



Spatial patterns and temporal variations of traffic-related air pollutants and estimating its health effects in Isfahan city, Iran

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Abstract

Isfahan as an important industrial city has faced with air pollution recently. Thus, we assessed the spatial and temporal trends of ambient PM_{2.5}, CO, SO₂, and O₃ and for estimating their health effect on Isfahan citizens between March 2018 and March 2019 through the AirQ+ software. Our results showed that citizens of Isfahan in almost 240, 167, and 134 of the days in the year has exposure to PM_{2.5}, SO₂, and O₃ higher than the WHO daily guideline, respectively. Daily variations of PM_{2.5}, CO, and SO₂ concentration showed the increasing trend of pollutants in the morning to evening. The maximum concentrations of O₃ were observed in the noonday. Also, the concentrations of these pollutants on Friday due to the holiday effect were higher than the weekdays. Except for O₃, the PM_{2.5}, CO, and SO₂ concentrations in the cold months and cold seasons was higher compared with the hot months and hot seasons. The total number of deaths because of lung cancer, natural mortality, ischemic heart disease, chronic obstructive pulmonary disease, stroke associated with ambient PM_{2.5} with the attributable proportion (AP) 11.43%, 11.63%, 15.96%, 15.15%, and 13.1% (95% CI) were 683, 19, 2, 202, and 55 cases, respectively. Therefore, the present study provides additional data for the provincial managers and politicians useful in planning proper strategies of air pollution control to decrease exposure and attributable mortalities.

Keywords Air pollution · AirQ+ software · PM_{2.5} · Risk assessment · Spatio-temporal trend

Introduction

Air pollution is a considerable environmental issue in cities in metropolitan cities of world [1]. Air pollution includes a variety of gaseous pollutants, particulate matters (PM), heavy metals, and polycyclic aromatic hydrocarbons (PAHs)

compounds [2–5]. Outdoor air pollution and the resulted adverse health impacts cause considerable risk factors, especially in developing countries [6]. According to the pollutant type, level, type, time of exposure and adverse events due to air pollution can be categorized as acute and chronic outcomes [7]. In October 2013, ambient air pollution categorized as Group 1 carcinogenic for human as recommended by the International Agency for Research on Cancer (IARC) [8]. According to the epidemiological investigation done during the recent decades, being exposed to air pollutants is linked to elevated deaths because of ischemic heart disease (IHD), stroke, lung cancer (LC), chronic obstructive pulmonary disease (COPD) and acute lower respiratory infections (ALRI) [9]. About 87% of the world's population lives in countries where the level of air pollution is higher than the limit recommended by regulatory agencies such as the World Health Organization (WHO) [10]. Based on the WHO report, about 80 present of premature mortalities are because of IHD and stroke, 14% of COPD and 6% of LC are resulted from air pollution [11]. Air pollution in addition to health effects increases the economic burden of countries, whereas, in 2016

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the costs of air pollution were as much as the gross domestic product (GDP) in some countries such as India, Canada, and Mexico. In Iran, the economic burden of air pollution is estimated at \$ 30 billion, or 2.48% of GDP [12]. Many types of research proved that Short- (acute) and long-term (chronic) exposure to the fine particulate matter (PM_{2.5}) increases mortality and morbidity in humans owing to its chemical characteristics [13]. PM species are among the important air pollutants in urban areas [14, 15]. PM_{2.5} has natural and anthropogenic origins, thus, in urban areas, traffic is the main cause of release [16, 17]. Through the recent decades, increases in respiratory and cardiovascular illnesses (e.g. heart attacks, bronchitis, decrease in lung function, and asthma,) and rate of mortality in the residents of cities are highly associated with atmospheric particulate matter [18]. The epidemiological studies demonstrated a significant correlation between PM_{2.5} exposure and increased risk of mortality [17, 19]. So that, A 10 µg/m³ elevation in the ambient PM_{2.5} is because of elevated death risk of all causes (4%), LC (9%), COPD (9%), and IHD (17%) [20, 21]. According to the reports, in 2015 approximated that chronic exposures to outdoor PM_{2.5} results in 4.2 million early mortality all over the world [22, 23]. Although, PM_{2.5} is extensively applied for the health effect evaluation of air pollution, the gaseous pollutants, like NO₂, CO, O₃ and SO₂, directly affect the elevated morbidity and mortality rates [13]. The number of deaths or hospitalizations due to exposure to air pollution can be estimated using the Health Impact Assessment (HIA) method. [24]. AirQ⁺ model has been recently applied for assessing the health effect of outdoor air pollution in different countries [25]. The WHO introduced AirQ⁺ software, by using outdoor air

pollution information, overall and at-risk people of the city, baseline incidence (BI per 10⁵ cases), relative risk (RR) and different epidemiological information, are able to estimate natural mortality as well as other mortalities because of ALRI, COPD, IHD, LC, and stroke [26]. Isfahan is a biggest city of Iran that has faced with serious air pollution because of unsustainable development, densely vehicular traffic and lack of outdoor air quality standards along with high daily consumptions of fossil fuels and associated emissions [27, 28]. Thus, the current study was carried out with the following aims: i) investigating the daily, weekly, monthly and seasonal variation in PM_{2.5}, CO, SO₂ and O₃ in ambient air of Isfahan, Iran; and ii) estimating all-natural mortality and other mortalities because of COPD, LC (adults ≥30 years), IHD, and stroke (adults ≥25 years) due to short and long-term exposure to PM_{2.5} and O₃ in the Isfahan between March 2018 and March 2019 through WHO AirQ⁺ software.

