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Concentration modeling of hydrocarbons, carbon monoxide, carbon dioxide and nitrogen oxides emitted from cigarette consumption in atmosphere of Isfahan, Iran

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ABSTRACT:

Introduction: Although many studies on Isfahan's air pollution have been done, there is no report about the effects of cigarette consumption in Isfahan. The aims of this study were (a) to find the amount of nitrogen oxides, hydrocarbons, carbon monoxide and carbon dioxide emitted by cigarette consumption in Isfahan; and (b) to model the distribution of such pollutants in Isfahan's atmosphere.

Materials and methods: Based on the literature, it is assumed that 15% of Isfahan's people consume cigarettes and each smoker on average smokes 1,147 cigarettes per year. Based on these assumptions, the 249,000 smokers living in Isfahan consume 285,000,000 cigarettes per year. The amount of pollutant emissions was calculated by existing emission factors for cigarette consumption. Finally, the distribution of the emitted pollutants from cigarette consumption in Isfahan's atmosphere was modeled using AERMOD.

Results: The results illustrated that each year, 2.85 kg nitrogen oxides, 2.85 kg hydrocarbons, 37.05 kg carbon monoxide and 142.5 kg carbon dioxide are emitted into Isfahan's atmosphere from residents' smoking. The modeling of pollutants' dispersion in Isfahan's atmosphere showed that only some of these pollutants result from cigarette consumption.

Conclusion: This study demonstrated that the amount of pollutants emitted by cigarette consumption was negligible compared to the other pollutant sources in Isfahan.

Introduction

Cigarette consumption has risen in developing countries during the past 30 years. It is estimated that there are 1.1 billion smokers all over the world, of whom 930 million currently live in the low-income and middle-income countries [1-3]. Cigarette consumption can produce a wide range of air pollutants; therefore, it may contribute to air pollution [4, 5]. However, no clear information is available about smoking's share in air pollution. Cigarette smoke contains thousands of chemicals of which several are very harmful to human health [6-9]. Based on a report in 2016, approximately 15% of Iranian people

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consume cigarettes [10]. They consume nearly 64,000,000,000 cigarettes annually. Only a few studies describe the pollutants emissions factors of cigarettes. In previous research, it was reported that on average, 0.01 mg hydrocarbons (HC), 0.13 mg carbon monoxide (CO), 0.5 mg carbon dioxide (CO_2), and 0.01 mg nitrogen oxides (NO_x) are emitted during the complete burning of each cigarette [11]. The annual emission rate of cigarette pollutants in Iran can be estimated by multiplying the above-mentioned emission factors by the number of cigarettes consumed in a year. A simple calculation shows that 0.64 tons of hydrocarbon, 8.62 tons of carbon monoxide, 32 tons of carbon dioxide, and 0.64 tons of nitrogen oxides are emitted into the atmosphere annually due to cigarette consumption in Iran.

Human mortality increases with inhalation of firsthand and secondhand cigarette smoke [12]. Cigarette smoke has a large amount of fine particles with diameters less than 2.5 μm ($PM_{2.5}$) that are also dangerous for human health. It has been reported that there is a significant relationship between exposure to fine particles and human health [13, 14]. Some studies show that there exists some relationship between the exposure to firsthand and secondhand cigarette smoke and many diseases such as lung cancer [15]. The risk of lung cancer and cardiovascular disease steeply increases at low exposure; it flattens out at higher exposure rates. There is a relationship between inhalation of firsthand and secondhand cigarette smoke and tuberculosis [3]. It is reported that indoor air pollution rises the risk of chronic obstructive pulmonary disease, and of acute respiratory infections in childhood. This is the most important reason of death among new-born babies in developing countries [16]. Evidence has also revealed associations among low birth weight and cigarette smoke inhalation. This piece of information proves the importance of knowing the concentration of air pollutants emitted from cigarette consumption. Nonsmokers are exposed to the emissions from cigarette consumption, and contrary to manufactories, there are no chimneys to release air pollutants above ground level [17]. Therefore, it is essential to understand the distribution of air pollutants emitted from cigarette consumption in cities.

Isfahan is a city of 1,961,000 located in central Iran. Isfahan is top on the list of Iran's cities with intensive air pollution problems [18]. This city's many industries include oil refineries, petrochemicals, electrical power plants, and iron and steel industries, all of which emit high amounts of various pollutants into Isfahan's atmosphere [19]. Although several studies have been conducted on Isfahan's air pollutant sources, such as industries, aviation, vehicles, wastewater treatment and solid waste disposal [20-25], to date no study has been carried out on pollutants emitted from smoking in Isfahan. The aim of this study was to model the dispersion of hydrocarbons, carbon monoxide, carbon dioxide, and nitrogen oxides emitted from cigarette consumption in Isfahan.

