 million, area 185 km^2, located in southwest of Iran (Fig.1). This city experiences hot desert climate with long summer and short winter, annual average temperature 24.9°C, and common sand and dust storms (Khafaie et al., 2024; Sadeghi and Sadeghi, 2024). Regarding the annual mean concentrations of particles, the Iranian cities classified as the most polluted in the world (Salmabadi et al., 2023; Sicard et al., 2020). Due to different industries such as steel, gas and petroleum companies, and oil refineries located inside and around the city along with dust storms originating from desert areas, high levels of particles is measurable in this city (Goudie, 2014).

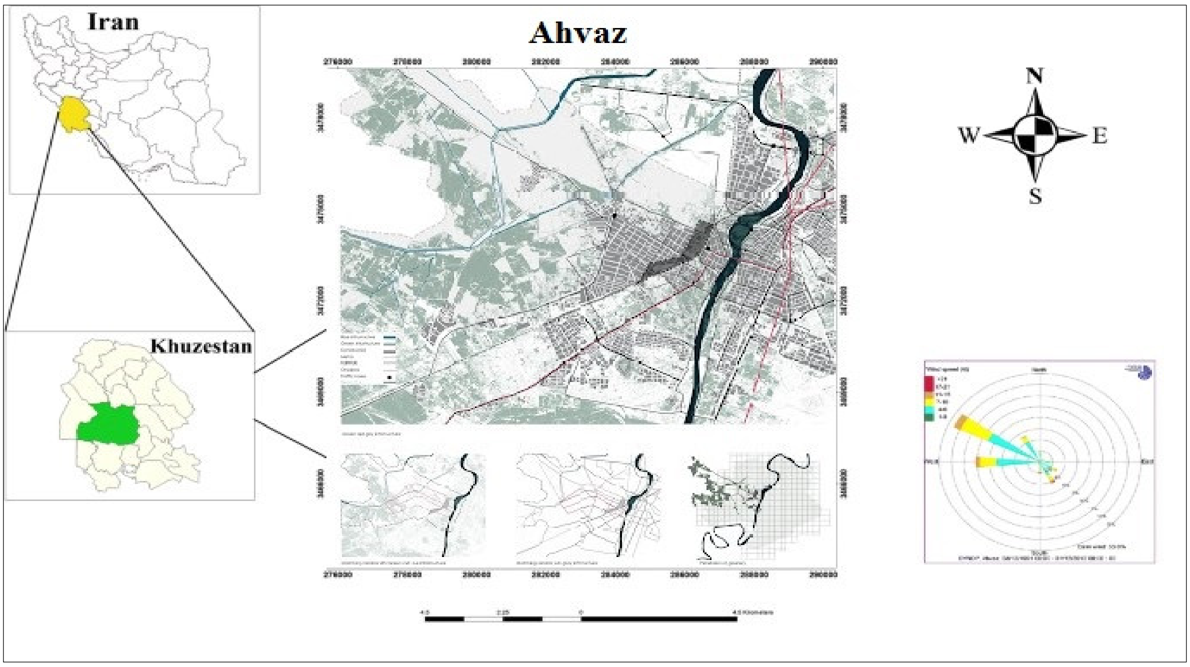

Fig. 1. Location of the study area in southwest of Iran.

Aerosol optical depth and HYSPLIT

To observe the variations in atmospheric aerosol, we have procured MCD19A2.006: Terra & Aqua MAIAC Land Aerosol Optical Depth (AOD) Daily 1km global datasets and visualized the value (scaled up) from 0 to 1000 through United States of Geological Survey (USGS) portal (https://lpdaac.usgs.gov/products/mcd19a2v006/), and for three time periods in 2019 (before COVID-19) and 2020 (during COVID-19). The time periods in 2020 were before (21st February to March 21), during (22nd March to April 21), and post-COVID-19 lockdown (22nd April to May 21).

To understand the variation in air particulate concentrations, pathways of contributing source were also assessed and mapped. We have utilized the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model developed by NOAA's Air Resources Laboratory to analyze the wind trajectories to understand the transportation of pollutants (Naqvi et al., 2021). We set the criteria when the particles were greater than 50 $\mu g\ m^{-3}$. The condition of days were classified: normal (PM < 50 $\mu g\ m^{-3}$), dusty days (50 $\mu g\ m^{-3} \geq$ PM < 200 $\mu g\ m^{-3}$), and dust storm (200 $\mu g\ m^{-3} \geq$ PM < 500 $\mu g\ m^{-3}$).

