Toxicology Reports 12 (2024) 56–64

Contents lists available at ScienceDirect

Toxicology Reports

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

Estimating the health impacts of exposure to Air pollutants and the evaluation of changes in their concentration using a linear model in Iran

Zahra Kazemi [a,b], Zohre Kazemi [a,b], Ahmad Jonidi Jafari [a,b], Mahdi Farzadkia [a,b], Javad Hosseini [c], Payam Amini [d], Abbas Shahsavani [e], Majid Kermani [a,b,*]

[a] *Research Center of Environmental Health Technology, Iran University of Medical Sciences, Tehran, Iran*
[b] *Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran*
[c] *Department of Biostatistics,School of Public Health,Hamadan University of Medical Sciences,Hamadan,Iran*
[d] *Department of Biostatistics, School of Health, Iran University of Medical Sciences, Tehran, Iran*
[e] *Air Quality and Climate Change Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran*

ARTICLE INFO

Handling Editor: Dr. L.H. Lash

Keywords:
Air pollution
AirQ$^+$ software
Health impact assessment
NO_2
O_3

ABSTRACT

In big and industrial cities of developing countries, illness and mortality from long-term exposure to air pollutants have become a serious issue. This research was carried out in 2019–2020 to estimate the health impacts of PM_{10}, NO_2 and O_3 pollutants by using AirQ$^+$ and R statistical programming software in Arak, Isfahan, Tabriz, Shiraz, Karaj, and Mashhad. Mortality statistics, number of people in required age groups, and amount of pollutants were gathered respectively from different agencies like Statistics and Information Technology of the Ministry of Health, Statistical Center, and Department of Environment and by using Excel, the average 24-hour and 1-hour concentration and maximum 8-hour concentration for PM_{10}, NO_2 and O_3 pollutants were gathered. We used linear mixed impacts model to account for the longitudinal observations and heterogeneity of the cities. The results of the study showed high number of deaths due to chronic bronchitis in adults, premature death of infants, and respiratory diseases in Mashhad. This research highlights the importance of estimation of health impacts from exposure to air pollutants on residents of the studied cities.

1. Introduction

Air is one of the most basic needs for the continuation of human life and other living creatures [1]. Inappropriate air quality in big cities causes harmful damage to people's health and environment [1–3]. Various researches have shown that short and long-term exposure to air pollutants cause a wide range of acute and chronic complications, reduction of public welfare, decrease in gross domestic product, and mortalities [4–16]. Pollutants like (PM) particles, sulfur dioxide, carbon monoxide, lead and nitrogen dioxide have been presented as criteria air pollutants by Environmental Protection Agency (EPA) [7,17–19]. PM_{10} is one of the most significant air pollutants that plays an important role in air pollution in European countries. Complications from exposure to PM_{10} can be lung cancer, Cardiovascular and respiratory diseases, Chronic obstructive pulmonary disease, lung inflammation, and asthma [19–22]. Furthermore, increased deaths from respiratory diseases leads to reduction of life expectancy [7]. Research has shown that with an increase in PM_{10} concentration of 310 $\mu g/m^3$, the death rate increases by almost 1% [20]. Compounds of nitrogen are another types of atmospheric pollutants. Motorized vehicles are important sources of NO_2 and NO_x emissions. Exposure to these pollutants can cause cough, wheezing, virus infections, inflammation of lungs and bronchi, asthma, and early death [19,23]. VOCs are precursors of ozone layer [24]. In their study, Medina-Ramon et al. and Burnett et al. found that exposure to ozone causes asthma and increase in hospitalizations [25].

In recent years, different programs like Aphekom, BenMAP, AirQ, and AirQ$^+$ have been used to measure the health impacts of air pollutants [16], but AirQ$^+$ is the most suitable in terms of measurement in anti-health impacts of exposure to atmospheric pollutants on people's health in specific time period and location [7,26,27] that can measure the mortalities related to pollutants by using total population statistics, population at risk, basic incidence rate, and relative risk [3,28].

Abbreviations: WHO, World Health Organization; BI, Basline Incidence; RR, Relative Risk; PM_{10}, Particulate Matter Less than 10 μm; NO_2, Nitrogen dioxide; O_3, Ozone; EPA, Europ Protection Agency.

* Corresponding author at: Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran.
E-mail addresses: majidkermani@yahoo.com, kermani.m@iums.ac.ir (M. Kermani).

https://doi.org/10.1016/j.toxrep.2023.12.006
Received 10 October 2023; Received in revised form 9 December 2023; Accepted 14 December 2023
Available online 15 December 2023

Although various studies have been conducted around the world to estimate the health impacts of exposure to pollutants affecting people's health [5]; however, few studies about the mentioned topic have been conducted in important metropolitan cities in Iran, which are among the most polluted cities in the world [29]. Therefore, considering the importance and sensitivity of the issue, the purpose of this research is to estimate the health impacts of long-term exposure to standard air pollutants (PM_{10}, NO_2, O_3) and evaluate the changes of pollutants over time using linear polynomial mixed impacts regression models during 2019–2020 in Arak, Isfahan, Tabriz, Shiraz, Karaj, and mashhad.

2. Methodology

In this study, the evaluation of health impacts caused by exposure to PM_{10}, NO_2, O_3 pollutants was calculated by $AirQ^+$ software and evaluation of changes in pollutants over time was done with the help of linear mixed impacts model method.

2.1. Data gathering and processing

The amount of hourly concentration of PM_{10}, NO_2, O_3 pollutants, the total population and over 30, and mortality statistics were respectively received from Department of Environment, Statistical Center, and Statistics and Technology of Ministry of Health during 2019–2020. Then, to validate the pollutants, zero and negative data were removed and 24-hour average concentration of PM_{10} pollutant, 1-hour average concentration of NO_2 and 8-hour maximum concentration of O_3 were obtained according to WHO standard by Excel software [30]. Fig. 1.

2.2. $AirQ^+$ software

$AirQ^+$ evaluates the health impacts of exposure to air pollutants by using baseline incidence (BI), relative risk (RR), and doze function in specific time period and location [31–33]. In Table (1), according to the standard of the World Health Organization (WHO), amounts of RR and BI are presented[31,34,35].

In order to evaluate the health risks caused by exposure to pollutants, data such as annual average values of pollutants (μg/m^3), total population and population at risk (number or percentage), basic incidence per 10^5 populations (for the incidence of asthma symptoms in asthmatic children, the prevalence of bronchitis in children and incidence of chronic bronchitis in adults), and basic incidence per 10^3 (premature death of infants) are needed. During this research, the evaluation of the health impacts was done based on the attributable population proportion [28,36]. Studies have shown that there is a relationship between relative risk (RR) and attributable proportion (AP), which is shown in Eq. (1).

$$AP = \frac{\sum[(RR(c) - 1) \times P(c)]}{[RR(c) \times P(c)]} \quad (1)$$

Here, the relative risk value for specific health impacts in category "c" of exposure (c)RR, which is obtained from the dose-response functions, AP attributable proportion of the health impacts, P(c) exposed group of the population proportion It is in category "c".

Rate of attributable proportion caused by exposure to pollutants can be evaluated when the baseline frequency of the specific health impact in the population is in the form of Eq. (2).

$$IE = I \times AP \quad (2)$$

Here, I baseline incidence of the health impacts is studied. IE is the health impact rate attributable to the exposure [37–39].

To calculate the population, the number of estimated excess cases caused by exposure to pollutants is obtained by using the Eq. (3).

$$NE = IE \times N \quad (3)$$

NE is the number of excess cases, and N is the size of the population under study.

