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Cardiovascular and respiratory mortality attributed to ground-level ozone in Ahvaz, Iran

Gholamreza Goudarzi · Sahar Geravandi · Hossein Foruozandeh ·
Ali Akbar Babaei · Nadali Alavi · Mehdi Vosoughi Niri ·
Mohammad Javad Khodayar · Shokrollah Salmanzadeh ·
Mohammad Javad Mohammadi

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Abstract Ahvaz, the capital city of Khuzestan Province, which produces Iran's most oil, is on the rolls of fame in view of air pollution. It has also suffered from dust storm during the recent two decades. So, emissions from transportation systems, steel, oil, black carbon, and other industries as anthropogenic sources and dust storm as a new phenomenon are two major concerns of air pollution in Ahvaz. Without any doubt, they can cause many serious problems for the environment and humans in this megacity. The main objective of the present study was to estimate the impact of ground-level ozone (GLO) as a secondary pollutant on human heath. Data of GLO in four monitoring stations were collected at the first step and they were processed and at the final step they were inserted to a health effect model. Findings showed that cumulative cases of cardiovascular and respiratory deaths which attributed to GLO were 43 and 173 persons, respectively. Corresponding RR for these two events were 1.008 (95 % CI) and 1.004 (95 % CI), respectively. Although we did not provide a distinction between winter and summer in case of mentioned mortalities attributed to GLO, ozone concentrations in winter due to more fuel consumption and sub adiabatic condition in tropospheric atmospherewere higher than those GLO in summer.

Keywords Air pollution · Ground-level ozone · Cardiovascular mortality · Respiratory mortality · Ahvaz

G. Goudarzi · A. A. Babaei · N. Alavi
Department of Environmental Health Engineering, School of Public Health, Environmental Technologies Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

S. Geravandi
Islamic Azad University, Tehran Medical Sciences Branch, Tehran, Iran

S. Geravandi · S. Salmanzadeh · M. J. Mohammadi
Razi Hospital Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

H. Foruozandeh · M. J. Khodayar
Department of Pharmacology and Toxicology, Pharmacy and Toxicology Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

M. V. Niri · M. J. Mohammadi (✉)
Department of Environmental Health Engineering, School of Public Health, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
e-mail: javad.sam200@gmail.com

M. J. Mohammadi
e-mail: Mohamadi.m@ajums.ac.ir

S. Salmanzadeh
Infectious and Tropical Diseases Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

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Introduction

Air pollution is of paramount importance in view of risk to health. With lesser pollution in the air, better condition in the atmosphere, health, life expectancy, as well as welfare will be expected. Nowadays, the world is suffering from outdoor air pollution but it may be different in view of pollutant concentration from a region to another area (Boyce et al. 2015; Geravandi et al. 2015; Ren et al. 2010; Shah et al. 2015; Zallaghi et al. 2014b). Health effect estimations revealed that air pollution has a remarkable role in producing human diseases and deaths (WHO 2014; Chen et al. 2015; Goudarzi et al. 2014a; Kariisa et al. 2015; Loomis et al. 2013; Katsouyanni et al. 2009). Early investigations on famous episodes from Meuse Valley in Belgium to London in the UK provided a good cornerstone for generations to come to focus on adverse impacts of air pollution (Geravandi et al. 2014; Yang et al. 2012; Katsouyanni et al. 2009). More coal consumption in power plants along with old technologies in governmental and private sectors have caused high concentration of pollutants which exceeded standards (Di Nardo and Laurenti 2015; Frampton et al. 2015; Jane and Fanny 2015). There is a strong relationship between air pollution in megacities and both mortality and morbidity in whole population (Franklin et al. 2015; Kampa and Castanas 2008; Kariisa et al. 2015; Li et al. 2015; Goudarzi et al. 2015), in which since 1980 so many epidemiological and environmental studies based on statistical models have reported association between air pollutants and hospitalization, diseases, and even mortalities (Pope et al. 2002; Lave and Seskin 2013; Norval et al. 2011; PAGE 2003; Zallaghi et al. 2014a). Criteria and also common air pollutants in ambient are particulate matter, ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), and carbon monoxide (CO) (Peters et al. 2000; Wong et al. 2002; Mohammadi et al. 2015; Zallaghi et al. 2014c). The ground-level ozone (GLO) as an ambient and ground-level pollutant poses many concerns to target community associated with chemical property, health effect, and control; ozone appears in air by a photochemical reaction between heat, sunlight, NOX, and hydrocarbons mostly in the form of VOCs (Trasande and Thurston 2005; Lippmann 1989; EPA 2013; Schlink et al. 2006; Sheffield et al. 2015; Sousounis et al. 2002; Wang et al. 2015). Several investigations around the world reported the impact of GLO in producing symptoms particularly in respiratory systems such as lung disease, asthma attacks, and pulmonary inflammation (Gryparis et al. 2004; Frischer et al. 1993; McClellan et al. 2009; Goudarzi et al. 2013; Mraihi et al. 2015; Peng et al. 2015; Pride et al. 2015; Raaschou-Nielsen et al. 2013; Woerman 2013). Also, many researchers found an association between premature death and high concentration of GLO in Asia, Europe, and the USA (Bell et al. 2004; Samoli et al. 2009). Researchers in Europe have shown that each 10 μg/m3 increase in GLO exposure would lead to an increase in mortality and heart failure attributed to GLO by 0.3 and 0.4 %, respectively (Gent et al. 2003; Desqueyroux et al. 2002).

