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EVALUATION OF EMISSION INVENTORY OF AIR POLLUTANTS FROM RAILROAD AND AIR TRANSPORTATION IN ISFAHAN METROPOLITAN IN 2016

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ABSTRACT:

Introduction: For many years, the historical city of Isfahan in the center of Iran has been faced with heavy transportation traffic. This heavy transportation is introducing large amounts of air pollutants into the city, causing many risks to human health, environment, etc. This study evaluates the fuel-based emission inventory of NO_x, SO_x, HCs and CO released into the atmosphere of Isfahan by both trains and airplanes. In addition, the emission inventory of PM_{10}, $PM_{2.5}$ and volatile organic compounds were investigated for Isfahan trains.

Materials and methods: The validated methods of the United States Environmental Protection Agency and the European Environmental Agency have been utilized to estimate the emission inventories of trains and airplanes in Isfahan metropolitan. Both methods are based on average emission factors.

Results: The results in 2016 show that, an average of 13,297 tons NO_x, 0.13 tons SO_x, 691 tons HC, 727 tons VOCs, 329 tons PM_{10}, 319 tons $PM_{2.5}$ and 1374 tons CO were released into the atmosphere of Isfahan metropolitan by trains every year. Investigations of the airplane emission inventory show that in 2016, an average of 8,076 tons CO_2, 3.8 tons HC, 19.4 NO_x, 22.8 tons CO and 2.54 tons SO_x are released annually into the atmosphere by airplanes in Isfahan metropolitan.

Conclusions: It is concluded that the most important pollutants emitted from railroad systems in Isfahan are nitrogen oxides. Sepahan-Shar suburb, in the southern part of Isfahan, receives the majority of generated pollutants by passing trains. At the present time aircraft are not an effective sources of pollutants in Isfahan.

INTRODUCTION

The air in Iran's major cities has become polluted during recent decades. Although several attempts have been made to report on the air pollution issues in various areas of the world, there has been no sufficient study of the air pollution in Iran. All of the available findings on this subject could be categorized into three areas, (i) pollutants elimi-

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nation from contaminated air [1-4], (ii) inhibition of pollutant emissions through enhancement of industrial processes [5] and (iii) the evolution of the state of air pollution [6, 7].

Evaluation of emissions inventory and recognition of all pollutant sources are the first steps in establishing an air quality improvement policy. The emissions inventory of cars and trucks has been widely studied worldwide, but there is not enough available literature on the emission inventory of trains and airplanes [1, 3], which are equipped with diesel engines and produce great amounts of nitrogen oxides and suspended particles [5,7] . More than 123000 tons of particulate matter less than 2.5 μm ($PM_{2.5}$) was released into China's atmosphere from road transportation systems in 2001, while in the same year, 161000 tons of $PM_{2.5}$ was released into China's atmosphere by non-road transportation [3]. An exact emission inventory of non-road transportation In Iran is desirable. To the best of author's knowledge, only a few studies have been carried out on emission inventory of non-road transportation sources in Iran.

The first railroad constructed and operated in Iran goes back to the year of 1848, and ran from Rasht to PirBazar and the Anzali ports, in northern Iran along the Caspian Sea. The remains of this railroad can still be found along the Rasht-PirBazar route. Many other railroads have since been constructed and successfully operated. The historical city of Isfahan at the center of Iran (GPS coordinates of 32.6546° N, 51.6680° E), possesses a prominent place in the nation's railroad industry. Many industries, power plants, steel companies, sugar factories, etc., near Isfahan rely upon railroad transportation. Most railroad systems coming in from the north pass through Isfahan, connecting with the southern regions; consequently, transportation intensity is higher in Isfahan. However, the contribution of railroad transportation to Isfahan air pollution had not been studied until the date of this study. As previously stated, no similar study has ever been conducted in other parts of country.

The airlines have also established a significant travel system in Isfahan, transporting both passengers and cargo. The airplanes also have produced significant amounts of pollution, which are then dispersed on a wider scale over the city. Hence, the evaluation of emission inventory of pollutants produced by aircraft is also of significant interest not only for atmospheric scientists but also for city policy makers.

The emission inventory of locomotives and airplanes has been analyzed in many places worldwide. In 2005, nearly 38% of all US transportation was conducted by rail systems [8]. Considering the vast amount of cargo transported within this system, the degree of air pollution seems relatively low [9]. Studies show that only 15% of nitrogen oxides and 12% of all suspended particles released into the atmosphere were generated by cargo transportation conducted by the railroad system [10]. The growth of railroad systems has already surpassed that of other systems of transportation and it is anticipated that this growth will continue until 2035 [10]. Railroad systems are generally ideal for their low rate of air pollution [11, 12], however, the intense growth of these systems has caused concerns related to the pollutants produced by diesel engines, including suspended particles known to increase cancer risks [13]. The amount of data available in regard to pollutants emission in Isfahan by locomotives is currently limited. Generally, the amount of pollution caused by Iran's locomotives is calculated by multiplying their degree of activity with the emission factor of a particular pollutant [9].

Two methods have been adopted to examine the contribution to pollution from locomotives. The first is the travel time–based method provided by the California Air Resources Board (CARB) [9]. The second one is a fuel-based method introduced by the United States Environmental Protection Agency (EPA) [14]. However, each method produces different results and is inadequate for use at a regional (or smaller) spatial scale. The obtained differences may be observed in Table 1. Because problems arose from activity measures that ignored differences in geography and freight rail services between regions; such measures were no longer available. Nevertheless, the results of Gould and Niemeier (2009) show that the fuel-based method proposed by the EPA would be the choice to evaluate the emission inventory of railroad transportation [14]. Hence, this method is adopted and utilized in this study.