Evaluation of health risks caused by exposure to pollutants was done using the linear-log method.

2.3. Statistical analysis

To describe the amount of each pollutants during the months in different cities, mean (standard deviation) was used. To analyze the development of pollutants and the impact of time in different cities, linear mixed effect (LME) model with polynomial was were utilized. The LMEL is a regression model in which assesses the impact of predictors on a continuous variable. The random effect in this model considers the variation caused by the longitudinal nature of the data for each city over the time. This model is usually used when unknown sources of variation exist and reduces the standard error of estimated coefficients using random effects. According to the dynamic nature of observed pollutants over the time, considering nonlinear association between the time and the pollutants is vital [40,41]. Therefore, we used polynomial LME models for our dataset. For city *i* at time *j*, the model can be written as follows in which Y_{ij} is the response variable (the pollutant), β_0 is the intercept, β_1 is the coefficient of first order impact of covariate X_1, β_2 is the coefficient of second order impact of covariate X_1, b_i the random intercept to capture the variation caused by the presence of different cities which follows a normal distribution with zero mean and varianceσ_b^2, and ε_{ij} is the error term.

$$Y_{ij} = b_i + \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{1ij}^2 + .. + \varepsilon_{ij}$$

The data analysis has been carried out using R statistical programming software using "lme4″ package. A probability value less 0.05 was considered as significant.

3. Results and discussion

3.1. criteria pollutants concentration

To evaluate the health impacts of exposure to standard air pollutants and assessing the polynomial trend of pollutants over the time and different major cities in Iran, the data from the average annual concentration of PM_{10}, NO_2 and O_3 given in Table (2), were used. The maximum and minimum average annual concentration of PM_{10} is related to Shiraz and Isfahan with values 54.60 ± 19.36 and 29.04 ± 17.78 respectively which was above the standard (WHO, 2006)[42]. This increase is probably due to the combustion of fuels, transportation, and dust storms which matched with the findings of Todorović et al., Serbia and Sicard et al. in three cities (Ahvaz, Kermanshah, and Arak) in

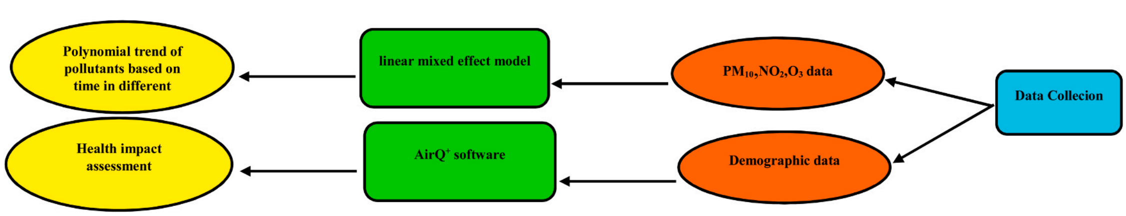

Fig. 1. The performance of steps in this study.

Table 1
Long-term health endpoints, baseline incidence (BI) range rates and relative risk (RR) values used in this study.

Air pollutant	Health endpoints	BI per 10^5 capita						RR (CI)	RR references
		Arak	Esfahan	Tabriz	Shiraz	Karaj	Mashhad		
PM_{10}	Incidence of chronic bronchitis in adults (age ≥ 30)	17.79	17.65	24.30	15.99	13.46	19.85	1.117 (1.040–1.189)	(Héroux et al., 2015)
	Post neonatal (age 1–12 months) infant mortality, all-cause	334.34	310.55	264.64	347.02	199.22	347.11	1.04 (1.02, 1.07)	(Héroux et al., 2015)
O_3	Mortality, respiratory diseases (age ≥ 30)	40.02	33.55	53.18	27.29	21.91	48.05	1.014 (1.005–1.024)	(Héroux et al., 2015)
NO_2	All natural mortality for adults > 30 years old	966.0	777.40	1003.0	797.0	549.0	936.4	1.041 (1.019 – 1.064)	(Héroux et al., 2015)

Table 2
Statistical summary of PM_{10},O_3,NO_2 pollutants in this study (2019–2020).

Parameter		Arak	Esfahan	Tabriz	Shiraz	Karaj	Mashhad
PM_{10} concentration (μg/ m^3)	Max	132	161.28	100.08	79.77	83.58	95.67
	Min	9.07	18.24	9.62	2.64	0.15	0.81
	Mean ± S.D	38.71 ± 11.90	54.60 ± 19.36	50.37 ± 16.86	29.04 ± 17.78	31.63 ± 14.98	49.14 ± 12.54
O_3 concentration (ppb)	Max	32.72	37.46	47.16	50.93	34.29	58.89
	Min	9.17	7.44	5.02	0.27	2.09	19.83
	Mean ± S.D	24.52 ± 4.84	23.32 ± 5.86	15.46 ± 5.23	15.36 ± 9.52	17.27 ± 7.31	35.99 ± 9.73
NO_2 concentration (μg/ m^3)	Max	49.90	16.35	66.79	59.55	37.54	58.58
	Min	4.04	14.16	0.11	11.46	0.49	0.04
	Mean ± S.D	32.43 ± 7.79	15.41 ± 0.46	25.07 ± 14.62	35.47 ± 9.01	2.60 ± 2.09	21.76 ± 16.45

Iran. Eskandari et al., in Dezfoul, Barzeghar in Tabriz, and Khaniabadi et al., in Ilam [7,15,19,43–45]. Eskandari et al. in their study in Dezfoul reported that the maximum and minimum average daily concentration of PM_{10} were 192 and 110 micrograms per cubic meter respectively which was above the standard [7]. During another similar study in Ahvaz, the maximum and minimum level of PM_{10} were 420.5 and 154.6 micrograms per cubic meter respectively [46]. Moreover, Eskandari et al., reported that the maximum and minimum concentration of PM_{10} in Dezfoul were 192 and 110 micrograms per cubic meter respectively [7]. Zarandi et al. in their research from 21 stations in Tehran, reported the concentration of PM_{10} between 56–153 micrograms per cubic meter [47]. In similar studies in Tehran, the average annual concentration of PM_{10} were reported to be between 78.9–89.9 micrograms per cubic meter [48]. Barzeghar et al., found that the maximum and minimum level of PM_{10} were 86.4 and 67.5 micrograms per cubic meter respectively [49]. In a study in Kermanshah, the annual concentration of PM_{10} was reported to be 86 micrograms per cubic meter [32]. Furthermore, in another study by Goudarzi et al., in Kermanshah, the average annual concentration of PM_{10} was reported to be 85.7 μg/m^3 [50]. Zallaghi et al., also found this value to be 90.03 in Kermanshah [32]. In a study by Sicard et al. in three cities in Iran (Ahvaz, Arak, and Kermanshah), it was reported that the average annual concentration of PM_{10} was above the standard of WHO [15]. Moreover, Khaniabadi et al. in their study in Ilam reported this value 78 μg/m^3 which was above the standard recommended by WHO [51]. Geravandi et al. also during their three-year research in Ahvaz found that the average annual concentration of PM_{10} was between 278–288 micrograms per cubic meter which was above the standard[52]. Like the mentioned study, in southwest China, the average daily concentration of PM_{10} reported to be 156.6 micrograms per cubic meter which was above the standard [53]. Another similar study was conducted in Mecca and the level of PM_{10} found to be 195.5 micrograms per cubic meter that was also more than the standard value[30]. Also, in another study in Serbia, the average annual concentration of PM_{10} reported to be more than air quality guideline (AQG) (20 micrograms per cubic meter) [19]. Moreover, in a study by Sicard et al., in Marseille, Nice, and Perpignan in France, the average annual concentration of PM_{10} in all cities except Perpignan were reported to be above the standard of WHO [15]. For O_3 and NO_2, the maximum and minimum maximum daily 8-hour mean and daily mean, average annual concentration were reported to be 35.99 ± 9.73, 15.36 ± 9.52 and 35.47 ± 9.01, and 2.60 ± 2.09 micrograms per cubic meter for Mashhad-Shiraz and Shiraz-Karaj which didn't go above the standard of WHO[19,54]. It seems that the high level of O_3 in Mashhad compared to the other studied cities is due to petrochemical industry in the region and increased transportation which matched with the finding of studies by Joaquim Rovira et al. in Catalonia, Spain, Barzeghar et al. in Tabriz, and Faridi et al., and Dehghan et al. in Tehran [33,42,49,55]. Also, high concentration of NO_2 in Shiraz compared to other cities under investigation is related to the emission of this pollutant from factories, industries, and increase in vehicle traffic which matched with the findings of Todorvocić et al. in Belgrade and Novi sad, Joaquim et al. in Catalonia, Spain, and Mazaheri et al. in Tehran [49,56,57]. In a similar in Ahvaz by Karimi et al., the average daily concentration of O_3 and NO_2 were reported to be 38.63 ppbv and 135.90 μg/m^3 respectively [16]. In a three-year research, they reported that the average annual concentration of NO_2 was 4.1, 1.9, and 4.3 times more than the standard value, while there was no.