Material and method

Study area

Isfahan city, with a population of more than two million, is the most populous city in central Iran. Isfahan is a large city (551 km²) and is also one of the most beautiful cities worldwide and one of the industrial hubs of Iran. It is between longitude 59°39'E and latitude 32°38'N and 1570 m above sea level [29]. Figure 1 indicates the Isfahan Map and Air quality monitoring stations.

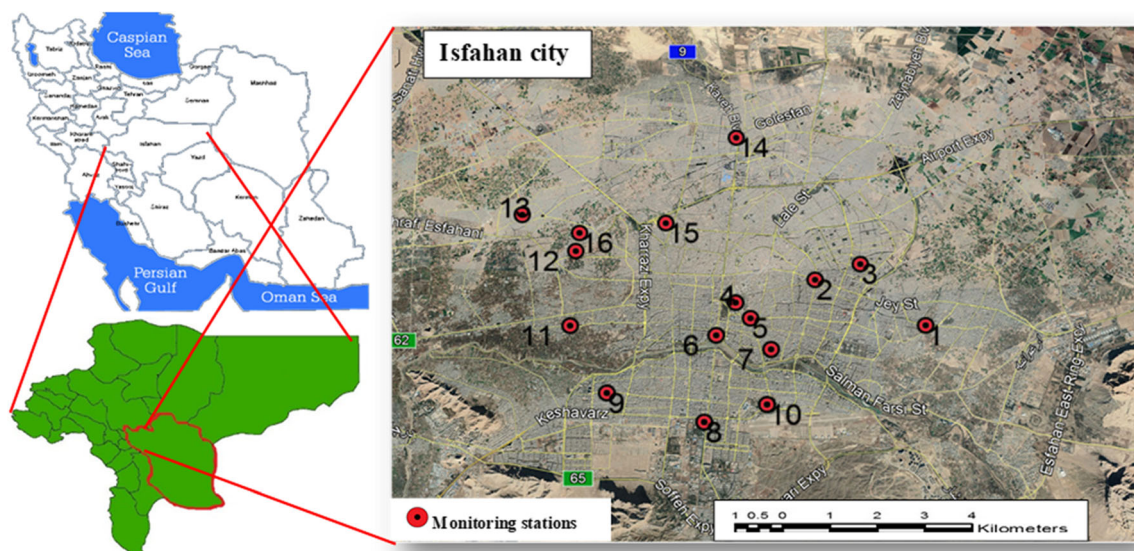


Fig. 1 The Map of the study area and Air quality monitoring stations

Data collection and processing

Of 16 Isfahan air pollution monitoring stations, seven ones were related to the Isfahan Department of Environment (IDOE) and nine ones were related to Isfahan Municipality. The hourly PM_{2.5}, CO, SO₂ and O₃ concentrations were gathered from the stations between March 21, 2018 and March 20, 2019. The PM_{2.5}, CO, SO₂ and O₃ values were analyzed using Excel software based on the WHO criteria [30, 31]. The 24 h averages for PM_{2.5} and SO₂; and Sum of ozone means more than 35 ppb (SOMO 35) for O₃ was calculated based on WHO Guideline [26]. Thus, merely valid values related to the stations were analyzed through AirQ⁺ software. To process PM_{2.5}, CO, SO₂ and O₃ data and to construct the graphs, Excel and R software was applied, respectively. Geographic Information System (GIS) (V.10.1) was also employed for the air pollutants spatial distribution level. The IDW method was used for generating maps of annual means.

Baseline mortality and population data

The Isfahan population between 2018 and 2019 regarding the all age groups, ≤5 years, ≥25, and ≥30 was achieved from the Statistical Centre of Ministry of Health and Medical Education, Iran. Regarding the death rates according to age in Isfahan between 2018 and 2019 provided by the Isfahan University of Medical Sciences, the BI numbers of natural mortality (because of all-natural reasons) and different mortality causes because of LC, IHD, COPD, and stroke were determined by integrated exposure-response (IER) model.

Health risk assessment (HIA)

The PM_{2.5} and O₃ health outcomes on those at risk was measured using the AirQ⁺ software based on the WHO through the annual mean of PM_{2.5} and O₃ and at-risk population, BI (per 100,000 population), a cutoff point for consideration (10 µg/m³ reported by WHO) and RR. Therefore, the natural mortality (because of all-natural reasons) and other mortalities because of COPD, LC (adult cases over 30 years), IHD, and stroke (adult cases over 25 years) can be estimated [32]. This method is based on the attributable proportion (AP) considered as the health effect section because of air pollution in people at risk (Eq. (1)) [26]:

$$AP = \frac{\{RR(c)-1\} \times p(c)}{\{RR(c) \times p(c)\}} \tag{1}$$

RR(c) presents the RR for the health consequences in the cases after exposure to air pollutants (c), and p(c) is the rate of cases in the exposure category (c).

The RR is measurable using Eq. 2.

$$RR = \exp [\beta \ln(x-x_0)] \tag{2}$$

β indicates the 95% CI, X represents the level of air pollutant, X₀ indicates the data of the counterfactual. The health outcomes (per 100,000 population) or (BE), as well as the overall number of AP related to the exposure (NE), are measurable using Eqs. (3) and (4), respectively [33]:

$$BE = B*AP \tag{3}$$

B is the baseline prevalence of the health outcomes (per 100,000 population). NE is measurable using the equation below:

$$NE = BE*N \tag{4}$$

N represents the number of people at risk.