This study was designed in order to evaluate the association between fluctuations in ambient GLO concentrations with cardiovascular and respiratory mortality in Ahvaz City (located in southwestern Iran) during 2012.

Material and methods

Ground-level ozone data was taken from stations which belong to the Ahvaz Department of Environment (ADoE). Stations are located in “Naderi,” “Behdasht Ghadim,” “Havashenasi,” and “Mohitzist”. AirQ model (WHO) was used to find an association between the GLO and both cardiovascular and respiratory deaths. Although cohort study reveals relationship between GLO values and health outcomes, this model also evaluates the same association between two sides (deaths and GLO values).

Area of study

Ahvaz city, the capital of Khuzestan Province, is located between 48° to 49° 29′ east of Greenwich meridian and between 31 and 45 min to the north of the equator (Fig. 1). As it has shown in figure 1 Ahvaz is located in dry area of Iran with a sweltering climate, and its average yearly rainfall is about 250 mm. In 2012, its population was 1,000,000 people, with an area of 8152 km2 (Goudarzi et al. 2014b).

Air pollution data

To make input file ground-level ozone data based on gravimetric unit which is required for health effects model, several steps were taken in the recent work. Conversion was conducted by the ideal gas formula below where P is atmospheric pressure, V is gas volume, and T is ambient temperature in Kelvin. Afterward, we ran a program to achieve ground-level ozone values that would be convenient and consistent as well as compatible with the model.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Statistical model

In the present study, we used a statistical model (AirQ) based on epidemiological investigations to find relationship between ground-level ozone concentrations and health endpoints.

The impact of GLO on human health can be assessed by calculating of attributable proportion (AP). AP implies to that part of health effects which can be attributed to the GLO exposure in Ahvaz population. Term of AP in percentage was calculated using the following formula:

$$\mathrm{AP} = \mathrm{SUM}\{[\mathrm{RR(c)}-1] \times p(\mathrm{c})\}/\mathrm{SUM}[\mathrm{RR(c)} \times p(\mathrm{c})]$$

where RR(c) is the relative risk for category c of exposure and p(c) is the proportion of Ahvaz population in category c of exposure.