Materials and methods

Pollutants estimation

Isfahan, with its population of 1,961,000, is one of the largest cities in Iran. It is estimated that nearly 15% of Iranians smoke cigarettes live there [10]. Approximately 249,000 smokers live in Isfahan. Annually, each Iranian smoker consumes about 1,147 cigarettes. Consequently, it is estimated that 285,000,000 cigarettes are annually consumed in Isfahan. In this study, the emission factors reported in the previous research which were used to estimate the emission rates of cigarette pollutants [11] (see Table 1). Eq. 1 was used for the necessary calculations:

Where *ER* is the pollutants emission rate in kg/year, *EF* is the cigarette emission factor in mg/consumed cigarette, and *A* is the number of consumed cigarettes.

Dispersion modeling

It was assumed that cigarette consumption in Isfahan had been homogenized. Moreover, it is assumed that all cigarette pollutants consumed within buildings are eventually ventilated into the outdoor environment. The effects of cigarette consumption on indoor air pollutants has already been delved into by other scientists [26-28]. As a result, this study only concentrated on the effects of cigarette consumption on outdoor air pollution. The concentration of hydrocarbons, carbon monoxide, carbon dioxide, and nitrogen oxides emitted from cigarette consumption in Isfahan's atmosphere were separately modeled using AERMOD. AERMOD is a Gaussian model which is applied for estimating pollutants' dispersion in the atmosphere. This model is developed by US Environmental Protection Agency. The AERMOD model is composed of four separate models including:

(a) A steady-state dispersion model developed to estimate the air pollutants dispersion from stationary industrial sources [29]: This model is applicable to pollutant distribution estimation up to 50 km [30]; (b) A meteorological data analyzer which uses data from on-site instrument towers, upper-air surroundings, and surface meteorological data to calculate the essential atmospheric parameters for a dispersion model such as Monin-Obukov: The factors involves had been length and surface heat flux, friction velocity, mixing heights, and atmospheric turbulence characteristics; (c) A terrain analyzer used to prepare effects of terrain features on the air pollutants plumes: the terrain analyzer provides data of location and height for all receptor locations. The terrain analyzer is also used to predict effects of hills on air pollutants plumes; (d) Plume rise model enhancements which are used to model the influence of downwash formed by the pollutants plume flowing over nearby buildings [31]: More information about AERMOD model can be obtained from [32].

To model the emissions of pollutants in the air, various hourly parameters were considered, such as wind direction, ceiling height, precipitation, global horizontal radiation, dry bulb temperature, relative humidity, station pressure, opaque cloud cover, as well as topographical data and land use in Isfahan. These data were collected through interrelated organizations such as the Islamic Republic of Iran's Meteorological Organization and the Iranian National Mapping Agency. The AERMOD model can calculate annual, monthly, weekly, and daily averages from hourly meteorological data.

Results and discussion

Results of this study revealed that only small amounts of nitrogen oxides, hydrocarbons, carbon monoxide, and carbon dioxide are annually emitted into the Isfahan`s atmosphere (see Table 2). These results were not enough to conclude that cigarette pollutant concentrations would be negligible. This is because of the fact that the pollutants distribution depends on several parameters such as wind speed, wind direction, and

Table 1. The applied emission factors in mg/consumed cigarette [11]

Pollutants	Hydrocarbons	Carbon monoxide	Carbon dioxide	Nitrogen oxides
EF	0.01	0.13	0.5	0.01

even topography of earth surface. Under certain circumstances, pollutants emitted from cigarette consumption can be concentrated in a special area in the city to increase the pollutants concentrations in that area. Therefore, it was so important to check the distribution of pollutants in order to arrive at any likely negligibility of cigarette pollutants concentrations inside the city. Furthermore, modeling of these pollutants distribution into the Isfahan`s atmosphere illustrated that very low amounts of the mentioned pollutants is related to smoking (Figs. 1 to 3).