Results and discussion

Temporal and spatial variations of air pollutants concentration

The annual variations

Table 1 summarizes the annual mean, minimum, and maximum levels of PM_{2.5}, CO, SO₂, and O₃ in the 16 monitoring station of Isfahan from 2018 to 2019. These values for PM_{2.5} was recorded 2.03, 606 and 30.14 ± 25.02 µg/m³, respectively. The annual mean PM_{2.5} levels is approximately 3 and 2.5 times higher compared with the WHO recommendation (10 µg/m³) and US-EPA Standards (12 µg/m³), respectively. The CO, SO₂, and O₃ were analyzed in 14, 12, and 2 stations, respectively. The mean annual concentration of CO, SO₂, and O₃ in monitoring stations was 2.54 ± 1.76, 24.46 ± 30.68, and 42.2 ± 27.86 µg/m³, respectively. During the study period the residents of Isfahan city about 240 days (65% of the days of the year) were exposed to the daily mean PM_{2.5} concentration higher compared with the WHO guideline (25 µg/m³). These values in Al-Hemond et al. 2019 and Guo et al. 2017 investigations were 6 and 7 times higher than the WHO guideline, respectively [34, 35].

The count of days with 24 h mean of SO₂ and O₃ higher than the WHO recommendation (20 and 50 µg/m³) was 167

Table 1 The mean, min and max of hourly concentrations of PM_{2.5}, CO, SO₂ and O₃

Pollutant	Min	Max	Mean	St. Deviation	No. of station
PM _{2.5} (µg/m ³)	2.03	606	30.17	25.02	16
CO (mg/m ³)	0.71	20.25	2.24	1.76	14
SO ₂ (µg/m ³)	1.51	383.17	24.46	30.68	12
O ₃ (µg/m ³)	3.86	110.12	42.2	27.86	2

and 134 days that The number of days with 24 h mean of SO_2 and O_3 higher than the WHO recommendation (20 and $50 \mu\text{g}/\text{m}^3$) was 167 and 134 days that these values for $\text{PM}_{2.5}$ and O_3 in Ahvaz (2014–2015) was 302 and 186 days [36, 37]. The reason for this is the high temperature and solar radiation and the photochemical reactions in the production of O_3 . Also, the presence of various industries and deserts all over this city and dust storms of the Middle East involved a role in increasing $\text{PM}_{2.5}$ concentrations.

Figure 2 (a, b and c) indicates distribution of $\text{PM}_{2.5}$, SO_2 and CO levels in the monitoring stations using ArcGIS software except for O_3 (due to lack of data on all stations). The distribution of $\text{PM}_{2.5}$, SO_2 and CO approximately follows a similar pattern. According to Fig. 4, the highest $\text{PM}_{2.5}$, SO_2 and CO concentration was found for the north, northwest, south and center. The following reasons can be mentioned for the high concentration of $\text{PM}_{2.5}$, SO_2 and CO in such areas: i) In the north, because of the highways, bus terminal, and the main line of the city buses; ii) In the northwest because of the monitoring station being near the main squares, and also stone-cutting industries and farming activities; iii) In the south and center because of the high population density, huge administrative and commercial buildings, and high traffic; iv) In the east, owing to the beltway, and the elevated transportation of diesel cars, the airport, and farming and road building activities. High concentrations of Criteria pollutants were reported in areas near main highways and those with terminals, higher traffic volume and population, as well as industrial and farming lands. Thus those living in such regions are more vulnerable against cardiovascular and respiratory disorders [9, 38–41].