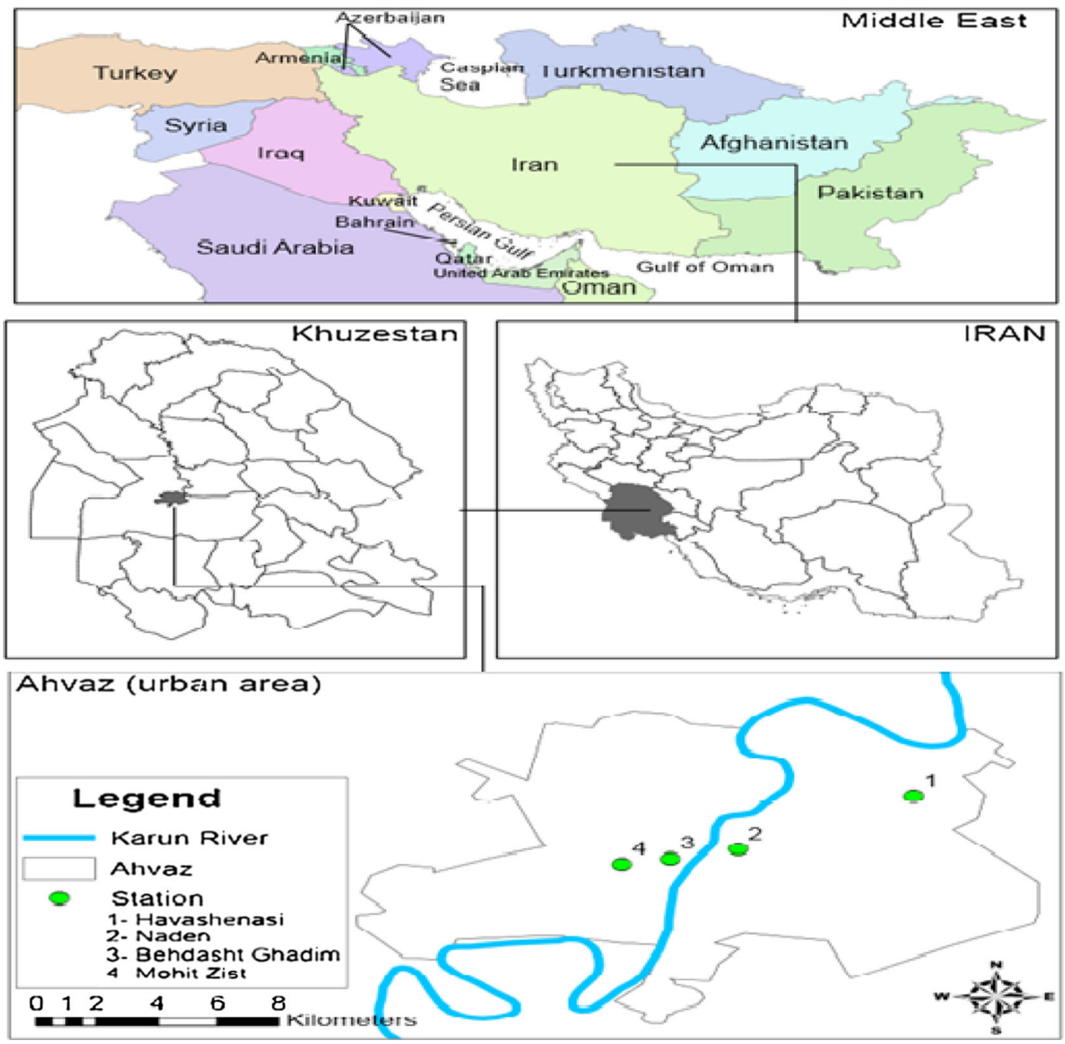


Fig. 1 Location of the study area and sampling station in the Khuzestan Province (Ahvaz city), in the southwest of Iran (Goudarzi et al. 2014c)

Table 1 The highest and the lowest stations for maximum 8-h mean concentrations of ground-level ozone (μg/m^3)

Stations Parameter	Ahvaz	Naderi	MohitZist
Annual	102.27	106.39	80.45
Summer	49.02	55.96	41.79
Winter	123.13	132.79	103.03
98 percentile	171.55	193.82	129.90

Generally, incidence or certain frequency of an outcome particularly cardiovascular and respiratory mortality in Ahvaz community is obvious but in rare cases it can be assumed. Therefore, the number of each case per unit of population which is caused by GLO exposure can be estimated as:

$$\mathrm{IE} = I \times \mathrm{AP}$$

If size of population is known, the number of cases attributable to the exposure will be estimated as the following equation:

$$N_{\mathrm{E}} = \mathrm{IE} \times N$$

where N_{E} is the estimated number of cases attributed to the exposure. N indicates the size of the investigated population.

Attributable proportion was multiplied at baseline incidence and divided to 10^5. Obtained value should be multiplied at population (10^6 as population of Ahvaz). The results will be the excess cases of mortality or morbidity attributed to GLO.