such result for O_3. Another similar study in Ahvaz was conducted by Dastoopoor et al. and the average daily concentration of O_3 and NO_2 were reported to be 62 μg/m^3 and 44.20 μg/m^3 (31,07 bbpv) [16]. Moreover, in a study by Zarandi et al. in Tehran, the average daily concentration of O_3 and NO_2 were found to be 61.9 and 115.1 μg/m^3 respectively [58]. The findings showed that the concentration of pollutants in south east was increased which might be due to the A lot of dust and vehicle traffic in that city [30]. Generally, because of the replacement of old vehicles with new ones and changing the type of fuel, the level of concentration of pollutants in Shiraz was less than the other studied cities [48].

3.2. Health impacts of criteria pollutants exposures

Activities of people in different fields leads to the release of air pollutants and ultimately will have negative effects on human health [7]. In this study, health impacts of long-term exposure to NO_2, O_3, and PM_{10} are evaluated by AirQ. These impacts include chronic bronchitis, premature death of infants, respiratory diseases, and all causes. According to Table (3), Attributable proportion (AP), the number of attributable cases (NAC), several attributable cases per 100.000

Table 3
Health effects attributed to long-term exposure to ambient criteria pollutants concentrations.

city	Parameter	Health endpoint	Attributable proportion (%)	Excess cases	Attributable cases per 100,000 people
Arak	PM_{10}	Incidence of chronic bronchitis in adults mortality	19.72 (7.49-29.08)	10 (4-15)	3.51 (1.33-5.17)
		Post neonatal (age 1–12 months) infant mortality	7.49 (3.86-12.57)	238 (123-400)	25.04 (12.89-42.02)
	O_3	Respiratory disease mortality	-	-	-
	NO_2	All natural mortality	6.67 (3.18-10.12)	319 (152-483)	64.47 (30.75-97.71)
Esfahan	PM_{10}	Incidence of chronic bronchitis in adults mortality	24.21 (9.36-35.19)	55 (21-80)	4.27 (1.65-6.21)
		Post neonatal (age 1–12 months) infant mortality	9.36 (4.84-15.59)	961 (497-1601)	29.07 (15.03-48.43)
	O_3	Respiratory disease mortality	0.03 (0.01-0.06)	0 (0-0)	0.01 (0.00-0.02)
	NO_2	All natural mortality	2.45 (1.16-3.76)	396 (187-608)	19.08 (9.00-29.27)
Tabriz	PM_{10}	Incidence of chronic bronchitis in adults mortality	23.18 (8.92-33.81)	54 (21-79)	5.63 (2.17-8.22)
		Post neonatal (age 1–12 months) infant mortality	9.36 (4.61-14.89)	648 (335-1082)	23.62 (12.20-39.41)
	O_3	Respiratory disease mortality	0.16 (0.06-0.28)	1 (0-1)	0.09 (0.03-0.15)
	NO_2	All natural mortality	5.22 (2.48-7.94)	828 (393-1260)	52.36 (24.88-79.69)
Shiraz	PM_{10}	Incidence of chronic bronchitis in adults mortality	15.79 (5.91-23.58)	26 (10-39)	2.53 (0.95-3.77)
		Post neonatal (age 1–12 months) infant mortality	5.91 (3.03-9.98)	573 (293-967)	20.51 (10.51-34.63)
	O_3	Respiratory disease mortality	0.52 (0.19-0.88)	1 (1-2)	0.14 (0.05-0.24)
	NO_2	All natural mortality	7.18 (3.43-10.86)	984 (470-1489)	57.20 (27.33-86.57)
Karaj	PM_{10}	Incidence of chronic bronchitis in adults mortality	16.98 (6.38-25.26)	26 (10-39)	2.29 (0.86-3.40)
		Post neonatal (age 1–12 months) infant mortality	6.38 (3.28-10.75)	394 (202-664)	12.71 (6.52-21.42)
	O_3	Respiratory disease mortality	-	-	-
	NO_2	All natural mortality	0.33 (0.15-0.51)	34 (16-53)	1.81 (0.85-2.79)
Mashhad	PM_{10}	Incidence of chronic bronchitis in adults mortality	22.86 (8.79-33.38)	73 (28-107)	4.54 (1.74-6.63)
		Post neonatal (age 1–12 months) infant mortality	8.79 (4.54-14.68)	2222 (1147-3710)	30.51 (15.76-50.94)
	O_3	Respiratory disease mortality	3.76 (1.37-6.33)	29 (11-49)	1.81 (0.66-3.04)
	NO_2	All natural mortality	4.42 (2.09-6.74)	1232 (584-1879)	41.37 (19.61-63.09)

populations at risk (NACPR), and problems of exposure to NO_2, O_3, and PM_{10} are measured. Values of baseline incidence (BI) of mentioned effects are calculated based on the equation. The maximum and minimum excess cases is 2222 and is related to Post neonatal (age 1–12 months) infants and Respiratory diseases. Also, the maximum and minimum mortalities of chronic bronchitis (10−73), premature death of infants (238–2222) in Mashhad and Arak, respiratory diseases (0−29) in Mashhad and Isfahan, and natural mortality (32–1232) in Mashhad and Karaj were reported (Table 3). During a research that was conducted in Ahvaz in order to estimate mortality of short-term exposure to PM_{10}, 278 cases of death was reported [30]. Maleki et al. in their study in Ahvaz reported the death rate due to long-term exposure to PM_{10} to be 630 cases [15]. Gholampour et al. reported 363 deaths due to exposure to PM_{10} in their study in Tabriz city[59]. In a research conducted in China and East Asia, it was shown that short-term exposure to PM_{10} pollutant plays a significant role in mortality from respiratory and cardiovascular diseases[21,22,60–64].