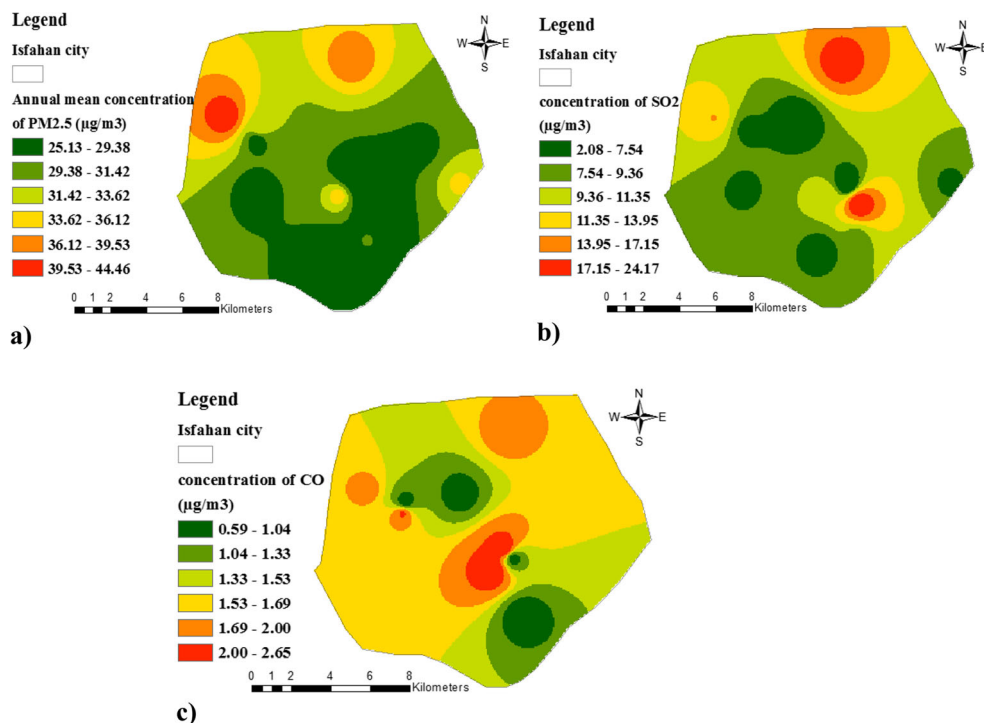
The hourly and daily variations

The mean hourly and daily concentration of $\text{PM}_{2.5}$, CO, SO_2 , and O_3 of all hourly concentration during the study period 2018–2019 are indicated in Fig. 3 (a,b,c and d) and Fig. 4 (a,b,c, and d), respectively. These are the results of the interaction between photochemical reactions, emission sources, and meteorological factors [42, 43]. Fig. 3a illustrates that the hourly concentrations of $\text{PM}_{2.5}$ increases in 4 phases. The first phase begins from 6:00 to 9:00 a.m., the second phase from midday (11:00 a.m. to 13:00), the third phase from 17:00 to 19:00, and the last phase from 21:00 to 22:00. Daily variations of concentration of CO and SO_2 follow almost the same pattern. So that, the highest concentration of CO and SO_2 were observed between 13:00–15:00 and 12:00–16:00, respectively (Fig. 3b and c).

The reason for the increasing trend of pollutants in the morning to evening has directly correlated to the road traffic caused by the opening (morning) and closure (afternoon) of offices and schools, construction and demolition activities and families shopping, and so on. Also, the increasing trend of pollutants such as $\text{PM}_{2.5}$ in the nighttime from 2.00 a.m. can be due to declining the temperature and low mixing height and weak wind and the occurrence of the inversion. Al-Hemoud et al. (2019) and Faridi et al. (2019) showed that mean hourly variations of air pollutants concentration exactly was related to road traffic [34, 42]. The daily peaks of $\text{PM}_{2.5}$, NO_2 , SO_2 , and CO in the morning and the evening was mostly attributed to traffic emissions [44].

The trend of O_3 concentration was increased since 7:00 a.m., so that the maximum concentrations was observed in midday between 13:00 and 16:00 and minimum concentrations in the late

Fig. 2 The zoning of the annual concentration of $\text{PM}_{2.5}$, SO_2 and CO in urban areas of Isfahan



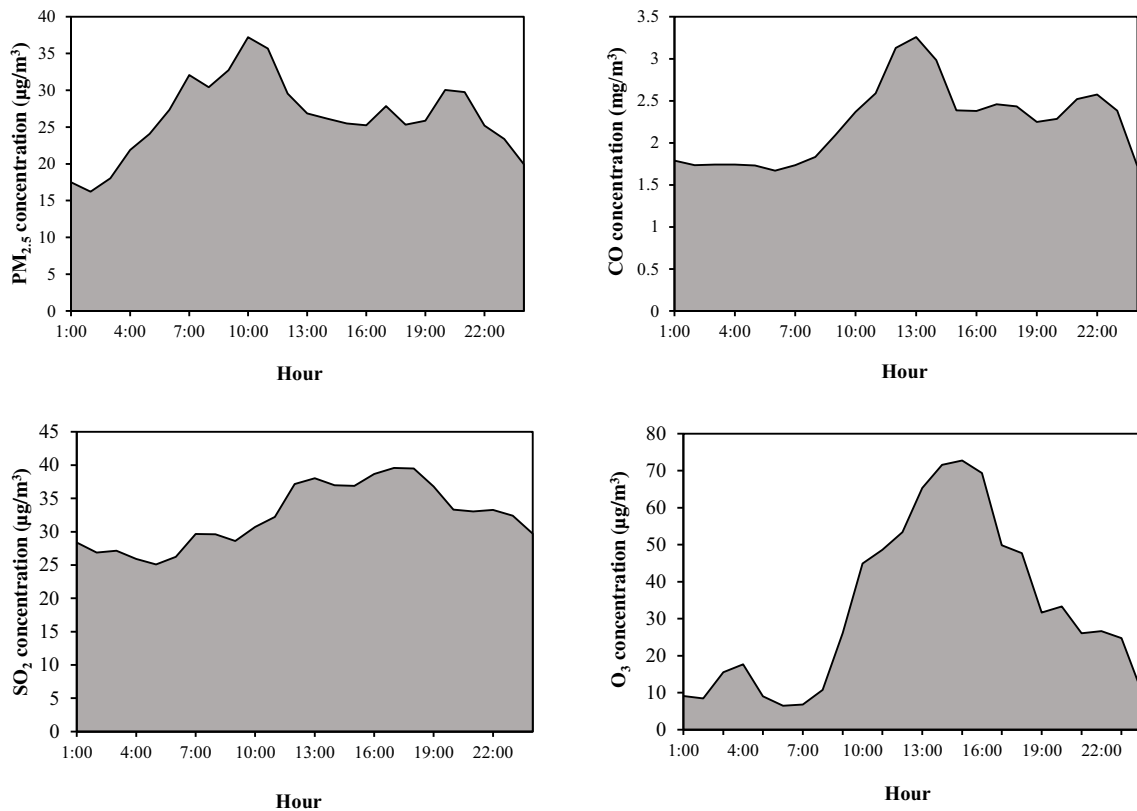
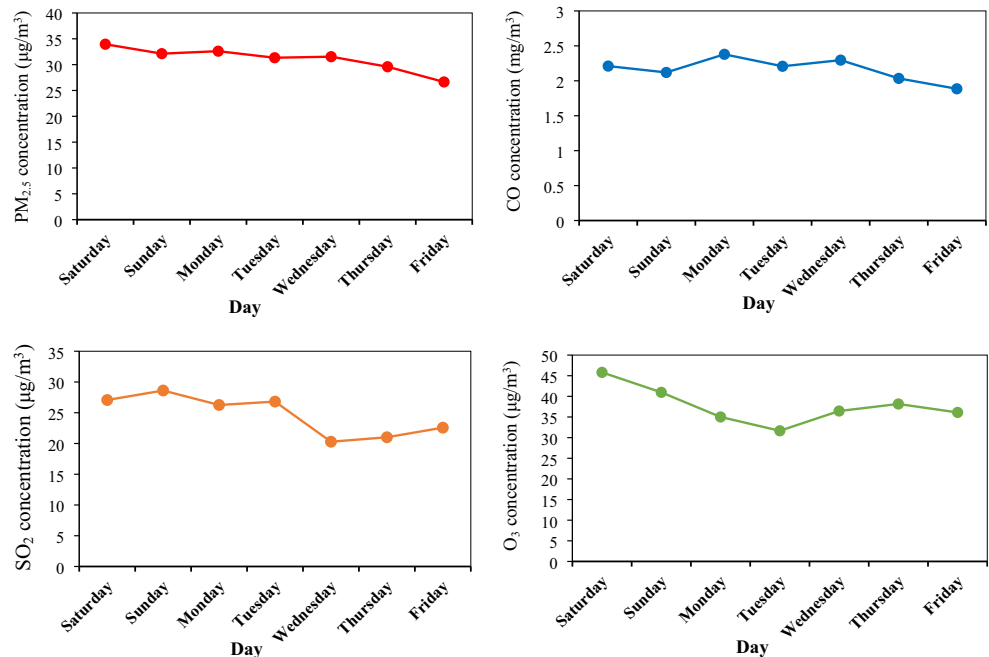