Results

Eight-hour average concentration for GLO in National Ambient Air Quality Standard (NAAQS) is 0.075 ppm. According to WHO guidelines which are based on expert evaluations in standpoint of scientific evidence of health effects, 100 μg/m^3 was accepted as the 8-h mean concentration of GLO (WHO 2014). Table 1 shows that annual mean of 8 h averaging time of GLO in Ahvaz was 102.27 μg/m^3 in 2012 which is higher than WHO air quality guidelines and also much higher than NAAQS values. In view of GLO concentrations, Naderi and Mohitzist points were the highest and the lowest stations during this year, respectively. The yearly average, summer mean, winter mean, and 98 percentile of GLO concentrations in these stations are presented in Table 1.

Figure 2 showed that winter 8-h average of GLO in Ahvaz in 2012 was higher than AQG WHO and also much higher than NAAQS standard. This figure also indicated that in winter 8-h average concentrations were the highest during this year.

RR and estimated AP percentage for cardiovascular and respiratory mortality are presented in Table 2.

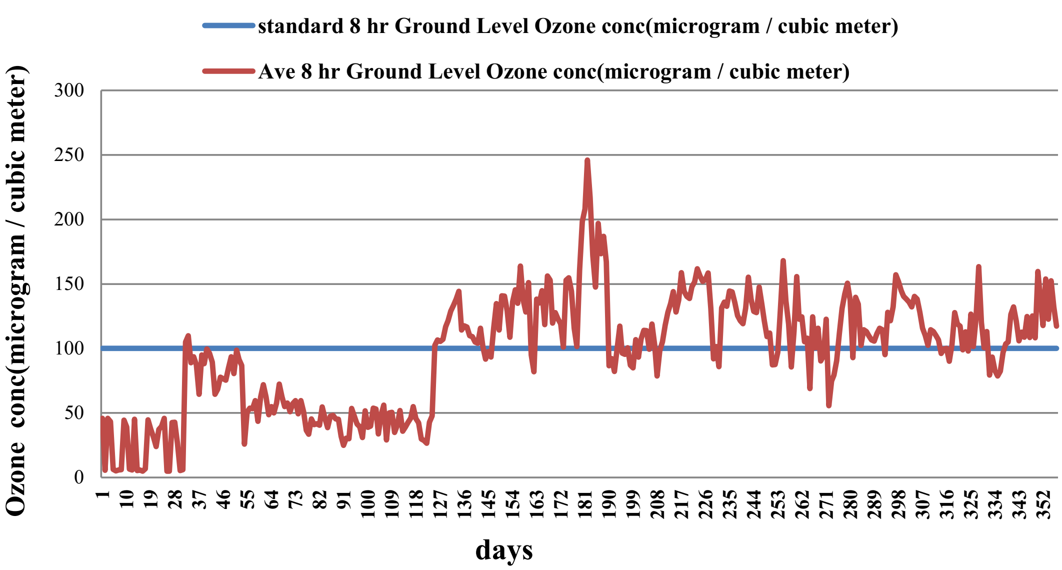


Fig. 2 Exceeded from standard related to GLO in summer and winter time

Table 2 Estimated RR and AP for cardiovascular and respiratory mortality in case of ground-level ozone

Mortality	RR, 95 % CI	AP (%)	Estimated number of excess cases (persons)
Cardiovascular	1.0080 (1.004–1.012)	3.1844	43
Respiratory	1.0040 (1.002–1.006)	6.1722	173

Baseline incidence (BI) of these health endpoints were 66 and 497 per 10^5, respectively, so the number of cardiovascular and respiratory death attributed to GLO was calculated 43 and 173 persons, respectively, at the centerline of relative risk.

Figure 3 shows the cumulative cardiovascular mortality and respiratory mortality versus GLO. Cumulative cases of this health endpoint were estimated which was 43 in 2012. Seventy-three percent of this number has occurred in the days with concentrations lower than 150 μg/m^3. One hundred seventy-three persons were estimated as respiratory mortality within 1 year of exposure. Fifty-three percent of these cases have occurred in days with GLO levels not exceeding 180 μg/m^3.

Cumulative cases of cardiovascular mortality attributed to GLO concentrations are illustrated in Fig. 4 with three ranges of relative risk. Fifty percent of these cases have occurred in days with GLO levels not exceeding 120 μg/m^3.

Respiratory mortality versus particulate matter concentration is shown in Fig. 5. Estimated cases which attributed to GLO for respiratory mortality at lower, central, and higher RR were 78, 173, and 231, respectively. Fifty-eight percent of this number has occurred in the days with concentrations lower than 190 μg/m^3. It should be noted that 75 % of above number are corresponded to the days with concentrations below 250 μg/m^3.