During a research in the Ahvaz, 44 and 362 natural deaths were estimated due to short-term exposure to O_3 and NO_2 pollutants, respectively [16]. Similar to mentioned study, Barzeghar et al. in their study in Tabriz found the mortality rate due to long-term exposure to O_3 to be 3–13 cases [49]. In addition, Faridi et al. in their study in Tehran reported the mortality rate of long-term exposure to O_3 to be 54 cases [15]. Goudarzi et al. reported the mortality rate of short-term exposure to O_3 to be 6,17% and 173 cases [16]. A study in 13 Italian cities was conducted by Martuzzi et al. and it was found that 516 people died due to long-term exposure to O_3 [38]. The result of a research in Suwon, South Korea showed that the number of people who died due to short-term exposure to O_3 was 43 cases [65]. In addition, during a study conducted Naples, Livorno and Rome in Italy, the number of deaths due to long-term exposure to O_3 was estimated to be 614 and 29990, respectively [15]. Also, during another research conducted in Italy and France, 3380 and 1780 people died due to long-term exposure to O_3, respectively [66]. During a similar study in Ahvaz by Karimi et al., the number of natural deaths due to long-term exposure to NO_2 pollutant was 4391 cases [16]. In a similar study in Ahvaz, Geravandi et al. reported 4.76% of natural mortality due to short-term exposure to NO_2 [16]. The reason for the difference between the results of our study and the aforementioned studies can be due to the study, relative risk values, exposure population, and period.

3.3. Changes in the concentration of pollutants during the time

The descriptive statistics of pollutants are shown as mean (standard deviation) for each city during one year in Table 4.

Table 5 shows the results of LME model in which the linear, quadratic and cubic impact of time on the pollutants are estimated via estimated coefficient (standard error). Time has a cubic effect on O_3 over the time for Arak ($time^3 = -102.57(12.29), p < 0.001$). The mean difference of O_3 at the baseline is significantly higher in Esfahan and Shiraz and lower in Tabriz in comparison to Arak ($p < 0.001$). Considering the third order effect, all cities except for Tabriz had higher mean O_3 over the time. The standard deviation of the random intercept (standard error) is 0.92 (0.09) which justifies the considerable difference among the cities in term of O_3. Fig. 2 shows the observed development of O_3 and fitted O_3 (95% confidence interval) for the cities over the time. The determinant coefficient of this model was 0.61.

Mean NO_2 at baseline was 42.84 higher in Arak comparing to Mashhad ($p < 0.001$) while it was not statistically different comparing to other cities. Similar to O_3, NO_2 follows a cubic trend over the time for Arak ($p < 0.001$). Comparing to Arak as the reference city, all other cities have lower average of NO_2 over the cubic time ($p < 0.001$). The standard deviation of the random intercept (standard error) for the LME model assessing NO_2 is 10.93 (1.78). Fig. 3 shows the observed development of NO_2 and fitted NO_2 (95% confidence interval) for the cities over the time. The determinant coefficient of this model was 0.52.

The result of the model for PM_{10} indicates that cities have the same average at baseline, however, the trend follows a quadratic and cubic pattern over the time for Arak ($p < 0.001$). The average of PM_{10} was 192.52 ($p < 0.001$) and 96.02 ($p = 0.038$) higher in Karaj and Mashhad comparing to Arak in a quadratic pattern over the time. In a cubic pattern, the average of PM_{10} was 278.14 ($p < 0.001$) lower and 253.29 ($p < 0.001$) higher in Shiraz and Tabriz over the time. The standard deviation of the random intercept (standard error) for the LME model assessing PM_{10} is 14.43 (1.23). Fig. 4 shows the observed development of PM_{10} and fitted PM_{10} (95% confidence interval) for the cities over the time. The determinant coefficient of this model was 0.69.

4. Conclusion

During this research, the health impacts of long-term exposure to PM_{10}, NO_2 and O_3 air pollutants in Arak, Isfahan, Tabriz, Shiraz, Karaj and Mashhad were investigated in 2019–2020. We investigated the trend of the pollutants over the time by considering the polynomial impact of time and the differences in the cities. The results of the research show that the concentration of PM_{10} and NO_2 pollutants in most of the studied cities was higher than the permissible limit of the World Health Organization. It is believed that global warming, shortage of water, removal of vegetation and dust are the main reasons for the increase in the concentration of pollutants. The findings of the health impact evaluation showed that the number of deaths caused by premature infant mortality was the highest among other diseases. Different concentrations of atmospheric pollutants, diversity of culture and

Table 4
The descriptive statistics of pollutants as mean (standard deviation) for each city during one year.

Pollutant	Month	Arak	Esfahan	Karaj	Mashhad	Shiraz	Tabriz
PM_{10}	1	32.04 (14.1)	74.19 (21.85)	23.34 (6.16)	37.88 (4.78)	11.59 (13.17)	20.71 (6.07)
	2	32.72 (21.21)	66.49 (21.85)	33.55 (9.43)	41.75 (6.79)	10.31 (3.60)	56.69 (15.47)
	3	39.15 (15.66)	65.43 (10.04)	52.76 (9.82)	53.26 (9.19)	15.15 (2.10)	63.43 (18.00)
	4	47.01 (13.26)	67.05 (21.70)	36.04 (15.2)	55.18 (8.26)	18.60 (4.64)	56.58 (17.04)
	5	42.36 (15.8)	66.08 (11.96)	6.78 (5.23)	41.87 (5.54)	15.06 (2.95)	64.05 (13.60)
	6	38.04 (8.57)	54.62 (8.65)	11.01 (12.81)	40.62 (5.85)	28.88 (14.98)	38.82 (8.73)
	7	39.41 (5.64)	53.53 (8.66)	42.41 (13.03)	50.14 (6.10)	47.32 (5.17)	52.89 (15.62)
	8	37.93 (5.24)	59.24 (11.81)	34.23 (4.44)	60.46 (17.78)	50.07 (8.60)	43.67 (15.76)
	9	38.82 (5.48)	39.08 (12.30)	35.86 (4.50)	41.22 (21.8)	46.21 (7.75)	49.99 (9.97)
	10	40.8 (4.15)	34.39 (7.58)	35.04 (4.53)	55.90 (5.88)	40.87 (18.92)	53.09 (7.63)
	11	38.11 (5.03)	36.02 (7.55)	33.66 (5.29)	56.58 (6.30)	24.86 (12.75)	52.28 (7.32)
	12	38.21 (5.22)	36.32 (6.51)	36.01 (4.72)	55.92 (6.65)	42.52 (12.12)	52.44 (7.54)
O_3	1	25.49 (1.63)	25.73 (1.83)	20.65 (1.86)	24.86 (2.34)	26.6 (3.49)	15.27 (1.78)
	2	27.09 (3.48)	26.08 (2.77)	20.16 (1.96)	24.87 (3.40)	30.63 (6.62)	11.19 (1.43)
	3	23.82 (1.66)	24.65 (3.18)	19.16 (1.86)	25.84 (2.82)	25.73 (11.01)	15.67 (9.77)
	4	16.08 (5.84)	28.11 (2.93)	20.63 (2.44)	26.19 (2.61)	16.86 (5.55)	13.14 (2.26)
	5	17.01 (5.72)	27.90 (3.38)	18.44 (2.52)	29.44 (7.60)	15.25 (5.54)	16.40 (3.38)
	6	24.56 (1.65)	25.25 (6.16)	19.96 (3.06)	44.42 (4.65)	12.21 (3.58)	18.28 (2.94)
	7	26.61 (1.67)	24.10 (3.25)	24.78 (3.30)	45.79 (3.50)	11.52 (5.19)	20.65 (2.78)
	8	27.12 (2.02)	24.04 (3.40)	24.50 (4.67)	42.24 (3.66)	12.34 (3.99)	17.45 (3.92)
	9	26.87 (1.56)	23.11 (2.21)	9.86 (6.66)	40.85 (5.15)	11.49 (4.35)	18.44 (3.37)
	10	27.65 (2.01)	23.20 (2.50)	6.48 (1.97)	40.6 (3.760)	7.48 (4.52)	18.05 (4.45)
	11	26.46 (2.50)	14.66 (6.45)	15.92 (9.14)	41.12 (4.40)	6.57 (2.61)	11.53 (4.03)
	12	26.01 (2.61)	12.10 (1.63)	5.85 (2.50)	47.42 (6.93)	6.24 (3.32)	9.35 (2.81)
NO_2	1	39.84 (2.15)	27.14 (12.98)	11.27 (8.25)	8.49 (1.35)	43.84 (5.56)	31.24 (8.27)
	2	40.35 (2.52)	27.89 (12.93)	9.19 (1.46)	8.70 (0.87)	42.97 (4.01)	40.89 (10.4)
	3	37.9 (2.11)	34.89 (12.94)	13.31 (1.96)	6.91 (1.64)	43.19 (3.63)	46.06 (12.1)
	4	38.79 (2.63)	35.01 (12.79)	6.49 (3.06)	4.76 (1.63)	42.05 (7.94)	16.73 (13.4)
	5	41.08 (5.05)	33.04 (13.82)	9.78 (3.38)	5.42 (4.92)	30.95 (3.08)	3.68 (1.24)
	6	27.3 (4.38)	22.24 (16.76)	7.88 (1.16)	14.79 (2.76)	35.86 (3.02)	7.39 (1.05)
	7	24.74 (3.27)	17.76 (3.87)	13.16 (1.89)	15.90 (3.03)	36.03 (7.72)	12.28 (1.71)
	8	20.74 (1.36)	35.9 (5.54)	11.46 (9.03)	31.83 (12.2)	32.12 (5.97)	23.8 (6.02)
	9	24.6 (9.78)	27.82 (6.52)	8.08 (1.16)	43.54 (4.67)	33.54 (3.12)	34.56 (7.63)
	10	30.75 (1.01)	28.33 (5.61)	13.39 (1.94)	42.4 (5.96)	38.73 (8.36)	28.46 (6.42)
	11	30.98 (1.02)	23.35 (6.56)	12.44 (7.71)	40.84 (5.32)	22.95 (6.10)	28.23 (5.04)
	12	31.02 (0.88)	15.63 (0.24)	9.16 (1.35)	41.01 (6.58)	22.18 (5.53)	27.87 (5.42)