Table 2. The amount of annual emitted pollutants from cigarette consumption in Isfahan

Nitrogen oxides (kg)	Hydrocarbons (kg)	Carbon Monoxide (kg)	Carbon Dioxide (kg)
2.85	2.85	37.05	142.5

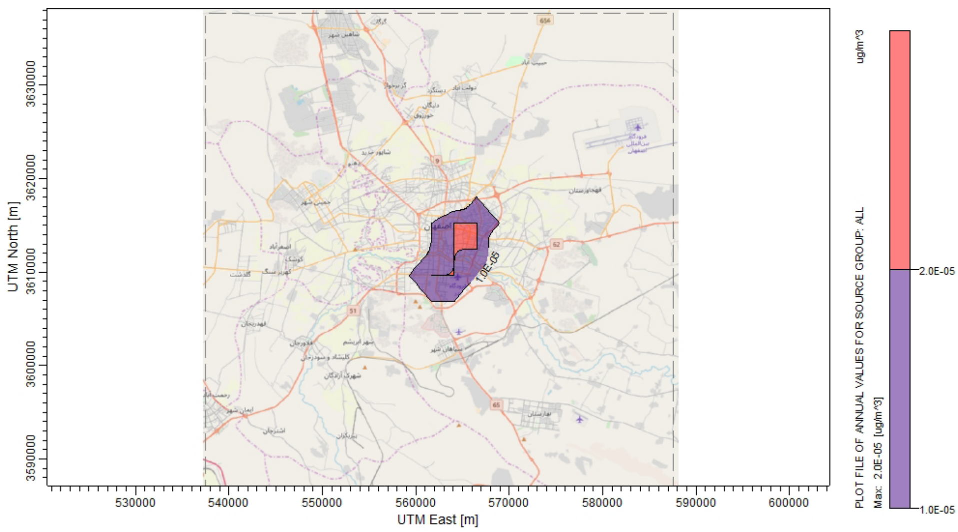

Fig. 1. Concentration distribution of nitrogen oxides and hydrocarbons emitted from cigarette consumption in Isfahan (in µg/m³)

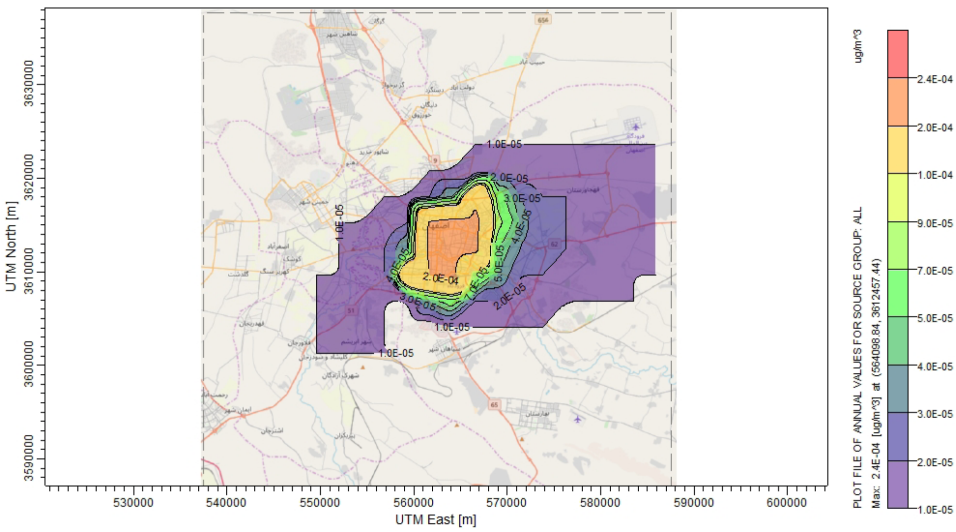

Fig. 2. Concentration distribution of carbon monoxide emitted from cigarette consumption in Isfahan (in µg/m³)