Discussion

Ahvaz is located in an arid area in southwest of Iran with long and hot summertime. Temperature reaches to 50 °C in June and July. Keep in mind, high density of industries (steel, oil, and gas) makes Ahvaz as one of the most important emitters (Rad et al. 2014). Breathing ground-level ozone can trigger a variety of health problems including increased rates of hospital admissions, induction of respiratory symptoms, chest tightness, wheezing, congestion, bronchitis, emphysema, asthma, inflammation of airways, cardiopulmonary disease, and death (Frampton et al. 2015; Li et al. 2015). Furthermore, ozone induces decrements in pulmonary function, shortness of breath, coughing, and throat irritation; reduces lung function; decreases forced vital capacity; and reduces the maximal inspiratory position (Pride et al. 2015; Yang et al. 2012; Bell and Dominici 2008). We found that in Ahvaz with approximately more than one million people all deaths attributed to GLO in case of respiratory and cardiovascular were 173 and 43 persons, respectively. These values are correspondent to 6 and 3 in terms of AP as well as 1.004 and 1.008 for RR, respectively. It should be noted that GLO had more

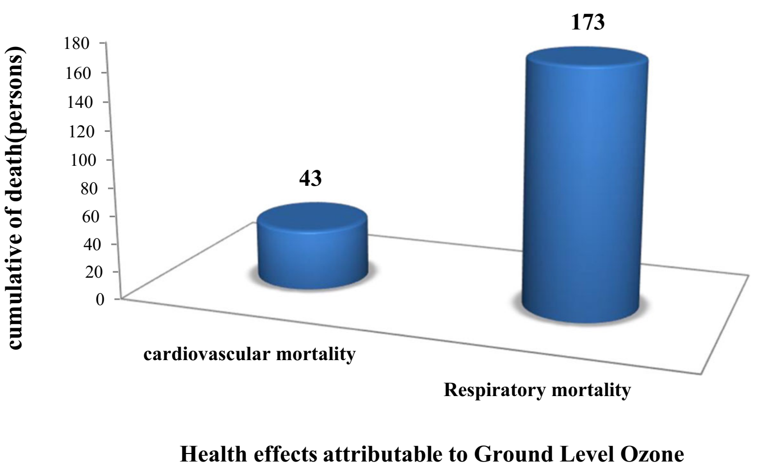
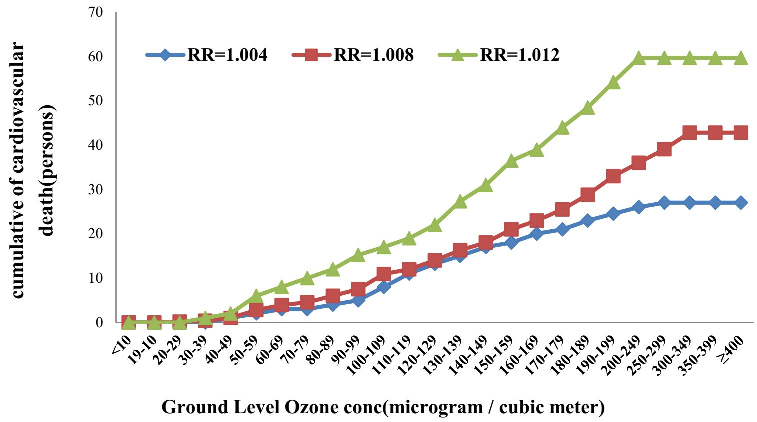


Fig. 3 Relationship between cumulative of cardiovascular mortality and respiratory mortality versus ground-level ozone