Data collection

The in-situ air quality monitoring data including real-time hourly $PM_{2.5}$ concentrations measured by three stations installed in Ahvaz were obtained from the local agency of the Iranian Department of Environment (https://www.doe.ir) for assess of PM concentrations. Then hourly concentrations of background monitoring stations were transformed into daily means with at least 80% validated or non-missing values with Microsoft Excel. The hourly $PM_{2.5}$ data were available from 1st January 2019 to 31st December 2020 for this study.

Data processing

In the risk assessment, exposure is considered equal to air pollutants concentrations at a specific point in space and time (Gilardi et al., 2023). Due to high level of $PM_{2.5}$ concentrations in Ahvaz, the AirQ plus model was applied for this study that designed and recommended by the WHO for assess of health risk among a population (Chipps et al., 2024). This model calculates the attributable number of population per 10^5 due to air pollution exposure, integrated exposure-response (IER) functions, the YLL, and the loss of life expectancy by entering the calculated input parameters and life tables (Al-Hemoud et al., 2018).

The IER function was developed from current systematic reviews and meta-analysis of various short- and long-term mortality health effects for $PM_{2.5}$ exposure. In this method, the baseline incidence (BI), relative risk (RR), and the number of population (N) an area are necessary to calculation mortality. The BI is the incidence rate of a specified health effect in an at-risk population (Sicard et al., 2019), furthermore the RR value is the probability to develop a disease related to air particulate exposure as a result, per each 10 µg m^{-3} increase in concentration and obtained from different published epidemiological and meta-analysis studies. The RR value calculates the probability of developing a disease associated with exposure to air pollutant by the following equation:

$$RR = exp\left[\beta \times \left(X - X_0\right)\right] \tag{1}$$

where β is a parameter which regulates the amount of RR increasing, X (µg m^{-3}) and X_0 (µg m^{-3}) also are respectively the measured air pollutant concentrations and background where no health effect recorded (De Marco et al., 2018).

To the quantification of mortality ischemic heart disease (M-IHD), chronic obstructive pulmonary disease (M-COPD), and lung cancer (M-LC), the IER functions from European cohort studies were used. If the amount of z is equal or lower than z_{cf}, the RR is obtained from the following equation. When z is less than z_{cf}, the amount of RR is equal 1.

$$R_{(z)} = 1 + \alpha\left\{1 - \exp\left[-\gamma \times \left(z - z_{cf}\right) \times \delta\right]\right\} \tag{2}$$

where z and z_{cf} are the annual and the counterfactual $PM_{2.5}$ concentrations respectively. Below it was assumed that there is not additional risk. Also, other parameters include α, γ, and δ are pre-integrated (Al-Hemoud et al., 2020; Amoatey et al., 2020; De Marco et al., 2018; Rovira et al., 2020). Furthermore, the attributable proportion (AP %) is the fraction of a health effect that can be statistically associated with the exposure to an air pollutant, c, in a population $P_{(c)}$ as it has illustrated been in the following equation:

$$AP = \frac{\Sigma\left(\left[RR_{(c)} - 1\right] \times P_{(c)}\right)}{\Sigma\left[RR_{(c)} \times P_{(c)}\right]} \tag{3}$$

where AP is the attributable proportion of the health effect, RR(c) is the relative risk for certain health impacts in category "c" (e.g., residential, or industrial) of exposure could be used from the exposure-response functions taken from different epidemiological conducted studies. P(c) is the number of exposed people under a specific pollutant (Daryanoosh et al., 2017; Fattore et al., 2011; Gurjar et al., 2010; Khaniabadi et al., 2017b). For the assess of selected health effect on a population, the number of cases NC_c per 100,000 people attributed to exposure to an air pollutant "C" with concentration "c" is calculated as NC_c=BI × AP (Hermayurisca and Taneepanichskul, 2023; Zhu et al., 2022). The number of cases NE_c attributed to the exposure to concentrations of a certain air pollutant is calculated as $NE_c = 10^{-5} \times [NC_c \times N]$ where N is the number of people at risk exposed to the air pollutant (Cakaj et al., 2023; Khaniabadi and

Table 1. Baseline incidence (BI) and relative risk (RR) values for health outcomes, and people at risk with 95% confidence intervals (95% CI) for each 10 μg m^{-3} increase in $PM_{2.5}$.

Health outcomes	BI	RR per 10 μg m^{-3} (95% CI)
Mortality, all-cause (age ≥30)	845–1832	1.062 (1.04–1.083)
Mortality, IHD (age ≥25)	101–177	IER function
Mortality, COPD (age ≥30)	13–20	IER function
Mortality, LC (age ≥30)	11–22	IER function

IHD: Ischemic heart disease, COPD: Chronic obstructive pulmonary disease, LC: Lung cancer, IER: Integrated exposure-response function.