Fig. 3 The mean hourly variations of PM_{2.5}, CO, SO₂, and O₃ concentration

night (23:00–2:00 a.m.) that are related to solar radiation intensity (Fig. 3b). According to Fig. 3b, a small peak of O₃ was seen between 3:00–4:00 a.m. Given that there was no photochemical reaction as well as ozone generation during the night, the reason can only be because of horizontal and vertical transportation of ozone

from other regions [42, 45]. In Iran, Saturday to Thursday are weekdays, and weekend is Friday. With this explanation, daily variations of PM_{2.5}, CO, SO₂, and O₃ in Fig. 4a, b, c, and d indicated that the trend of these pollutants changes follows a similar pattern. So that the concentration of pollutants decreases from

Fig. 4 The daily variations of all hourly concentrations of PM_{2.5}, CO, SO₂, and O₃



Saturday to Friday and the lowest concentration of pollutants was seen on weekends, i.e. Friday. The increase in these pollutants on weekdays can be attributed to the start of schools and office activities, which leads to increased concentrations of air pollutants due to congestions and road traffic. But, the reduction in the concentration of these pollutants at the weekend (Friday) is due to the “holiday effect” which leads to reduced vehicle traffic and other emission sources [42]. The Kuerban et al. (2020) indicated that, in North China, the PM_{2.5}, PM₁₀, SO₂, NO₂, and CO concentrations on the weekend were lower than weekdays [44]. Based on Fig. 4, almost a small decrease was found in pollutant levels on Tuesday which may be due to the car-free Tuesday’s plan that is running in Isfahan in recent years.

The monthly and seasonal variations of air pollutants

The monthly and seasonal box plot graph of the hourly average level of PM_{2.5}, CO, SO₂, and O₃ through the research period 2018–2019 is indicated in Figs. 5 and 6, respectively. According to Fig. 5a the PM_{2.5} concentrations trend in cold months (October, December, November, and January) were more compared with others. Also, the lowest and highest PM_{2.5} concentration was related to October (40.26 µg/m³) and February (20 µg/m³). The highest and lowest CO level were found in March (2.74 mg/m³) and October (1.28 mg/m³), respectively (Fig. 5 b). SO₂ concentrations in November (34.98 µg/m³) and February (37.83 µg/m³) was greater than the other months (Fig. 5c). Based on Fig. 5d, O₃ concentration enhanced by an increase in air temperature, so that O₃

concentrations had the highest and lowest concentrations in June (83.87 µg/m³) and March (10.25 µg/m³), respectively.

Based on the seasonal variations of the hourly PM_{2.5} levels (Fig. 6a), the PM_{2.5} level in cold seasons was more than the warm ones. With the start of autumn, temperatures begin to decrease, so the atmosphere starts to reverse the process. This trend of PM_{2.5} variation and its increase in the cold seasons have been announced earlier [17, 46, 47]. The seasonal variations of CO in Fig. 6b showed that the concentration of CO is as follows: spring > winter > summer > autumn. Based on Fig. 6c, the mean SO₂ levels in the winter was more compared with the other seasons.

According to Fig. 6a, most fluctuations in PM_{2.5} and SO₂ concentrations are related to seasonal changes. So that, the pattern of increasing the concentration of these pollutants in cold seasons are mostly ascribed to: i) The temperature inversion as well as stability of weather during cold seasons because of climate conditions, like low winds and mixing height, and temperatures [42, 48, 49]; ii) the decline of temperature and an increase in to use fossil fuels in Residential, commercial, and industrial regions that can be considered as an important emission sources of air pollutants during the cold seasons [48, 50] iii) A drop in O₃ concentration, the subsequent, decline of hydroxyl radical, and resulting, the decrease in the oxidation potential in winter.