Table 5
The results of LME model in which the linear, quadratic and cubic impact of time on the pollutants.

Parameters	O_3		NO_2		PM_{10}	
	Estimate (SE)	p-value	Estimate (SE)	p-value	Estimate (SE)	p-value
Intercept.	22.205 (1.065)	<0.001	40.157 (10.965)	<0.001	37.124 (14.499)	0.010
Esfahan	7.356 (1.506)	<0.001	-7.736 (15.507)	0.618	40.136 (20.505)	0.050
Karaj	1.625 (1.506)	0.281	-30.113 (15.507)	0.052	-8.082 (20.505)	0.693
Mashhad	0.934 (1.506)	0.535	-42.845 (15.507)	0.006	4.609 (20.505)	0.822
Shiraz	5.95 (1.506)	<0.001	5.63 (15.507)	0.717	-27.554 (20.505)	0.179
Tabriz	-6.52 (1.506)	<0.001	-12.224 (15.507)	0.431	10.069 (20.505)	0.623
time	0.013 (0.002)	<0.001	-0.042 (0.004)	<0.001	0.009 (0.007)	0.189
$month^2$	57.222 (12.296)	<0.001	123.758 (20.594)	<0.001	-97.438 (32.697)	0.003
$month^3$	-102.57 (12.296)	<0.001	125.175 (20.594)	<0.001	76.078 (32.697)	0.020
Esfahan × *month*	-0.047 (0.004)	<0.001	0.015 (0.006)	0.010	-0.133 (0.009)	<0.001
Karaj × *month*	-0.048 (0.004)	<0.001	0.044 (0.006)	<0.001	0.005 (0.009)	0.558
Mashhad × *month*	0.058 (0.004)	<0.001	0.176 (0.006)	<0.001	0.032 (0.009)	0.001
Shiraz × *month*	-0.083 (0.004)	<0.001	-0.014 (0.006)	0.017	0.098 (0.009)	<0.001
Tabriz × *month*	-0.014 (0.004)	<0.001	0.027 (0.006)	<0.001	0.009 (0.009)	0.354
Esfahan × $month^2$	-180.115 (17.39)	<0.001	-235.083 (29.125)	<0.001	32.165 (46.24)	0.487
Karaj × $month^2$	-173.49 (17.39)	<0.001	-108.953 (29.125)	<0.001	192.527 (46.24)	<0.001
Mashhad × $month^2$	-136.947 (17.39)	<0.001	19.369 (29.125)	0.506	96.023 (46.24)	0.038
Shiraz × $month^2$	22.818 (17.39)	0.189	-159.971 (29.125)	<0.001	-107.719 (46.24)	0.020
Tabriz × $month^2$.2	-167.393 (17.39)	<0.001	216.24 (29.125)	<0.001	-61.987 (46.24)	0.180
Esfahan × $month^3$	71.06 (17.39)	<0.001	-100.838 (29.125)	0.001	-12.443 (46.24)	0.788
Karaj × $month^3$	85.856 (17.39)	<0.001	-173.161 (29.125)	<0.001	-49.572 (46.24)	0.284
Mashhad × $month^3$	46.545 (17.39)	0.007	-358.683 (29.125)	<0.001	3.797 (46.24)	0.935
Shiraz × $month^3$	105.011 (17.39)	<0.001	-177.876 (29.125)	<0.001	-278.147 (46.24)	<0.001
Tabriz × $month^3$	17.779 (17.39)	0.307	-213.947 (29.125)	<0.001	253.29 (46.24)	<0.001