Sicard, 2021; Naghan et al., 2022).

As recommended by the WHO, by obtained RR, all-cause-mortality (M-all-cause) was estimated attributable to the exposure to $PM_{2.5}$. Besides, to the assess of cause-specific mortality, including M-IHD, M-COPD, and M-LC among adults more than 25 and 30 years old for exposure to $PM_{2.5}$, we used the IER function described by (Burnett et al., 2014; Faridi et al., 2018; Héroux et al., 2015). Table 1 shows the year-specific BI used in this study for assess of health effects attributed $PM_{2.5}$. To the estimate of YLL, life table evaluation method was used for adults i.e., ages ≥ 30 years-old (Hadei et al., 2020), along with loss of life expectancy or losses of expected life remaining in a population. For this, the population rate of the city and deaths by age groups during same year are required. These data were obtained from the Iranian Ministry of Health. The loss of life expectancy using population-weighted was also estimated.

Statistical analyses

The correlation analyses were performed by using the Pearson and linear regression between $PM_{2.5}$ concentrations during two successive years from January 2019 to January 2020, before and during COVID-19 pandemic.

RESULTS AND DISCUSSION

Spatiotemporal

In the south, west, and southwest of Iran, there is encountered with high levels of air particulate matters from inside areas and outside of boarders, and also Arabians' desserts sources in Middle East (Broomandi et al., 2022). In Iran, the period 21st March to 21st April 2020 were selected as lockdown period by the government for reducing COVID-19 cases. During the lockdown, the results showed that a reduction in $PM_{2.5}$ concentrations in Ahvaz compared to the month before (21st February to 21st March 2020). The spatiotemporal variation among 2019 and 2020 illustrated that the AOD scaled-up values > 400 in yellow-red color patches are disappeared in post-lockdown from 22 April to 21 May, 2020, compared to the pre-lockdown phase. So this represents lower AOD values (Fig. 2). Furthermore, near and above to 0 aerosol optical depth values depicts more in post-lockdown phase compared to pre-lockdown and in 2019 period. This results are in agreement with the results of (Naqvi et al., 2021) which illustrated a reasonable decline in post-lockdown in India. In London the $PM_{2.5}$ reduced by 9% after lockdown for 100 days from 23 March to 30 June 2020 (Higham et al., 2021).

For our trajectory analysis, we have selected one random location in Ahvaz city shown by black stars (location: 31.32N, 48.67E). In this trajectory analysis, several wind direction patterns were observed on various dates (Fig. 3). The wind moved towards the southeast on 17 August 2019 and 17 August 2020. On 15 February 2019, the initial direction was towards the northwest; however, after a few hours, the wind started to rise and recurred towards the northeast. A similar pattern was observed on December 27, 2019, when the wind direction initially pointed northwest before rising and recurring towards the northeast. On 15 February