According to a similar study in Tehran, the average concentration of PM_{2.5} in winter and fall was more than summers and springs [51]. In contrast to our research, studies in Hamadan, Ilam, Ahvaz (Iran) and India found that PM_{2.5} level in warm

Fig. 5 The monthly box plot graph of the hourly mean concentration of PM_{2.5}, CO, SO₂, and O₃

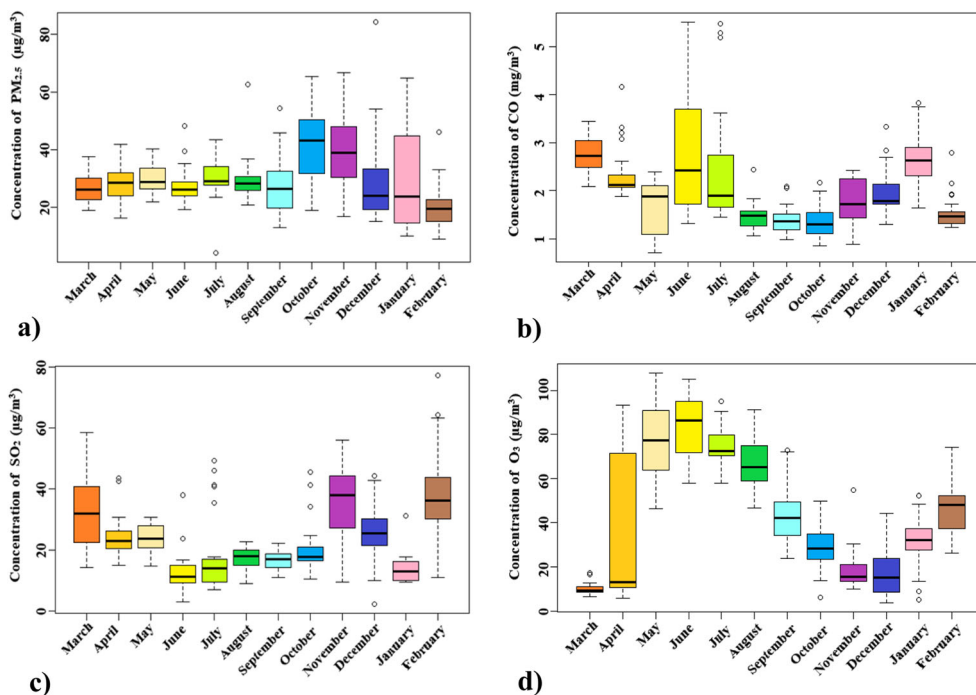
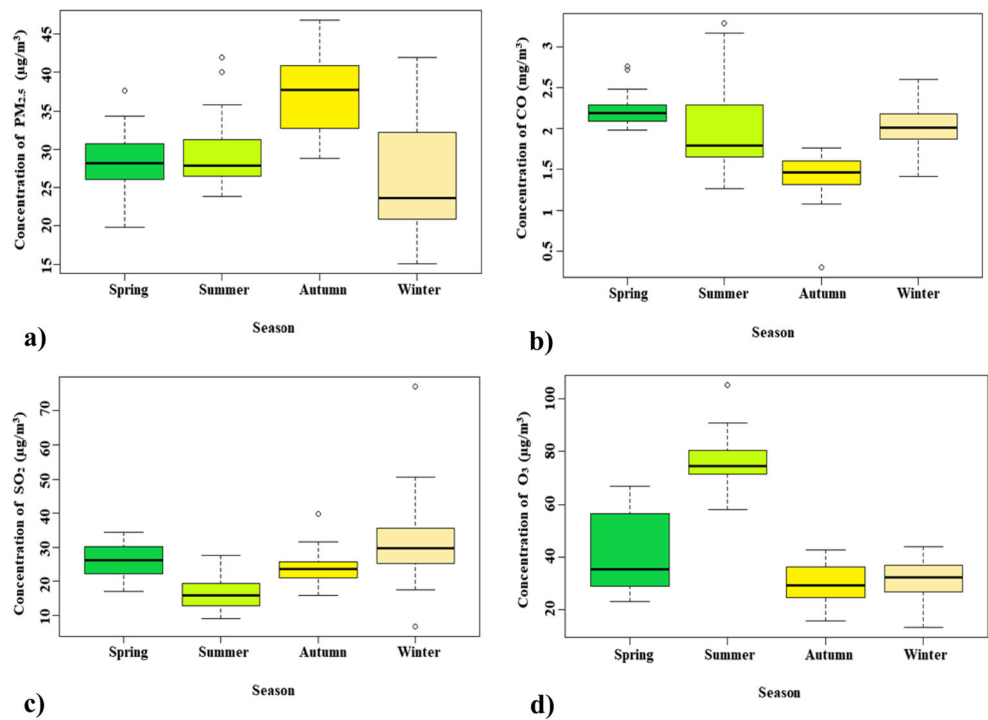


Fig. 6 The seasonal box plot graph of the hourly mean concentration of PM_{2.5}, CO, SO₂, and O₃



seasons because of high temperatures, low wind as well as speed severity of sand storms are higher compared with other seasons [13, 37, 52, 53]. Also, Yousefian et al. in Tehran (2020) and Geo et al. in Beijing (2017) Showed that the concentration of PM_{2.5}, NO₂, SO₂, and CO in the cold seasons because of decrease sunshine time, temperature inversion, and air stability was higher than the warm seasons [35, 51].