Table 1. The calculated results of nitrogen oxide, carbon monoxide and suspended particles produced by locomotives, achieved by both methods of the US Environmental Protection Agency and the California Table 1. Air Resources Board (CARB).

Pollutant type	EPA (in tons/year)	CARB (in tons/year)	Percentage of difference
NO_x	90,780	72,967	-19.6
CO	8,994	10,946	21.7
PM_{10}	2,258	1,668	-26.1

The emission inventory of railroad and air transportation in Iran and in particular in Isfahan has not yet been studied. The main aim of this study is to compile the emission inventory of nitrogen oxides (NOx), sulfur oxides (SOx), hydrocarbons (HC) and carbon monoxide (CO) emitted from airplanes and trains, two important sources of air pollution in Isfahan metropolitan's atmosphere. In addition, the emission inventory of particulate matter less than 10 µm (PM_{10}), $PM_{2.5}$ and volatile organic compounds (VOCs) was produced for trains. By analyzing the statistics and data provided by the Islamic Republic of Iran Railways and Isfahan Shahid Beheshti International Airport (hereinafter "Isfahan airport"), we estimated the amount of pollution produced in 2016 by trains and airplanes. The amount of pollution produced by trains is calculated by the method provided by the EPA. The emission inventory of pollutants by airplanes is calculated by the method of the European Environmental Protection Agency.

MATERIALS AND METHODS

The evaluation of emission inventory of trains

All necessary data for this section were gathered by interviews with the staff of Isfahan Railway Company in October 2016.

The EPA has conducted a vast study on the emission coefficients of trains. Accordingly, trains that did not employ any exhaust output pollutant control system have been shown to produce much higher degrees of pollution [14]. The EPA categorized all trains into two groups, line-haul/passenger and switching. Since various trains in Iran are usually categorized into a group of six, including maneuvering, trafficking, railway track laying, local, passenger and cargo, it was necessary to reassign these groups to the EPA classification. This reassignment is presented in Table 2 (Part A). The EPA emission factors for trains with no output pollution control system are also presented in this table.

In order to calculate the emission inventory of trains, their emission factor in g/L can be multiplied by their consumed fuel in million L/year to achieve the annual pollutants emission rate in tons/year. The EPA estimates that each train consumes 1.548 million L of fuel per year [14]. Since the consumption rate of fuel is also a contributing factor in the calculation of trains' emission inventory, it is necessary to determine this value. In this study, the specific rate of fuel consumption in locomotives was carefully extracted from the data provided by the Isfahan railroad system agency.

Even though the train emission factors for PM_{10}, HC, NO_x and CO are mentioned in the EPA estimates, VOCs and SO_2 are not addressed. The EPA has provided a solution for this issue. HCs account for the majority of VOCs. Therefore, the EPA has proposed the HC conversion coefficient at 1.053 [14]. This means that in order to convert the emission factor of HCs to VOCs, one has only to multiply the HCs emission factors by 1.053.

Table 2. Reassignment of train groups to the proposed EPA classification (Part A) [14]

Categorization of trains in Iran	Maneuvering, railway track laying, local	Passenger, cargo and trafficking
Categorization of trains by the EPA	Switching	Line-Haul and passenger

The emission factors for different pollutants in trains with no output pollutant control system in g/L (Part B)				
Train type	**NOx**	**CO**	**HC**	**PM_{10}**
Switching	97.25	10.05	5.54	2.41
Line-Haul and passenger	68.68	7.03	2.63	1.75

Furthermore, to estimate the emission factor of SO_2, one can apply the amount of sulfur that is present in the consumed fuel by the trains. Over 5% of the sulfur in the train fuel is in the form of sulfate, which is ultimately converted into suspended particles. Therefore only 95% of the sulfur in the train fuel is converted into SO_2 [14]. To calculate the emission factor of SO_2, the EPA created the following equation [14]:

$$EF_{SO_2} = FD \times CF \times SC \times 2 \times 10^{-6} \quad (1)$$

where EF_{SO_2} is the emission factor of this compound in g/gal, *FD* is the density of train fuel in g/gal, *CF* is the conversion factor of sulfur into SO_2, which is normally equal to 5% and *SC* is the concentration of sulfur in the train fuel in ppm. Based on the report of the National Oil Products Distribution Company of Iran, the density of train fuel is 3200 g/gal and the amount of sulfur present in the fuel is 300 ppm [15]. Hence, the emission factor of SO_2 in Iranian trains was calculated as 0.025 g/every L of consumed diesel fuel. The total rate of pollutants emitted into the atmosphere by the trains is calculated as:

$$EE = L \times CF \times T \times EF \quad (2)$$

Where *EE* is the total released pollutant in the atmosphere per year, *L* is the total length of railroad in the particular region, *CF* is the fuel consumed per kilometer, *EF* is the emission factor of the compound and *T* is the number of trips made in a period of one year.