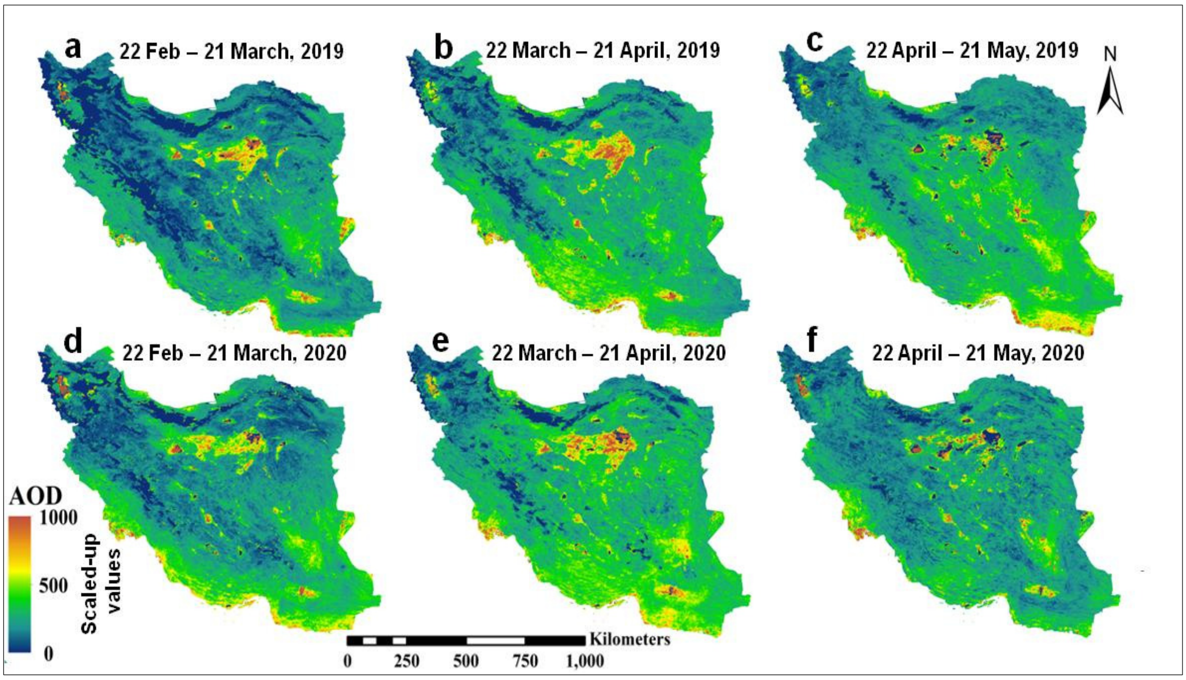

Fig. 2. The satellite aerosol optical depth spatiotemporal variations in Iran during three monthly periods; before (21st February to March 21, 2020), during (22nd March to April 21, 2020), and post (22nd April to May 21, 2020) COVID-19 lockdown compared with same times in 2019.

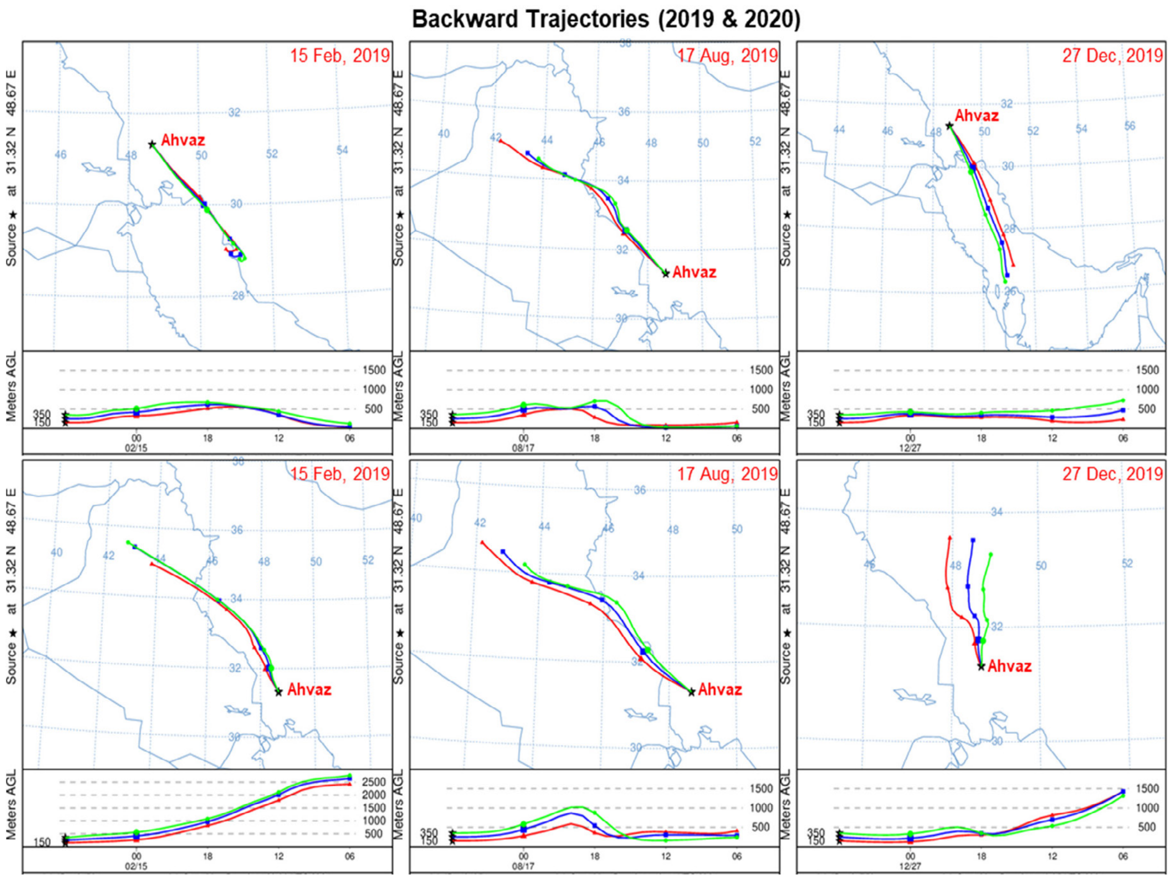

Fig. 3. Backward trajectories at every two hours for Ahvaz city at three days when PM concentrations were highest/unusual on 15 February, 17 August, and 27 December 2019 and 2020.