SE: Standard Error, P: p-value

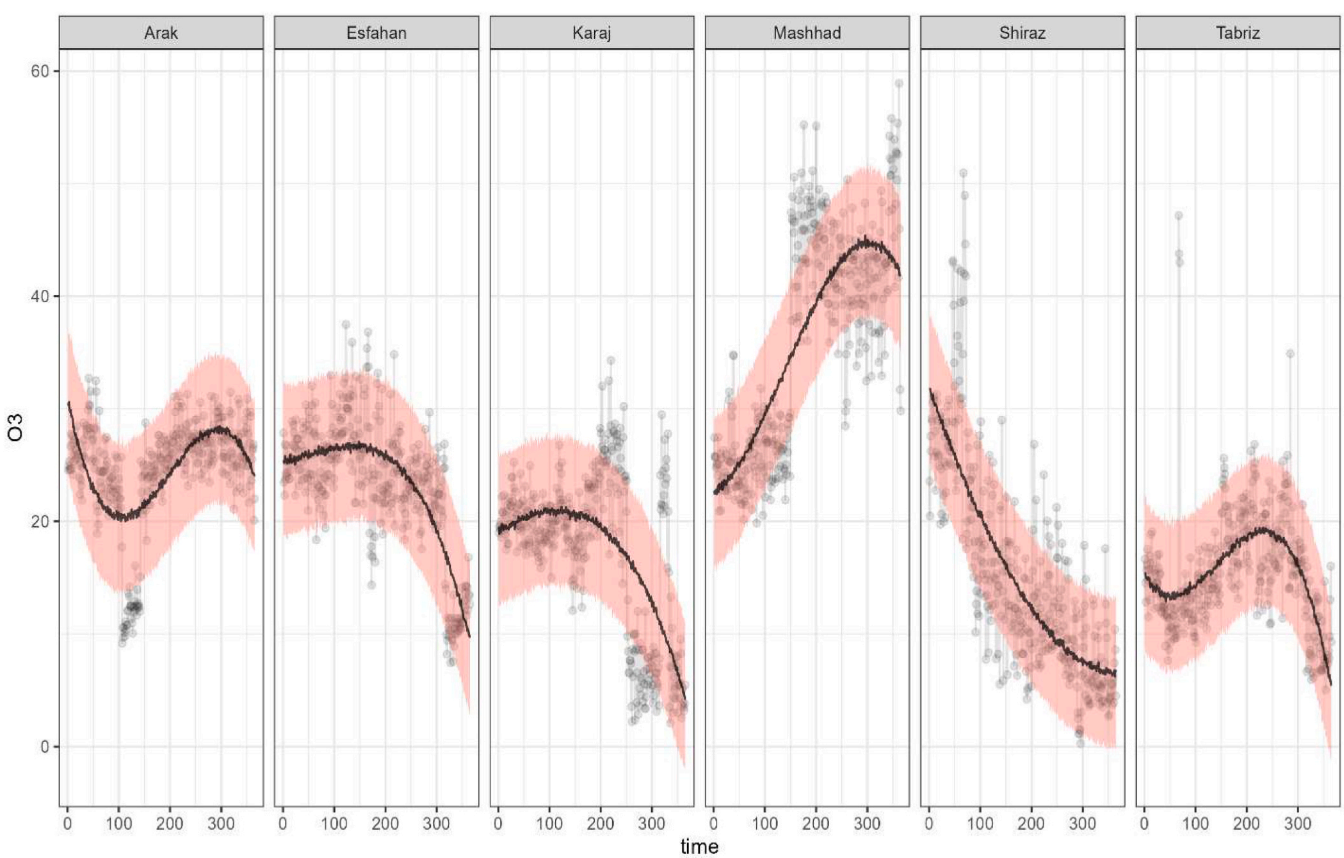

Fig. 2. The observed (dots) and fitted (line) (highlighted: 95% confidence interval) trend of O_3 for the cities over the time.

customs, and duration of exposure were effective reasons on the difference in number of deaths. The results of this research can provide policymakers with appropriate solutions such as replacing new and electric cars with scrap cars, proper dust control, and reducing the consumption of harmful fuels to control the amount of pollutants. Due to the necessity and importance of estimating the health effects of exposure

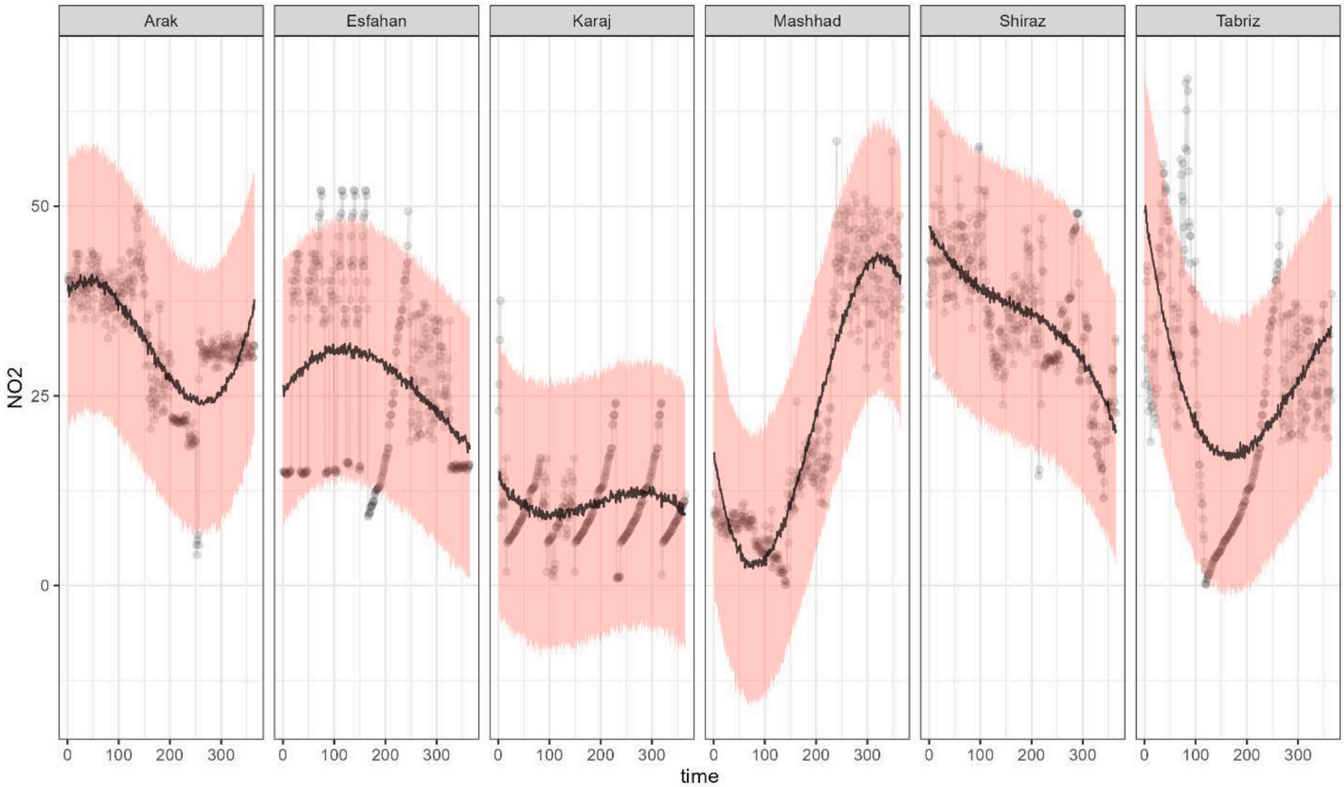

Fig. 3. The observed (dots) and fitted (line) (highlighted: 95% confidence interval) trend of O_3 for the cities over the time.