The evaluation of emission inventory by airplanes

Information was collected in October 2016 from several employees of Isfahan Airport. Trips made by airplanes were categorized into various stages, including: 1) The trip made from the terminal to the beginning of the runway and the trip along the runway to reach the ideal speed for take-off (taxi-out), 2) Taking off from the ground and gaining altitude up to 1000 m, 3) Gaining more altitude until the ideal climb height is reached, 4) Cruising toward the destination, 5) Descending down to 1000 m, 6) Descending from 1000 m and preparing for touchdown (landing) and 7) Landing on the runway and taxi-in to the terminal [16]. Since the airplane in the 3rd and the 4th stage is outside the area of the Isfahan metropolis, only stages 1, 2, 6 and 7 are considered in this study. To determine the emission inventory of airplanes, the first step was to gather the required information regarding the types of airplanes and the number of take-offs and touchdowns at Isfahan airport. Subsequently, emission inventory of various pollutants was evaluated by employing the emission coefficients provided by the related agencies. The emission coefficients used in determining the emission inventory of pollutants from Isfahan airport airplanes are presented in Table 3.

The modeling of the pollutants emitted into the atmosphere

By determining the emission inventory of pollutants produced by trains and airplanes and specifying their travel routes, the pollutants emission into the atmosphere was then modeled by the AERMOD View 8.9.0. The Isfahan Weather Forecast Organization collects a large amount of hourly meteorological data, including wind direction, ceiling height, hourly precipitation, global horizontal radiation, dry bulb temperature, relative humidity, station pressure and opaque cloud cover. These data were utilized in the AERMOD to model the dispersion of pollutants emitted into the atmosphere from Isfahan airport and the railway systems. In addition, other parameters such as topographical data of the Isfahan airport and the railway systems were collected from the National Cartographic Center of Iran.

RESULTS AND DISCUSSION

Meteorological situation

The speed and direction of predominant winds throughout the Isfahan metropolitan area are shown in a wind rose (Fig. 1). 43.5% of the winds fall within the category of very slow and the rest have noticeable speed. As can be seen in this wind rose, the predominant wind direction is east to west, as shown in Fig. 1. Since Isfahan airport and the main parts of the Isfahan railways are located in the east of the city, the wind trans-

Table 3. The emission coefficients of various airplanes in g/every take off/touch down [16-20]

Aircraft type	CO_2	HC	NO_x	CO	SO_x
BAE 146	5450	1.25	2.03	14.8	1.72
MD 80	3180	1.87	11.97	6.46	1.01
F100	2390	1.43	5.75	13.84	0.76
MD83	3180	1.87	8.43	4.021	1.01
MD 88	3180	1.87	4.604	4.021	1.01
A320	2570	0.57	9.01	6.19	0.77
RJ	950	0.67	2.17	5.61	0.3
ART72-500	620	0.29	1.82	2.33	0.2
F50	929	0.2	2.9	2.8	0.059
B737	2480	0.84	7.19	13.03	0.78
M80	3180	1.87	11.97	6.46	0.87
CRJ-100ER	1060	0.63	2.27	6.7	0.33
A319	2310	0.59	8.73	6.35	0.73
A 300	5450	1.25	25.86	14.8	1.72

ports the emitted pollutants toward Isfahan. The wind speed of 8.3 m/s is considered adequate to disperse the emitted pollutants [21].

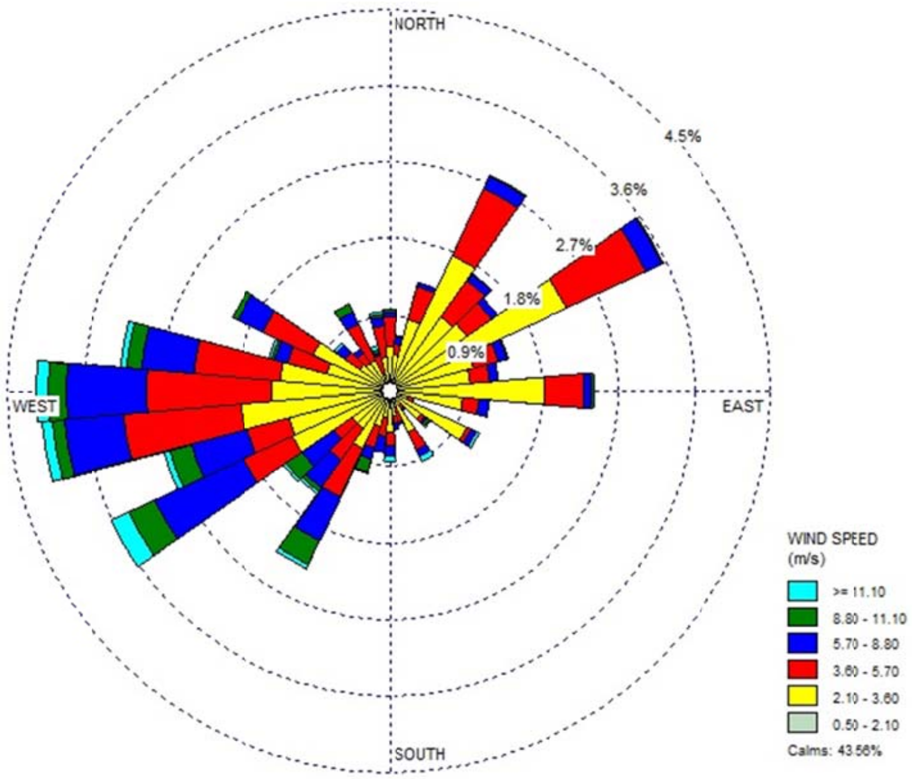

Fig. 1. Isfahan wind rose

Emission inventory of trains

The results showed that the cargo and passenger trains have the most trips among the railroads, 2285 and 13041, respectively. The average distance covered by type of train per trip is shown in Fig. 2.