2020, the wind was moving towards the southeast, similar trend was also recorded on 27 December 2020. In a study by (Goudarzi et al., 2021a) in Ahvaz, the authors showed that the dust events occurred mainly when temperature is decreased in cold days, which is in agreement with finding of current study. Our results also showed that many of the trajectories originate from desert areas inside and outside of Iran. This finding aligns with the broader understanding that dust from the Arabian Desert region can travel long distances and contribute significantly to particulate pollution in regions such as Ahvaz. (Broomandi et al., 2021) said it seems the dust storms from external sources in the Middle East are passed through the Persian Gulf. A study by (Mousavi et al., 2024) showed that due to lack of vegetation and sandy nature, the Tigris and Euphrates River basins in the Iraq country are significant sources of dust storms in the Middle East, showing the west and southwest of Iran have experienced an increase 0.37 to 0.41 in AOD levels during the past 20 years. In India, low air temperatures and higher relative humidity increase the dust storms (Haritash and Kaushik, 2007). Furthermore, higher altitude of air particulates can increase the average of movement at a wider region with more time (Goudarzi et al., 2021a; Kopanakis et al., 2018). Another study in Khorramabad, Iran, showed that dust from Sub-Saharan and Arabian Deserts can move long distances and contribute significantly to PM levels (Anbari et al., 2024).

Temporal variations

In this study, as it can be seen in Fig.3a, the results of time-series variations showed that in all days 2019 and in 97.7% of the days in 2020, $PM_{2.5}$ concentrations were higher than the WHO air quality guideline (WHO-AQG) limit value (15 µg m^{-3}) for daily exposure (Khaniabadi et al., 2022). The highest daily $PM_{2.5}$ concentrations were observed on 27th December 2019 (198.18 µg m^{-3}) and 6th May 2020 (121.6 µg m^{-3}). Assess the seasonal variation illustrated that the mean of $PM_{2.5}$ during winter is more than summer due to higher turbulent and wind speed during cold season (Bullock et al., 2012). The results by (Chen et al., 2019) illustrates in Beijing and Guangzhou, the $PM_{2.5}$ mean concentrations were higher during winter season. The annual $PM_{2.5}$ mean concentrations in 2019 (44.5 µg m^{-3}) and 2020 (38.2 µg m^{-3}) were respectively exceeded 8.9 times and 7.64 times from the annual limit value (5 µg m^{-3}) established by the WHO-AQG for human health protection (Pai et al., 2022), showing the $PM_{2.5}$ mean concentration annually decreased by 6.3 µg m^{-3} in 2020 (Box and Whisker model in Fig.3b). In the study by (Kerimray et al., 2020) in Almaty, Kazakhstan, the annual mean of $PM_{2.5}$ in 2019 (40 µg m^{-3}) was more than 2020 (31 µg m^{-3}). This difference might be due to restrictive measures regarding to COVID-19 and lockdown, caused a decline in the $PM_{2.5}$ annual mean. These findings are confirmed by the (Benchrif et al., 2021), (Kerimray et al., 2020), (Anbari et al., 2023), and

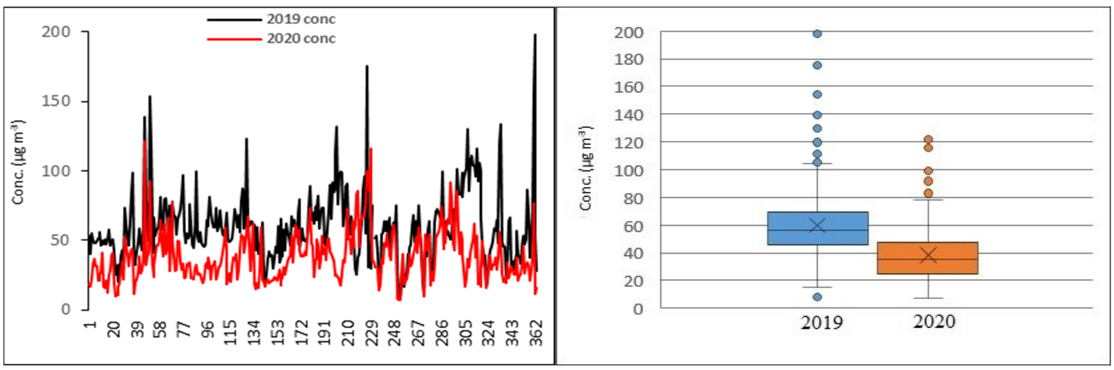

Fig. 3. (a) Trend variations of $PM_{2.5}$ concentrations, and (b) Box and Whisker model in Ahvaz (Iran), during 2019 and 2020.