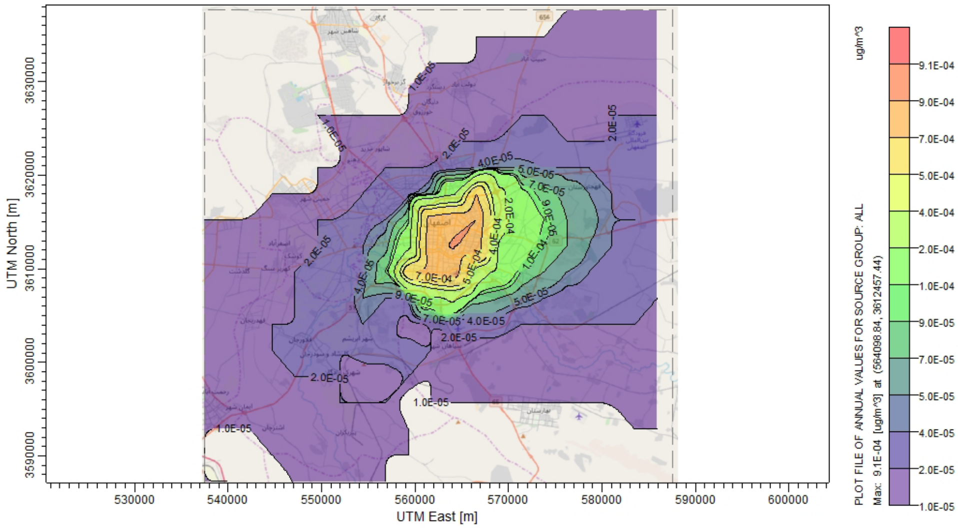

Fig. 3. Concentration distribution of carbon dioxide emitted from cigarette consumption in Isfahan (in µg/m[3])

The amount of annual emitted pollutants from cigarette consumption in Isfahan is brought out in Table 2. The calculations made it clear that carbon dioxide at 142.5 kg/year level was the highest amount of pollutant emitted from cigarettes in Isfahan. Although carbon dioxide is not a toxic compound, it is a strong greenhouse gas which can contribute to global warming [33]. Hydrocarbons are a wide range of organic chemicals, many of which are toxic, carcinogenic, and teratogenic [34, 35]. Roughly 2.85 kg of hydrocarbons were emitted yearly from cigarette consumption in Isfahan. The amount of nitrogen oxides emitted from cigarette consumption was estimated to be 2.85 kg/year. Consumption of cigarettes in Isfahan can produce 37.05 kg carbon monoxide per year. It was reported that 25 tons of nitrogen oxides, 16,300 tons of carbon dioxide, 153 tons of carbon monoxide and 8.76 tons of hydrocarbons are emitted by Isfahan's taxis annually [36]. The amount of nitrogen oxides, carbon dioxide, carbon monoxide and hydrocarbons emitted by smoking is only 0.00011%, 0.0000087%, 0.00024%, and 0.00001% of the emissions from Isfahan's taxies, respectively. These results demonstrated that smoking is an insignificant air pollutant source in cities. However, it is important as a source of indoor air pollution [26]. Many studies demonstrated that non-smokers could significantly be exposed to air pollutants emitted from cigarette consumption in indoor environments [27]. Sometimes, people consume cigarettes in their private buildings. It is estimated that nearly 31 million of the US population are exposed to second-hand cigarette smoke due to consumption of cigarettes in private buildings [37]. These actually reaffirm our own proposition regarding the marking of smoking as a significant indoor air pollutant. Preparation of an air pollutants emission inventory is an essential project in any comprehensive air pollution management program in cities [38]. Based on the results of this study, there is no need to include cigarette consumption in an air pollutants emission inventory.

The concentration of nitrogen oxides, hydrocarbons, carbon monoxide, and carbon dioxide emitted from cigarette consumption in different parts of Isfahan was modeled using AERMOD model. The results are shown in Figs. 1 to 3. The modeling results prove that only 1×10^{-5} to 3×10^{-5} μ/m^3 nitrogen oxides and hydrocarbons concentration in Isfahan's atmosphere was due to cigarette consumption (Fig. 1). Additionally, 1×10^{-5} to 2.4×10^{-4} μ/m^3 and 1×10^{-5} to 9.1×10^{-4} μ/m^3 of carbon monoxide and carbon dioxide, respectively, in Isfahan's atmosphere had its original source in cigarette consumption (Figs. 2 and 3).

Conclusion

This study estimated the amount of annual emission of nitrogen oxides, hydrocarbons, carbon monoxide, and carbon dioxide emitted by smoking in Isfahan. The results demonstrated that each year 2.85 kg nitrogen oxides, 2.85 kg various hydrocarbons, 37.05 kg carbon monoxide, and 142.5 kg carbon dioxide are emitted into Isfahan's atmosphere. The amount of pollutants emitted by cigarette consumption is negligible compared with other pollutant sources, such as Isfahan's taxis. Furthermore, the modeling of pollutants dispersion in Isfahan's atmosphere revealed that only a few of these pollutants are attributable to cigarette consumption. Consequently, the calculation of cigarette pollutants in projects including a pollutant emission inventory appears unnecessary. Also, some cigarette air pollutants including hydrocarbons can be converted to dangerous pollutants due to photochemical reactions in atmosphere. These photochemical reactions were not the topic of investigation in this study. It is suggested that in future studies such conversions be investigated.

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Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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Ethical considerations

Authors are aware of, and comply with, the best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

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