As can be observed, the passenger trains, with 998 km of covered distance, have the highest covered distance per type of travel and the cargo trains, with 838 km, rank second. The railway track laying, trafficking, local and maneuvering trains with, respectively, 603, 365, 345 and 225 km of coverage stand on the next places. The longest distance per year, 5,460,000 km, belongs to the cargo trains, while the passenger trains with 2,280,000 km of covered distance per year are second. Isfahan is mostly an industrial city with many large industries, power plants, factories, steel companies, etc., less than 50 km from the center of the city, so this level of transportation for cargo trains seems to be logical. The total amount of covered distance per year by local, trafficking, railway track laying and maneuvering trains in comparison with the cargo and passenger trains has been trivial, totaling 79,300 km. The average covered distance per year is presented in Fig. 3.

In this study, the average consumed fuel per train has also been determined (Fig. 4). Since the amount of fueling by every train is carefully recorded by the Isfahan railroad system agency, the average fuel consumption rate of every train per trip has been calculated (Fig. 5). It can be observed that the cargo trains, with 3,654 L of diesel fuel, have the highest fuel consumption rate per trip. This is a logical observation since cargo trains transport much heavier cargos in higher quantities. In second place, there are the trafficking trains, with 3162 L of diesel fuel per trip, followed by the passenger trains with 3164 L, the railway track laying trains with 2800 L, the maneuvering trains with 1778 L and the local trains with 1650 L of diesel fuel per trip. Cargo trains, at 48,000,000 L of diesel fuel per year, possess the highest consumption per year compared with all other types, mainly due to their higher amount of travel. The passenger trains follow with 7,230,000 L of diesel fuel per year.

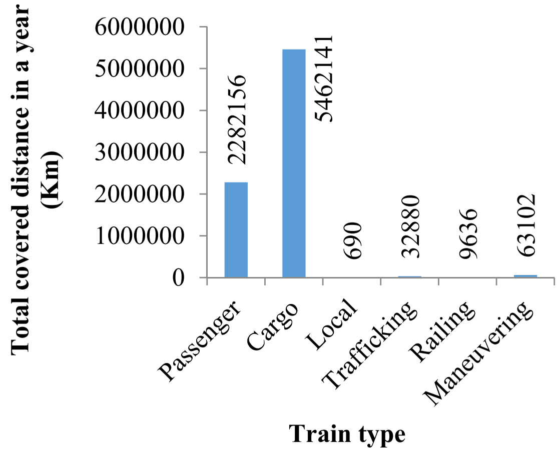

Fig. 3. Total covered distance by train type per year

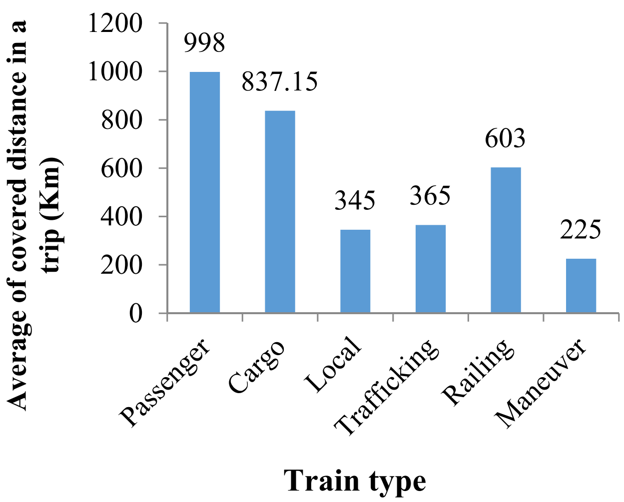

Fig. 2. The average distance traveled in 2016 per trip by train type

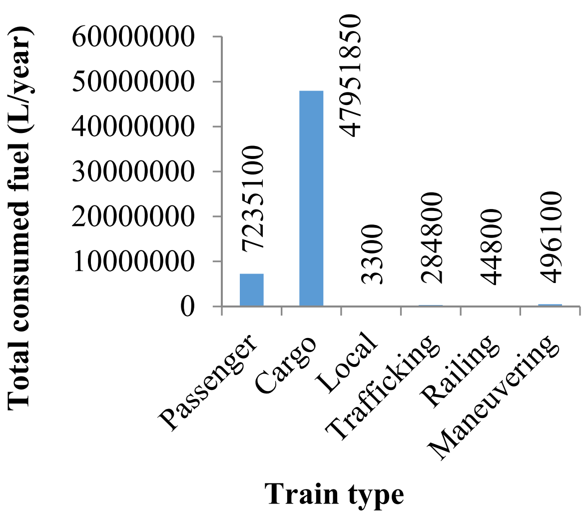

Fig. 4. Fuel consumption of all train types per year (based on data of 2016)

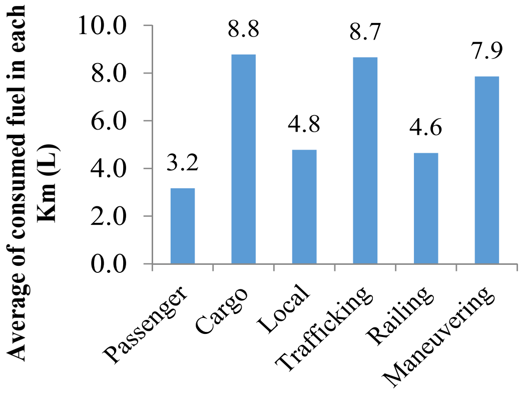

Fig. 5. The average fuel consumption per trip made by each train type (based on data of 2016)