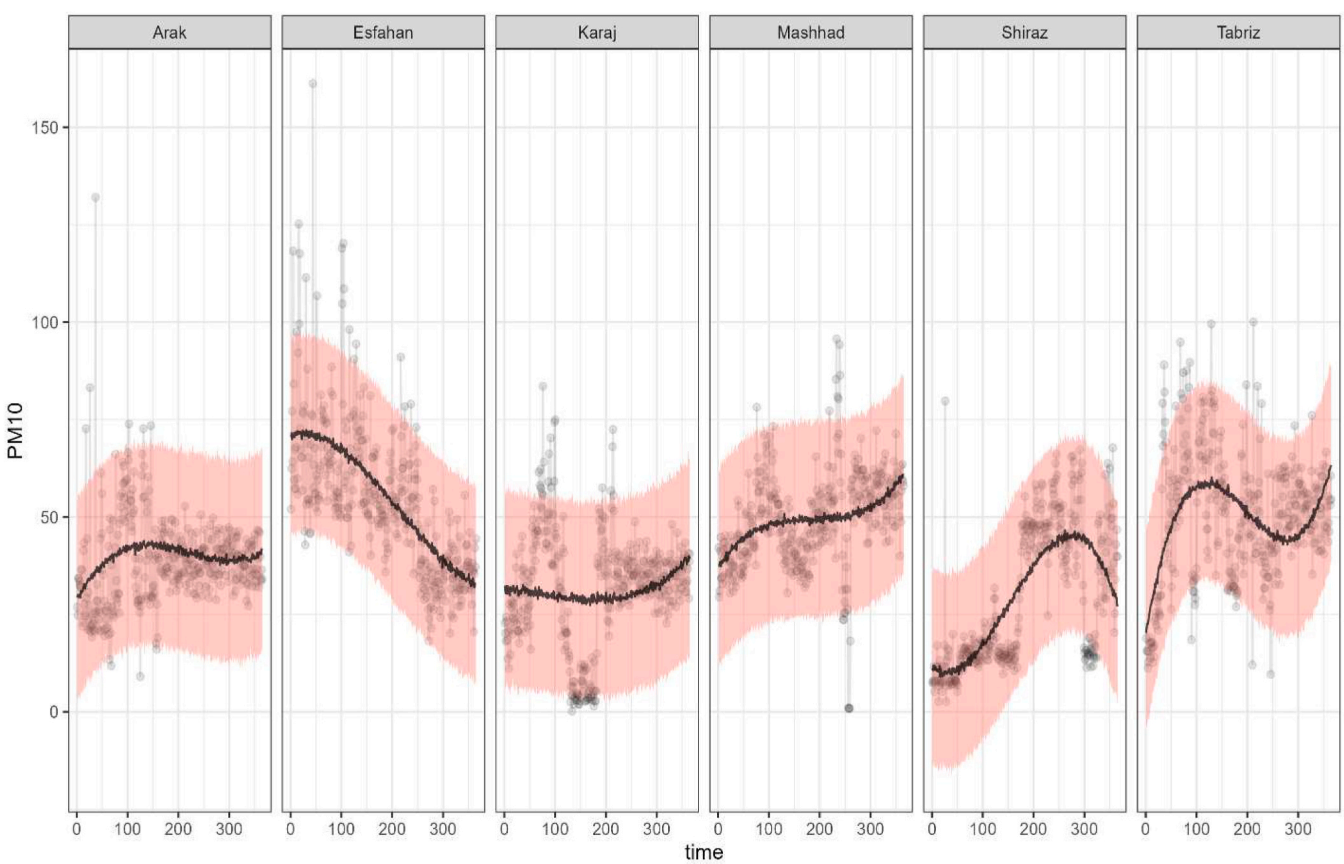

Fig. 4. The observed (dots) and fitted (line) (highlighted: 95% confidence interval) trend of O_3 for the cities over the time.

to pollutants on people's health, more extensive research is needed in this field.

CRediT authorship contribution statement

Zahra Kazemi, Zohre Kazemi: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Ahmad Jonidi Jafari, Mahdi Farzadkia:** Methodology, Writing – review & editing, Investigation. **Javad Hosseini, Payam Amini, Abbas Shahsavani:** Methodology, Writing – review & editing, Project administration. **Majid Kermani:** Methodology, Writing – review & editing, Supervision, Funding acquisition.

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

The data that has been used is confidential.

Acknowledgments

The authors gratefully acknowledge the financial support given by the Research Center for Environmental Health Technology, Iran University of Medical Sciences, Tehran, Iran (Grant Number: 1400–12-20121).

References

[1] K. Farzad, et al., A study of cardiorespiratory related mortality as a result of exposure to black carbon, Sci. Total Environ. 725 (2020) 138422.
[2] J.G. Bartzis, K.K. Kalimeri, I.A. Sakellaris, Environmental data treatment to support exposure studies: the statistical behavior for NO2, O3, PM10 and PM2. 5 air concentrations in Europe, Environ. Res. 181 (2020) 108864.
[3] Y. Hajizadeh, et al., Concentrations and mortality due to short-and long-term exposure to PM 2.5 in a megacity of Iran (2014–2019), Environ. Sci. Pollut. Res. 27 (2020) 38004–38014.
[4] J.D. Sacks, et al., 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.
[5] 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.
[6] Q. Deng, et al., Particle deposition in the human lung: health implications of particulate matter from different sources, Environ. Res. 169 (2019) 237–245.
[7] Z. Eskandari, et al., Temporal fluctuations of PM 2.5 and PM 10, population exposure, and their health impacts in Dezful city, Iran, J. Environ. Health Sci. Eng. 18 (2020) 723–731.
[8] M. Dastoorpoor, et al., Acute effects of air pollution on spontaneous abortion, premature delivery, and stillbirth in Ahvaz, Iran: a time-series study, Environ. Sci. Pollut. Res. 25 (2018) 5447–5458.
[9] R.A. Rohde, R.A. Muller, Air pollution in China: mapping of concentrations and sources, PloS One 10 (8) (2015) e0135749.
[10] B. Alharbi, M.M. Shareef, T. Husain, Study of chemical characteristics of particulate matter concentrations in Riyadh, Saudi Arabia, Atmos. Pollut. Res. 6 (1) (2015) 88–98.
[11] P. Avino, M. Manigrasso, Dynamic of submicrometer particles in urban environment, Environ. Sci. Pollut. Res. 24 (16) (2017) 13908–13920.
[12] I. Bagayev, J. Lochard, EU air pollution regulation: a breath of fresh air for Eastern European polluting industries? J. Environ. Econ. Manag. 83 (2017) 145–163.
[13] M. Daryanoosh, et al., Risk of morbidity attributed to ambient PM10 in the western cities of Iran, Toxin Rev. 37 (4) (2018) 313–318.
[14] Y.O. Khaniabadi, et al., Chronic obstructive pulmonary diseases related to outdoor PM 10, O 3, SO 2, and NO 2 in a heavily polluted megacity of Iran, Environ. Sci. Pollut. Res. 25 (2018) 17726–17734.
[15] P. Sicard, et al., Effect of O 3, PM 10 and PM 2.5 on cardiovascular and respiratory diseases in cities of France, Iran and Italy, Environ. Sci. Pollut. Res. 26 (2019) 32645–32665.
[16] A. Karimi, et al., Concentrations and health effects of short-and long-term exposure to PM2. 5, NO2, and O3 in ambient air of Ahvaz city, Iran (2014–2017), Ecotoxicol. Environ. Saf. 180 (2019) 542–548.
[17] S. Geravandi, et al., An estimation of COPD cases and respiratory mortality related to ground-level ozone in the metropolitan Ahvaz during 2011, Archiv. Hygiene Sci. 5 (1) (2016) 15–21.
[18] H. Maleki, et al., Air pollution prediction by using an artificial neural network model, Clean. Technol. Envir. 21 (2019) *1341–1352*.
[19] M.N. Todorović, et al., Evaluation of mortality attributed to air pollution in the three most populated cities in Serbia, Int. J. Environ. Sci. Technol. 16 (2019) 7059–7070.
[20] O.F. Althuwaynee, A.L. Balogun, W. Al Madhoun, Air pollution hazard assessment using decision tree algorithms and bivariate probability cluster polar function: evaluating inter-correlation clusters of PM10 and other air pollutants, GIScience Remote Sens. 57 (2) (2020) 207–226.
[21] B.J. Malig, et al., Coarse particles and respiratory emergency department visits in California, Am. J. Epidemiol. 178 (1) (2013) 58–69.
[22] X. Wang, et al., Ambient coarse particulate pollution and mortality in three Chinese cities: association and attributable mortality burden, Sci. Total Environ. 628 (2018) 1037–1042.
[23] M. Kowalska, et al., Effect of NOx and NO2 concentration increase in ambient air to daily bronchitis and asthma exacerbation, Silesian voivodeship in Poland, Int. J. Environ. Res. Public Health 17 (3) (2020) 754.
[24] G. Luo, et al., Quantifying public health benefits of PM2. 5 reduction and spatial distribution analysis in China, Sci. Total Environ. 719 (2020) 137445.
[25] C.P. Loughner, et al., The benefits of lower ozone due to air pollution emission reductions (2002–2011) in the Eastern United States during extreme heat, J. Air Waste Manag. Assoc. 70 (2) (2020) 193–205.
[26] B. Emam, et al., Cause-specific mortality attributed to fine particles in Mashhad, Iran (2013-2017), J. Air Pollut. Health 3 (3) (2018) 127–134.
[27] A. De Marco, et al., Mortality and morbidity for cardiopulmonary diseases attributed to PM2. 5 exposure in the metropolis of Rome, Italy, Eur. J. Intern. Med. 57 (2018) 49–57.
[28] E. Fattore, et al., Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy, Environ. Res. 111 (8) (2011) 1321–1327.
[29] M. Hadei, et al., Mortality and morbidity economic burden due to PM2. 5 and ozone: an AirQ+ modelling in Iran, J. Air Pollut. Health 5 (1) (2020) 1–10.
[30] S. Fallahizadeh, et al., The effects of meteorological parameters on PM10: Health impacts assessment using AirQ+ model and prediction by an artificial neural network (ANN), Urban Clim. 38 (2021) 100905.
[31] Y.O. Khaniabadi, et al., Hospital admissions in Iran for cardiovascular and respiratory diseases attributed to the Middle Eastern Dust storms, Environ. Sci. Pollut. Res. 24 (2017) 16860–16868.
[32] Y.O. Khaniabadi, et al., Exposure to PM 10, NO 2, and O 3 and impacts on human health, Environ. Sci. Pollut. Res. 24 (2017) 2781–2789.
[33] S. Faridi, et al., Long-term trends and health impact of PM2. 5 and O3 in Tehran, Iran, 2006–2015, Environ. Int. 114 (2018) 37–49.
[34] Y.O. Khaniabadi, et al., Acute myocardial infarction and COPD attributed to ambient SO2 in Iran, Environ. Res. 156 (2017) 683–687.
[35] Y.O. Khaniabadi, et al., Human health risk assessment due to ambient PM10 and SO2 by an air quality modeling technique, Process Saf. Environ. Prot. 11 (1) (2017) 346–354.
[36] Omidi, Y., et al., Health impact assessment of short-term exposure to NO2 in Kermanshah, Iran using AirQ model. 2016.
[37] M. Khaefi, et al., Association of particulate matter impact on prevalence of chronic obstructive pulmonary disease in Ahvaz, southwest Iran during 2009-2013, Aerosol air Qual. Res. 17 (1) (2017) 230–237.
[38] Y.O. Khaniabadi, et al., Cardiopulmonary mortality and COPD attributed to ambient ozone, Environ. Res. 152 (2017) 336–341.
[39] Y. Omidi Khaniabadi, et al., Air quality modeling for health risk assessment of ambient PM10, PM2. 5 and SO2 in Iran, Hum. Ecol. Risk Assess.: Int. J. 25 (5) (2019) 1298–1310.
[40] M. Huang, D. Zhang, Testing polynomial covariate effects in linear and generalized linear mixed models, Stat. Surv. 2 (2008) 154.
[41] B.M. Bolker, Linear and generalized linear mixed models, Ecol. Stat.: Contemp. Theory Appl. (2015) 309–333.
[42] J. Rovira, J.L. Domingo, M. Schuhmacher, Air quality, health impacts and burden of disease due to air pollution (PM10, PM2. 5, NO2 and O3): application of AirQ+ model to the Camp de Tarragona County (Catalonia, Spain), Sci. Total Environ. 703 (2020) 135538.
[43] E. Ahmed, et al., Long-term trend of airborne particulate matter in Seoul, Korea from 2004 to 2013, Atmos. Environ. 101 (2015) 125–133.
[44] E. Jang, et al., Spatial and temporal variation of urban air pollutants and their concentrations in relation to meteorological conditions at four sites in Busan, South Korea, Atmos. Pollut. Res. 8 (1) (2017) 89–100.
[45] M.B. Marzouni, et al., A comparison of health impacts assessment for PM10 during two successive years in the ambient air of Kermanshah, Iran, Atmos. Pollut. Res. 7 (5) (2016) 768–774.
[46] H. Maleki, et al., 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.
[47] M. Hadei, et al., Burden of mortality attributed to PM2. 5 exposure in cities of Iran; contribution of short-term pollution peaks, Atmos. Environ. 224 (2020) 117365.
[48] F. Yousefian, et al., Temporal variations of ambient air pollutants and meteorological influences on their concentrations in Tehran during 2012–2017, Sci. Rep. 10 (1) (2020) 1–11.