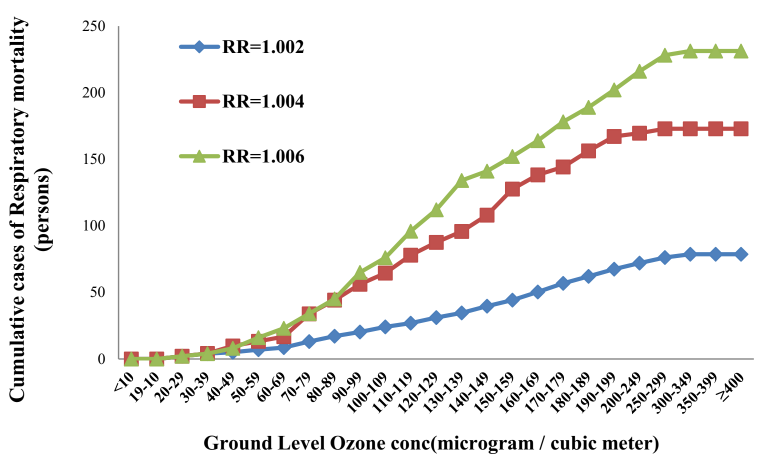
Fig. 4 Relationship between cumulative of cardiovascular mortality versus ground-level ozone concentration



impact on the respiratory tract than the heart and cardiovascular system, and this was why respiratory mortalities were four times higher than cardiovascular death cases. As it has mentioned earlier, 50 % of cumulative cases of cardiovascular mortality occurred in days with GLO concentration not above 120 μg/m^3. For respiratory deaths, 58 % of cumulative cases occurred in those days with GLO levels below 190 μg/m^3. Although other criteria pollutants such as CO, NO_2, and SO_2 and particles had their adverse impact on citizens (Geravandi et al. 2014, Goudarzi et al. 2013, Goudarzi et al., 2014a, b), it was not feasible and also reasonable to add their attributed deaths to these new GLO relevant mortalities. Bear in mind that GLO was born more in winter than summer due to abundant VOC_S and CO emissions from industries, high traffic districts, as well as incomplete combustion in residential areas. It is quite apparent that photochemical reaction between nitrogen oxides, volatile organic compounds, heat, and sunlight is the predominant mechanism to enable atmosphere to born GLO. Therefore, most of these cases could be possibly exposed to a higher concentration of GLO in winter than summer.

Bell et al. found that there is an association between short-term exposure in 95 megacities of the USA and mortalities attributed to ozone. Findings showed a 10-ppb increase in ozone concentration was related to a 0.52 % increase in daily deaths (Bell et al. 2004). In a similar work, Gryparis et al. studied the health effects of ambient ozone concentrations on humans. Data were collected from 23 European cities. Based on the results, an increase in the 1-h ozone concentration by 10 μg/m^3 was associated with a 0.33 % increase in the total daily number of deaths, 0.45 % in the number of cardiovascular deaths, and 1.13 % in the number of respiratory deaths (Gryparis et al. 2004). In another study, McConnell et al. in 2002 conducted a work to find the relation between asthma as a health outcome and different concentration of ozone in a scenario of exposing children sport teams to this pollutant. The

Fig. 5 Relationship between cumulative of respiratory mortality versus ground-level ozone concentration



results of this study showed that the number of cases of asthma in children playing sports exposed to high ozone concentrations was higher compared with those exposed to low level of mentioned pollutant (McConnell et al. 2002).

Finally, it was supposed to study cumulative cases of respiratory and cardiovascular deaths attributed to GLO in the present work but it should be mentioned that all morbidities such as hospital admissions, asthma, emphysema, bronchitis, and COPD can be at paramount of importance in standpoint of health effect attributed to GLO.

Conclusion

This study was conducted to estimate cumulative case of cardiovascular and respiratory mortalities attributed to GLO in Ahvaz, Iran. Cumulative cases of these deaths were 43 and 173, respectively, in Ahvaz population during a year (2012). Although GLO is considered as a summertime air pollutant, the precursors of this in Ahvaz are very high during wintertime. Trends in daily maximum 8-h ozone concentration, annual means of hourly concentration of GLO, monthly means and maximum concentration, as well as 98 percentile in Ahvaz indicated that low maximum mixing height and more fuel consumption are responsible for the formation of high GLO in winter. In addition, blowing strong wind in horizontal and vertical layer of atmosphere particularly in summertime would have led to displace precursors from inside Ahvaz City to far distances. Moreover, wintertime in Ahvaz is not as cold as other cities in Iran. Therefore, mild temperature and air stagnation besides more VOCs emissions in winter provide a better condition to bear GLO.

The results obtained from this study could not be extended to other criteria air pollutants, and future research on this field could be focused on setting up new statistical models to find out concentration response function to achieve an association between pollutant levels in one side and mortality or morbidity in another side.

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