According to the availability of both of the total amount of fuel consumption for each type of train and their distance travelled per year, the average fuel consumption per kilometer can easily be determined. As can be observed in Fig. 6, cargo trains, which use 8.8 L/km, possess the highest rate of fuel consumption, while the passenger, trafficking, maneuvering, local and railway track laying trains follow, respectively. Based on these results, the passenger trains consume the least amount of fuel passing through Isfahan. The total number of trips taken per year by each type of train is presented in Fig. 7. The cargo trains with 13,123 trips are at the top, followed by passenger trains with 2288 trips. The total number of trips taken by local, trafficking, railway track laying and maneuvering trains in 2016 is only 387, insignificant compared with the cargo and passenger trains. The amount of fuel used by passenger, cargo, local, trafficking, railway track laying and maneuvering trains was obtained from the Isfahan railroad system agency. Then this amount was divided into all lengths of train trips for each type of train to calculate average fuel consumed per kilometer. The average fuel consumed per kilometer for all passenger and cargo trains is 7.97 L/km. This value for local, trafficking, railway track laying and maneuvering trains is 7.92 L/km.

By considering the emission factors provided for various trains by the EPA, the rate of produced pollutants per hour for trains passing through different cities approaching Isfahan is calculated and presented in Table 4, Part a. As can be observed, NO_x at 52,000,000 g/year for maneuvering, local, trafficking and railway track laying trains, the 3,960,000,000 g/year for cargo and passenger trains are the highest rates of pollution produced by trains. Several studies show that NO_x and particulate matter are the most important pollutants emitted from diesel engines [7]. Table 4, Part b shows the average pollutant emission rates per locomotive type per hour. 45 to 65% of diesel fuel in China is consumed by tractors, off-road equipment, locomotives, vessels and boilers [22], and trains and airplanes are primarily responsible for diesel fuel consumption; therefore, including this source in the emission inventory is necessary. NO_x emission from locomotives is a serious problem worldwide. For example, it was reported that the NO_x emission levels of switch locomotives used in Ukraine are higher than the maximum allowable values recommended by the EPA and European Union standards [23]. It was reported that NO_x emitted from locomotives can be reduced by using oxygen-enriched combustion in their engines [24]. No report could be found regarding airplane and railroad contribution to air pollution in Iran.

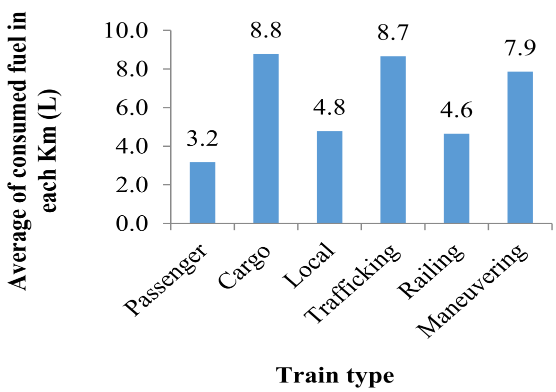

Fig. 6. Average fuel consumption by train type per kilometer

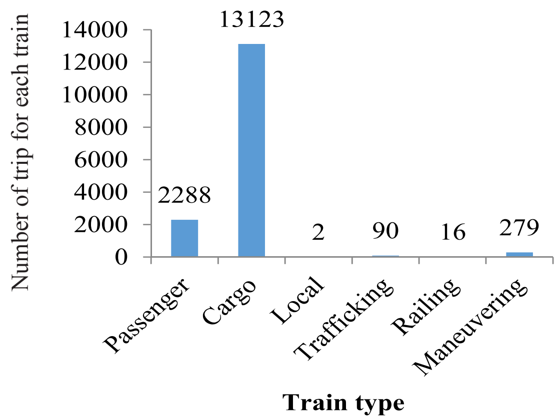

Fig. 7. The total number of trips made by train type

Table 4. The amount of emitted pollutant in g/year (Part a)

Train type	NO_x	SO_x	HC	VOCs	PM_{10}	CO	$PM_{2.5}$
Maneuvering, local, trafficking and railway track laying	52,000,000	267,000	3,290,000	3,463,616	956,000	5,470,000	928,000
Cargo and passenger	3,960,000,000	2,720	146,000,000	1.54,000,000	97,500,000	3.90,000,000	94,600,000

The emission rate of pollutants in g/h (Part b)

Train type	NO_x	SO_x	HC	VOCs	PM_{10}	CO	$PM_{2.5}$
Maneuvering, local, trafficking and railway track laying	5900	31	360	400	110	620	110
Cargo and passenger	452,000	3,100	16,700	18,000	11,100	44,500	10,800

The amount of pollutants received in Isfahan metropolitan from the trains in tons/year (Part c)

Train type	NO_x	SO_x	HC	VOCs	PM_{10}	CO	$PM_{2.5}$
Maneuvering, local, trafficking and railway track laying	16.41	0.13	26.81	28.23	12.78	53.32	12.40
Cargo and passenger	12781.09	0.003	664.22	699.42	316.73	1320.82	307.23
Total pollutants	13297.11	0.13	691.03	727.66	329.52	1374.14	319.63

The released pollutants within the Isfahan region were also studied during this study. For this purpose, metropolitan Isfahan was limited from the north, west, south and east to Shahin Shahr, Zarrin Shahr, Mobarakeh and Sejzi, respectively, as illustrated in Fig.8. In this region, 242.8 km of railroads exist from which the cargo, passenger and other trains make their way in and out of the city. Eq. (2) determines the total amount of train pollutants released into the atmosphere.