[49] V. Barzeghar, et al., 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 (2020) 101988.
[50] G. Goudarzi, et al., Health risk assessment of exposure to the Middle-Eastern Dust storms in the Iranian megacity of Kermanshah, Public Health 148 (2017) 109–116.
[51] Y.O. Khaniabadi, et al., Impact of Middle Eastern Dust storms on human health, Atmos. Pollut. Res. 8 (4) (2017) 606–613.
[52] S. Geravandi, et al., A comparative study of hospital admissions for respiratory diseases during normal and dusty days in Iran, Environ. Sci. Pollut. Res. 24 (2017) 18152–18159.
[53] W. Huang, et al., Characterizing spatial distribution and temporal variation of PM10 and PM2. 5 mass concentrations in an urban area of Southwest China, Atmos. Pollut. Res. 6 (5) (2015) 842–848.
[54] W.H. Organization, Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide, World Health Organization, 2006.
[55] A. Dehghan, et al., The relation between air pollution and respiratory deaths in Tehran, Iran-using generalized additive models, BMC Pulm. Med. 18 (1) (2018) 1–9.
[56] Y. Liu, et al., Rapid enkephalin delivery using exosomes to promote neurons recovery in ischemic stroke by inhibiting neuronal p53/caspase-3, BioMed. Res. Int. 2019 (2019).
[57] A. Mazaheri Tehrani, F. Karamali, E. Chimehi, Evaluation of 5 air criteria pollutants Tehran, Iran, Int. Arch. Health Sci. 2 (3) (2015) 95–100.
[58] S. Motesaddi Zarandi, et al., Effects of ambient air pollutants on hospital admissions and deaths for cardiovascular diseases: a time series analysis in Tehran, Environ. Sci. Pollut. Res. (2022) 1–13.
[59] A. Gholampour, 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.
[60] H. Lee, et al., Short-term exposure to fine and coarse particles and mortality: a multicity time-series study in East Asia, Environ. Pollut. 207 (2015) 43–51.
[61] D.W. Graff, et al., Exposure to concentrated coarse air pollution particles causes mild cardiopulmonary effects in healthy young adults, Environ. Health Perspect. 117 (7) (2009) 1089–1094.
[62] K. Meister, C. Johansson, B. Forsberg, Estimated short-term effects of coarse particles on daily mortality in Stockholm, Sweden, Environ. Health Perspect. 120 (3) (2012) 431–436.
[63] R.D. Peng, et al., Coarse particulate matter air pollution and hospital admissions for cardiovascular and respiratory diseases among Medicare patients, JAMA 299 (18) (2008) 2172–2179.
[64] H. Qiu, et al., Effects of coarse particulate matter on emergency hospital admissions for respiratory diseases: a time-series analysis in Hong Kong, Environ. Health Perspect. 120 (4) (2012) 572–576.
[65] S.J. Jeong, The impact of air pollution on human health in Suwon City, Asian J. Atmos. Environ. 7 (4) (2013) 227–233.
[66] D. Nuvolone, D. Petri, F. Voller, The effects of ozone on human health, Environ. Sci. Pollut. Res. 25 (2018) 8074–8088.