(Hashim et al., 2021). In a study, (Benchrif et al., 2021) have reported that in Malaysia, $PM_{2.5}$ concentrations decreased by 23-32% during lockdown. This significant reduction of particle levels were widely observed in Europe, the United States, and in Asia before and during the lockdown (Tobías et al., 2020). In another study in Ahvaz, the results showed that during 2012 to 2018 the annual means of $PM_{2.5}$ were between 5.96 – 6.9 times of the WHO-AQG (Naghan et al., 2021). The Air Quality Control Company revealed that each year more than 8600 tons of PM is released from the vehicles in Tehran (Yarahmadi et al., 2018).

All-causes mortality

Table 2 shows the at-risk population, estimated AP%, and mortality rate for $PM_{2.5}$ exposure. The number of all-causes mortality for age ≥ 30 years-old due to $PM_{2.5}$ concentrations above 10 $\mu g\ m^{-3}$ was ranged from 6.6 to 48 per 10^5 people in 2019, and 10 to 38.2 per 10^5 people in 2020 in Ahvaz, Iran. Although in Iran the population is increased yearly, a decline in the attributable proportion and all-cause mortality rate for adults aged over 30 years-old was observed in 2020, due to lower $PM_{2.5}$ concentrations for exposure. On average, the number of all-causes deaths was 37.5 and 31.2 per 10^5 people with a decrease 14.8% in 2020. Another study in Ahvaz illustrated that all-cause mortality for $PM_{2.5}$ exposure was 47 died persons per 10^5 for adults ≥ 30 years-old in 2016 (Karimi et al., 2019). In Tehran, (Yarahmadi et al., 2018) showed that the number of all-causes mortality was 58 deaths per 10^5 people in an annual mean $PM_{2.5}$ concentration 36.4 $\mu g\ m^{-3}$. In Marseille, the number of non-accidental all-causes mortality averagely decreased by 1.15 per 10^5 people approximately due to decrease in $PM_{2.5}$ concentrations from 2010-2019 (Khaniabadi and Sicard, 2021). With each 10 $\mu g\ m^{-3}$ increase in the rate of daily $PM_{2.5}$ exposure, 1.04 % increased mortality was achieved for non-accidental causes worldwide (Atkinson et al., 2014).

IHD mortality

The IHD mortality rate due to exposure to $PM_{2.5}$ above reference concentrations 10 $\mu g\ m^{-3}$ for people aged over 25 years-old was ranged from 2.6 to 18.9 per 10^5 people in 2019, averagely decreased 16.9% in 2020 from 12.6 to 10.3 per 10^5 people (Table 2). In Tehran, Iran, the attributable number of IHD mortality was 86 and 84 per 10^5 people during 2013 and 2014, respectively (Hadei et al., 2017). In a study in Semnan, Iran, the IHD mortality rate due to $PM_{2.5}$ exposure was assessed. The results of recent study showed that with annual mean 123.8 $\mu g\ m^{-3}$, IHD mortality estimated ranging 31 to 85 per 10^5 people, while it was decreased during COVID-19 to 28 - 78 per 10^5 people. These findings are in agreement with the results of our study. Some conducted studies in other areas also showed a significant $PM_{2.5}$-mortality association (Gutiérrez-Avila et al., 2018; Singh et al., 2024; Thurston et al., 2016). In the global scale, approximately 1.39 million deaths were caused by IHD for $PM_{2.5}$ exposure (Bu et al.,

Table 2. At-risk population, estimated AP %, and the number of cases due to $PM_{2.5}$ exposure in 2019 and 2020.