The O₃ level demonstrates an inverse seasonal trend Compared to PM_{2.5}, SO₂, and CO, so that, the highest mean concentrations of O₃ with a value of 76.34 µg/m³ related to the summer season, which was higher than in other seasons' values (Fig. 6d). The results of similar studies showed that the O₃ concentrations within summers and springs were significantly more than that of other seasons [53, 54].

The high O₃ concentration in the warm seasons, especially in summer, is mainly attributed to sun radiation due to the rising daylight and sunshine hours and increasing the surface temperatures, which all increasing ozone-producing photochemical reactions [35, 55]. Solar radiation and high temperature with O₃ production are positively correlated [56, 57].

Health risk assessment of exposure to PM_{2.5} and O₃

Table 2 presents the health impacts of short and long-term exposure to ambient PM_{2.5} level more than 10 µg/m³ achieved from the AirQ⁺ software. The AP of 11.43% (95% CI: 7.62–14.86) was calculated for the natural mortality for PM_{2.5} levels and the excess death cases of 683 (454–887) cases was approximated. Comparing the rate of natural mortality due to

PM_{2.5} in similar investigations indicated that the related cases in the current research was lower compared with other investigations. For instance, in Tehran, the rate of those attributable to long-term exposure to PM_{2.5} from 2015 to 2016 and 2017 to 2018 was 5073 and 6710 cases, respectively [33, 58]. Karimi et al. (2019) in Ahvaz reported 4061 deaths because of long-term exposure to PM_{2.5} from 2006 to 2015 [25]. Also, Manojkumar et al. (2019) reported 90,807, 57,812 and 26,635 deaths because of long-term exposure to PM_{2.5} in Delhi, Chennai, and Lucknow, respectively [59]. The high number of deaths because of long term exposure to PM_{2.5} in India, Tehran, and Ahvaz in comparison with our research may be the high at-risk population as well as high PM_{2.5} concentration in such research. We estimated that on average 11.43% (7.59% -14.84%) of deaths in Isfahan in 2018–2019 was due to long term exposure to PM_{2.5} that it was 15% reported by a relevant research in Tehran [20]. The number of deaths because of respiratory diseases due to long-term exposure to O₃ with AP 0.07% (95% CI: 0.03–0.12) was 0 (0–1) cases which is negligible. This value in the study conducted in Ahvaz during 2016–2017 was reported 1 (0–2) case [25]. In our research, the natural death rate because of short-term exposure to PM_{2.5} with AP 0.63% (95% CI: 0.23–1.02) during 2018–2019 was 38 (14–61) cases. The death rate of 131 cases was reported from Hamadan towing to short-term exposure to PM_{2.5} [13]. According to Table 2 the total natural death rate because of short-term exposure to O₃ was 1 negligible case.

Also, based on Table 2, the total death rate from Lung cancer due to long term exposure to PM_{2.5} with AP 15.96% (95% CI: 7.61–23.22%) in 2018–2019 was estimated 2 (6–17)

Table 2 The health outcomes, attributable proportion (AP %) and excess cases due to ambient PM_{2.5} and O₃

Exposure	Pollutant	Health Endpoint	BI	RR	AP (%)	Excess cases	Attributable cases
Long-term	PM _{2.5}	Natural mortality ^a	479.3	1.062 (1.04–1.083)	11.43% (7.61–14.86)	683 (454–887)	54.76 (36.46–71.2)
		COPD mortality ^a	11.63	1.09 (1.04–1.14)	13.41% (8.08–19.84)	19 (12–29)	13.41 (8.08–19.84)
		LC mortality ^a	6.01	IER function	15.96% (7.61–23.22)	2 (6–17)	0.96 (0.46–1.4)
		IHD mortality ^b	90.99	IER function	15.15% (9.61–30.2)	202 (128–403)	13.78 (8.75–27.48)
		Stroke mortality ^b	28.87	IER function	13.1% (6.99–20.44)	55 (30–86)	3.78 (2.02–5.9)
	O ₃	Respiratory mortality ^a	58.72	1.014% (1.005–1.024)	0.04% (0.02–0.08)	0 (0–1)	0.03 (0.01–0.05)
Short-term	PM _{2.5}	Natural mortality	479.3	1.014% (1.005–1.024)	0.63% (0.23–1.02)	38 (14–61)	3.02 (1.11–4.91)
	O ₃			1.0029% (1.0014–1.0043)	0.01% (0.0–0.01)	1 (0–1)	0.01 (0.0–0.01)

^a Mortality for adults >30 years old; ^b mortality for adults >25 years' old

cases. In similar studies were obtained the death rate because of long-term exposure to PM_{2.5} owing to LC in Islamabad and Tabriz were 24 and 7 cases [46, 48]. Yarahmadi et al. (2018) in Tehran reported 427 deaths from LC were because of long-term exposure to PM_{2.5} [58]. The difference between death rates due to LC reported in our research and Yarahmadi et al. study may be the differences in the baseline death rates since the at-risk population in Tehran was more than the Isfahan. LC is the fourth reason for mortality because of outdoor air pollution, so that, PM_{2.5} can penetrate the lungs and secrete cytokines and oxidative stress resulting in LC [33, 60]. According to Boldo et al., 15 and 20 µg/m³ decrease in ambient PM_{2.5} level can reduce nearly 1296 and 1901 causes of mortality in 23 European cities [61]. In the current research, on average 2.66% (8–22.66%) of deaths from LC was because of exposure to PM_{2.5} for a long time. Ansari et al. (2019) reported that 17.36% of deaths because of LC in Tehran from 2017 to 2018 resulted from exposure to PM_{2.5} for a long time [33].