Health impact	At-risk population		Estimated AP (%)		Mortality rate	
	2019	2020	2019	2020	2019	2020
Mortality, all-cause (age≥30)	208,600	209,100	7.71 (3.2-8.8)	6.58 (1.8-10.1)	37.5 (6.6-48)	31.2 (10-38.2)
Mortality, IHD (age≥25)	65,554	65,630	11.3 (2.85- 16.8)	10.6 (2.0- 18.75)	12.4 (2.6-18.9)	10.3 (3.2-13.2)
Mortality, COPD (age≥30)	101,220	103,458	5.6 (1.8- 9.55)	3.8 (1.1- 3.4)	29.0 (8.9-53.6)	28.2 (5.0-52.6)
Mortality, LC (age≥30)	72,188	72,940	13.7 (4.9- 25.6)	10.4 (5.3-22.55)	16.2 (8.21-31.2)	11.25 (3.55-19.3)

IHD: Ischemic heart disease, COPD: Chronic obstructive pulmonary disease, LC: Lung cancer

2021). In southeastern of China, the results showed that age-standardized IHD mortality rate attributable to $PM_{2.5}$ exposure decreased averagely 1.71% between 1990-2019 (Wang et al., 2023).

COPD mortality

The main cause of non-accidental mortality among individuals with 30-years or older due to exposure to $PM_{2.5}$ concentrations above 10 µg m^{-3} was COPD (Table 2). This finding is confirmed by the study of (De Marco et al., 2018) in Rome, Italy. In Tehran (Faridi et al., 2018) showed the number of M-COPD increased by 57% from 2010 to 2015, while the mortality rate due to COPD decreased in Ahvaz during 2020 from a range of 8.9 – 53.6 to 5 – 52.6 per 10^5 people. Our study showed the highest change in non-accidental deaths for $PM_{2.5}$ exposure was observed for M-COPD and M-IHD, respectively. Averagely, lowest change in the mortality rate was for COPD in 2020 rather than 2019. As seen in Table 2, the M-COPD decreased from 29 to 28.2 per 10^5 people i.e. a decline 2.9 2 per 10^5 people in 2020. In Khorramabad, Iran, the highest variation in mortality rate was M-COPD (1.8 deaths per 10^5 inhabitants) in 2020 (Anbari et al., 2023). In Chongqing, China, (Gou et al., 2023) reported that exposure to $PM_{2.5}$ is related to increased risk of M-COPD. In a study conducted in 204 countries and territories, the authors reported that globally, the number of M-COPD has increased from 3.52×10^5 to 6.95×10^5 people in the period 1990 to 2019, which was generally related to increase in $PM_{2.5}$ exposure (Yang et al., 2021).

LC mortality

The LC mortality rate in aged adults more than 30 years in Ahvaz due to $PM_{2.5}$ exposure in 2019 and 2020 were obtained 16.2 and 11.25 per 10^5 people, respectively (Table 2). Our results demonstrated that the number of M-LC was reduced by 4.9 per 10^5 people due to a decline in $PM_{2.5}$ exposure during 2020, as mentioned before the BI value was kept constant during 2 years. This finding is confirmed by (Yarahmadi et al., 2018) in Tehran. The M-LC was increased from 2013 to 2018 in Delhi, India due to increasing $PM_{2.5}$ concentrations (Afghan and Patidar, 2020). Also, the WHO reported that the rate of mortality due to air particulate exposure is approximately 227,000 people yearly in the world (Yarahmadi et al., 2018). The number of premature deaths in 2020, excluding COVID-19 impact, for $PM_{2.5}$ exposure was M-all-cause=22.4, IHD=7.4, COPD=21.8, LC=8.6 per 10^5 people for adults. The estimated LC mortality in a study in Isfahan, Iran showed that on average 17.2% of M-LC was related to long-term exposure to outdoor $PM_{2.5}$ concentrations above 10 µg m^{-3} during 2014 to 2019 (Hajizadeh et al., 2020). In the study by (Fu et al., 2015), the authors concluded that the exposure to $PM_{2.5}$ is an important risk factor for lung cancer, and resulted that there is a positive association between $PM_{2.5}$ exposure and M-LC for males and females in China.

Years of life lost and loss of life expectancy

Table 3 shows the YLL and loss of life expectancy for adults ≥ 30 years-old in relation to $PM_{2.5}$ exposure. As shown, the highest YLL was 2,177 in 2019, then it was declined by 16% in 2020. The WHO has reported been the YLL caused by particulate pollution in Iran was 37,894 during 2012 (WHO, 2016), showing this finding is consistent with our results regarding to Ahvaz population. The YLL calculated for Ahvaz was higher than the YLL obtained in northern Italy with 433 YLL for 2007 (Fattore et al., 2011), while it was lower than estimated YLL in different groups of Kuwait (Al-Hemoud et al., 2018) with annual $PM_{2.5}$ mean concentrations 42 and 87.9 µg m^{-3}, respectively. The YLL attributable to $PM_{2.5}$ for individuals higher than 30 years old was decreased by 30% during 10 years (2006-2015) in Tehran, Iran (Faridi et al., 2018).