The total mortality of COPD attributable to PM_{2.5} during 2018–2019 with AP 13.41% (95% CI: 8.08–19.84%) was estimated 19 (12–29) cases (Table 3). The mean rate of COPD mortality due to exposure of PM_{2.5} for a long time in Rome, Ahvaz and Tehran was 279, 75 and 158 cases [17, 25, 58]. In the present study, on average 13.1% (8.27–20%) of deaths because of COPD was due to long-term exposure to PM_{2.5} thorough the research. This value in Mashhad was 4.5% [62]. In our study, the contradiction between the numbers of deaths from COPD with other studies may be due to the difference in the value of baseline mortalities.

Based on the WHO, IHD, stroke, and COPD are respectively the first, second and third reasons for mortality because of exposure to air pollution (WHO, 2014). There was an association between 10 µg/m³ increase in the atmospheric PM_{2.5} levels and 25% increase in mortality due to IHD and 0.51% increase from cardiovascular admissions [17, 63]. The overall death rates of IHD due to PM_{2.5} in 2018–2019 with AP 15.15% (95% CI: 9.61–30.2%) was estimated 202 (128–403) cases, respectively (Table 2). The studies conducted in

Taiwan and Iran (Tehran) 1477 to 3797 people died of IHD because of PM_{2.5}, respectively [64, 65]. The comparison of our findings with the mentioned investigations indicated that the death rate of IHD in Tehran was more compared with the Isfahan since those at risk and PM_{2.5} levels are higher in Tehran. The annual average PM_{2.5} level in Tehran was 49 µg/m³ [66], which was 30.17 µg/m³ in our research. The present study estimated that on average 15.15% (9.6–30.23%) of mortality due to IHD thorough the research was because of exposure to PM_{2.5} for a long time, which was 17.4% in a relevant research in Tehran from 2006 to 2015 [42].

Many epidemiological studies indicated a positive correlation between stroke and exposure to ambient PM_{2.5} level for a long time [67–69]. Increasing every 5 µg/m³ in the PM_{2.5} level increased hazard ratio nearly 1.11 (95% CI: 1.05, 1.17) for the occurrence and mortality of stroke [69]. The mortality rate because of stroke has an association with exposure to PM_{2.5} for a long time between 2018 and 2019 with AP 13.1% (95% CI: 6.99–20.44%) was estimated to be 55 (30–86) cases (Table 2). According to the similar studies, the death rates because of Stroke in Tehran from 2015 to 2017 due to ambient PM_{2.5} were 1500 and 1145 cases, respectively [33, 64]. The difference between the death rates owing to Stroke in our research with similar investigations can be the differences in the baseline death rates. In our research, 13% (7.09–20.33%) of mortality because of stroke was associated with exposure to PM_{2.5} for a long time thorough the research.

Conclusion

This study was done for investigating daily, weekly, monthly and seasonal differences of PM_{2.5}, CO, SO₂, and O₃ and assessing the health risk of short- and long-term exposure to ambient air pollutants in Isfahan during 2018–2019. We used the AirQ⁺ software for estimating natural mortality as well as other mortalities because of COPD, LC, IHD, and stroke resulting from long-term exposure to PM_{2.5}. Based on our results, the annual average

concentrations of PM_{2.5}, O₃, SO₂, and CO from 2018 to 2019 were between 30.17, 42.2, 24.46 µg/m³ and 2.54 mg/m³, respectively. The annual mean PM_{2.5} levels were approximately 3 times more compared with the WHO recommendation. Also, our results showed that those living in Isfahan during 2018–2019 in almost 240, 167, and 134 of the days during 1 year has exposure to PM_{2.5}, SO₂, and O₃ over than the WHO daily recommendation (25, 20 and 50 µg/m³), respectively. Daily variations of PM_{2.5}, CO, and SO₂ concentration showed the increasing trend of pollutants in the morning to evening which has directly correlated to the road traffic. The maximum concentration of O₃ was observed in midday 13:00 and 16:00 that are related to solar radiation intensity. The concentration of PM_{2.5}, CO, SO₂, and O₃ on weekends (Friday) due to the “holiday effect” (low traffic and other sources of emission) was lower than the weekdays. The monthly and seasonal differences in PM_{2.5}, CO, and SO₂ showed that approximately, the concentrations of these pollutants in the cold months and cold seasons were more compared with the hot months and hot seasons. But, the concentration of O₃ due to solar radiation and increasing ozone-producing photochemical reactions in warm months and seasons was higher than in other months and seasons. The mortality rate resulting from natural death, COPD, LC, IHD, and stroke showed an association with ambient PM_{2.5} were 683, 19, 2, 202, and 55, respectively. Based on our study estimation, 11.43% of the natural mortality, 2.66% of LC, 13.1% of COPD, 15.15% of IHD, and 13% of stroke mortalities in Isfahan was associated with long-term exposure to ambient PM_{2.5}. We indicated that the high mortality rate due to air pollution in Isfahan can cause several economic burden. Thus, according to the daily, monthly and seasonal variations of critical air pollutants in Isfahan, provincial managers as well as politicians should use proper models and techniques to control air pollution in order to decrease the mortalities due to air pollutants.

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Declarations

Ethical considerations The authors declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

Competing interests The authors declare that they have no conflict of interest.

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