Table 3. Years of life lost and expected life remaining due to exposure to $PM_{2.5}$ above 10 µg m^{-3} in 2019 and 2020.

Year	YLL (age ≥ 30)	YLL for 10^5/capita	Life expectancy (age ≥ 30)
2019	2,147 (438–2750)	41.4 (10.4–48.2)	0.69 (0.16-1.1)
2020	1,802 (466–2521)	32.0 (12.5-44.0)	0.44 (0.26-0.90)

YLL: years of life lost, ELR: expected life remaining.

The results also showed that exposure to air $PM_{2.5}$ in 2019 and 2020 reduced the life expectancy 0.69 and 0.44 years during each year, respectively. In a study in Tehran, the loss of life expectancy due to exposure to $PM_{2.5}$ concentrations in Iran was estimated ranging from 0.43 to 1.87 years (Hadei et al., 2020), in agreement with this study. In Kuwait, (Al-Hemoud et al., 2018) demonestrated that the life expectancy for adults older than 30 years-old would increase more by the decline in $PM_{2.5}$ exposure. The conducted study in 23 European cities illustrated that the average life expectancy at birth would increase more than 2 years, if the exposure to $PM_{2.5}$ was reduced in highly polluted cities of Bucharest and Rome (Boldo et al., 2006). In Brazil, the authors said the life expectancy would be improved 0.78 (0.66–0.9) years if the new WHO-AQG limit value of 5 µg m^{-3} to be settled as threshold (Yu et al., 2022).

The assess of health effects due to air particulate exposure is an important topic, because air pollution is a risk factor for human health, especially in developing Middle East countries such as Iran where air pollution is continue to rise (Shamsipour et al., 2019). Local researches on health effect are limited, leading to providing software and models such as AirQ plus and exposure-response functions for investigation of potential outcomes of air pollution exposure. Thus, there are some limitations for example in this method the information of interactions between air contaminants is not available (Aliyu and Botai, 2018). In this approach only we can focus on single pollutant without considering the real-time exposure to multiple pollutants. The mobility of citizens, combined air pollutants, and changes in their concentrations was ignored (Cakaj et al., 2023). The model assumes the measured concentration in central monitoring station is representative of the exposure to all people of a city, so potential exposure is misclassified (Anbari et al., 2024). Further limitation is that the applied RR was derived from the studies conducted in other areas of the world (Amoatey et al., 2021; Anbari et al., 2023), while here is not a special or local RR for Ahvaz.

CONCLUSION

In this study, a positive correlation was observed between decrease in $PM_{2.5}$ concentrations and reduction in mortality rate. The main source of air particulate matters as the most serious air pollutant within Iran, is Middle East dust storms from Arabian countries (Goudarzi et al., 2021b; Karimi et al., 2019), leading to high rate of mortality in Iran (Khaniabadi et al., 2018; Khaniabadi et al., 2017a). Previous studies provided quantitative estimates of the ability of green infrastructure to ameliorate urban air quality at city scale worldwide (Adhikari and Yin, 2020; Khaniabadi and Sicard, 2021). It is necessary to conduct studies to more precisely apportion the sources of particulate matter in west and southwest of Iran. Although there is not adequate information about the sources of air $PM_{2.5}$ pollution in Ahvaz, our experiment shows the high concentrations of $PM_{2.5}$ can be related to i) topography and climate conditions such as high temperature and evaporation, low rainfall, low wind speed, radiative inversions during winter, surrounding deserts without vegetation and native plants, unsuitable urban spaces and road asphalt, and dust storms events (Amoatey et al., 2021; Soleimani and Amini, 2017), and ii) anthropogenic activities such as construction the numerous factories inside and outside the city especially steel industries and carbon black, use of personal old vehicles and lack of public transportation, passing trucks to seaports and Iraq, heavily traffics, burning the sugarcane during winter (Velayatzadeh, 2020) and fossil fuels applying (Goodarzi et al., 2023). To reduce related health impacts due to $PM_{2.5}$ exposure, health strategies and prevention management should be adopted.

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CONFLICT OF INTEREST

There is no conflict of interest in this study.

ETHICAL STATEMENT

The current study has been approved by Research and Education Department at Petroleum Industry Health Organization (PIHO), Ahvaz, Iran.

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