As mentioned earlier, the average consumed fuel per kilometer for all passenger, trafficking and cargo trains is 7.97 L/km. This value for all local, railway track laying and maneuvering trains is 7.92 L/km. The total amount of various emitted pollutants is calculated and presented in Table 5, Part c by applying Eq. (2). As can be observed, among all types of trains, the cargo and passenger trains possess the highest rate of pollutants production, such as CO, NOx, SOx, VOCs and HC. The distribution of air pollutants within the studied region are illustrated in Figs. 9 to 15. These figures show that Sepahan Shahr, in the southern part of Isfahan, is received the majority of the pollutants generated by the passing trains. Figs. 9 to 15 illustrate that the amount of NO_x, SO_x, HC, VOCs, PM_{10}, CO and $PM_{2.5}$ concentrations around Sepahan-Shar are 576, 500, 29.9, 31.5, 14.13, 59.5 and 13.8 $\mu g/m^3$, respectively. Other regions of Isfahan receive a lower concentration of less than 0.1 $\mu g/m^3$ of pollutants released by trains. Five other areas have high amounts of pollutants, all outside of the residential areas of Isfahan.

Fig. 8. The covered region for the evaluation of generated pollution by trains in Isfahan

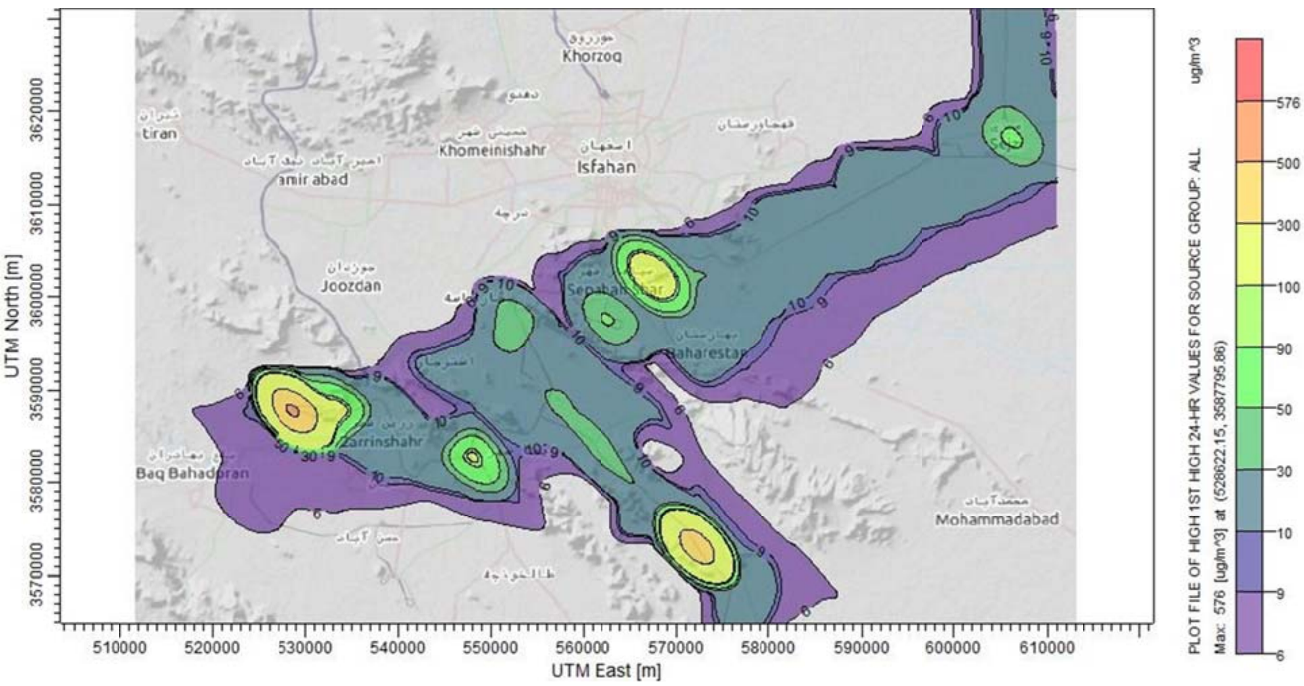

Fig. 9. The NO_x emissions caused by passing trains in Isfahan in 2016

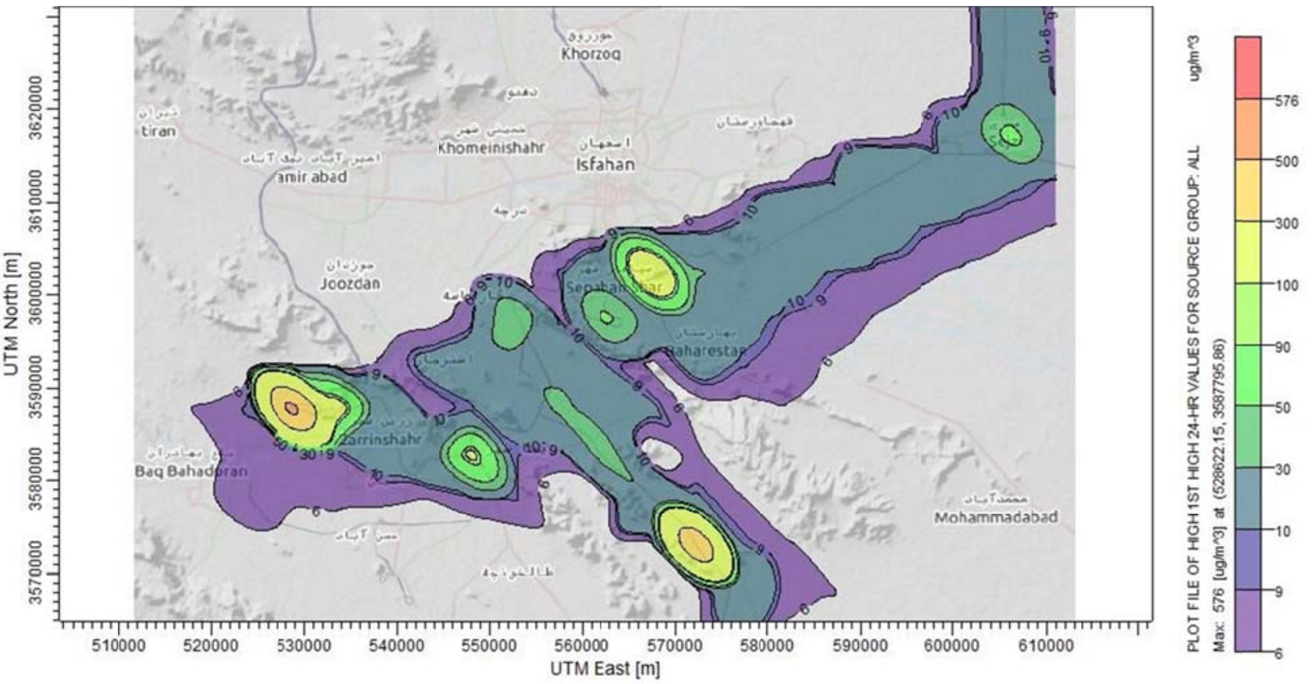

Fig. 10. The SO_x emissions caused by passing trains in Isfahan 2016

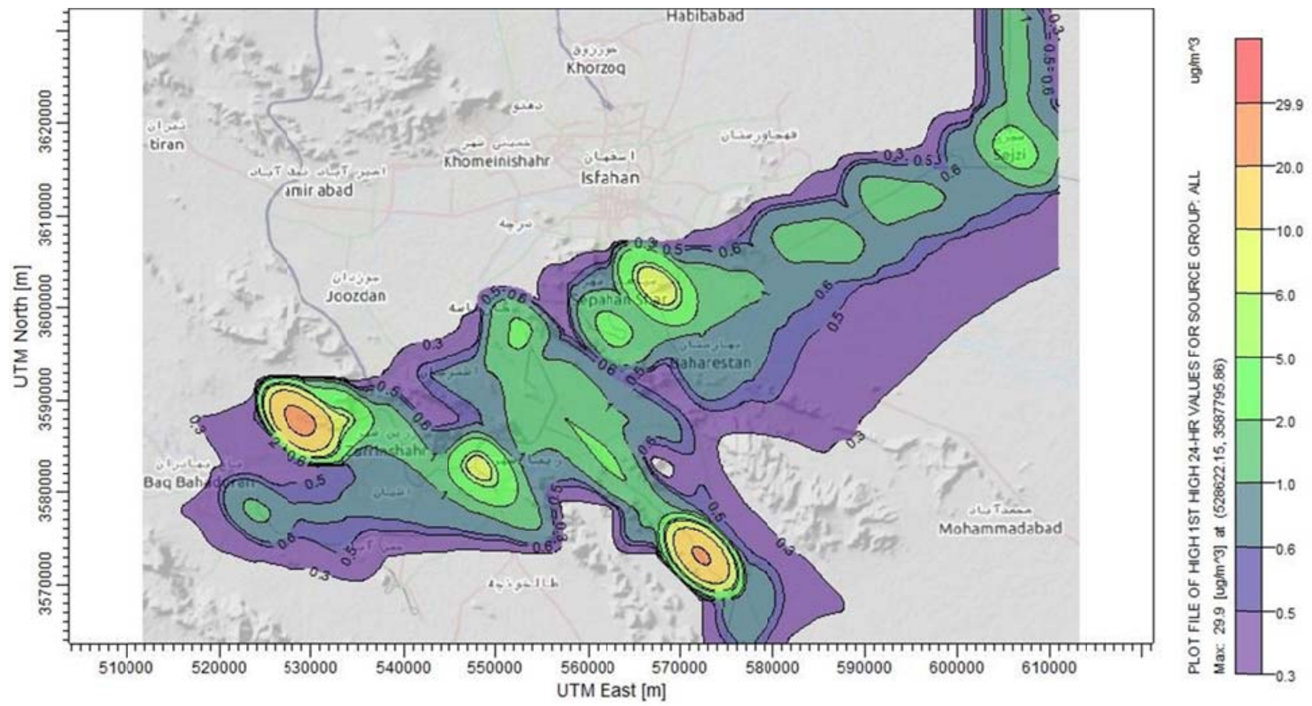

Fig. 11. The HC emissions caused by passing trains in Isfahan in 2016

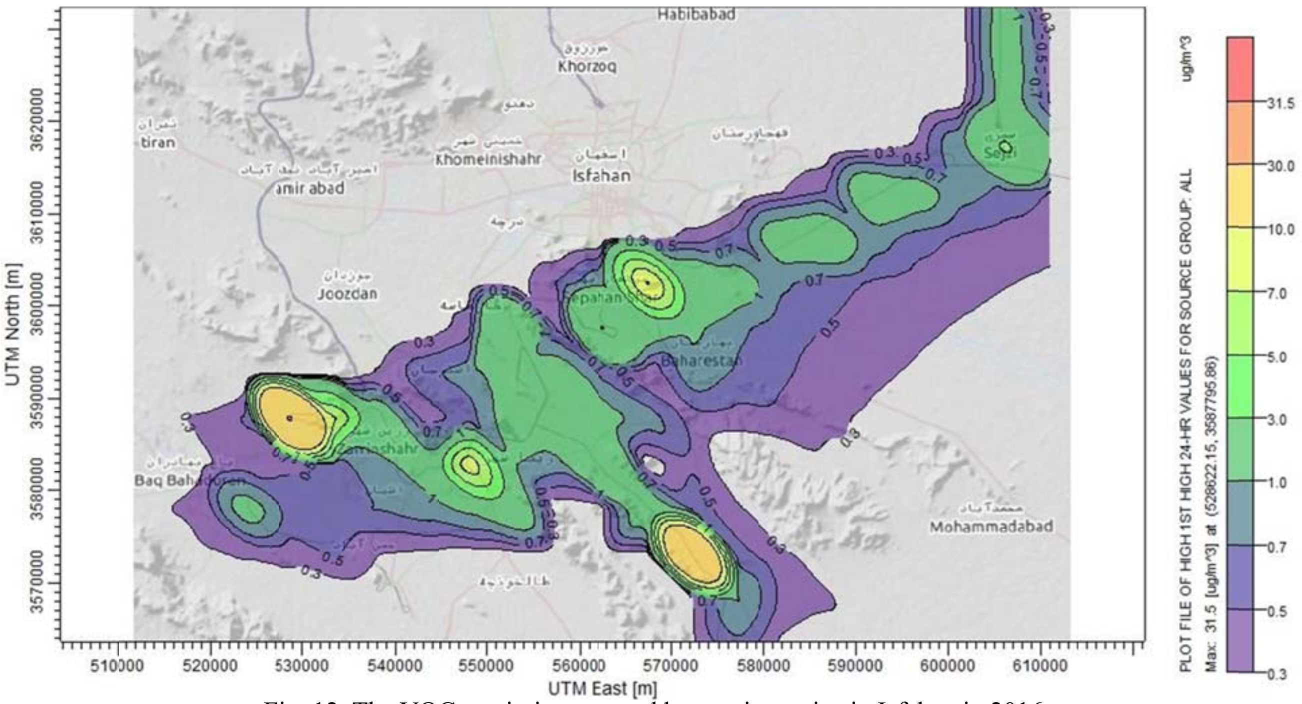

Fig. 12. The VOCs emissions caused by passing trains in Isfahan in 2016

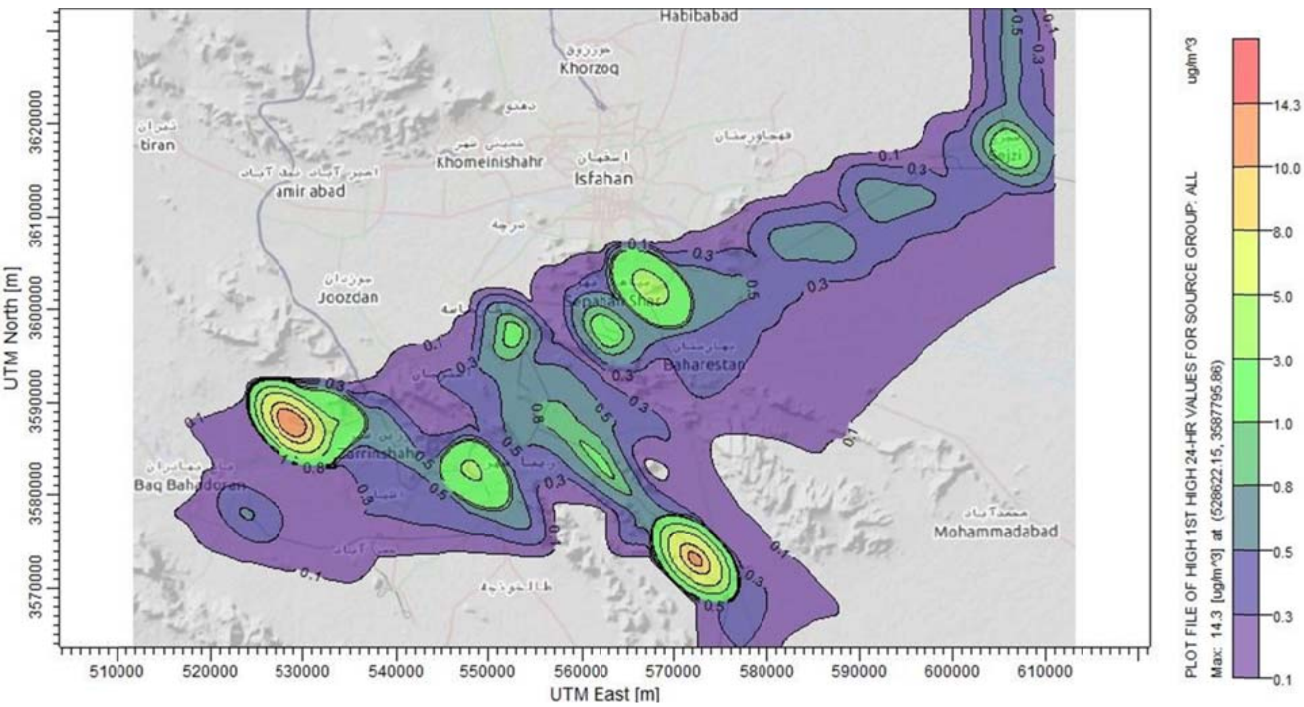

Fig. 13. The PM_{10} emissions caused by passing trains in Isfahan in 2016

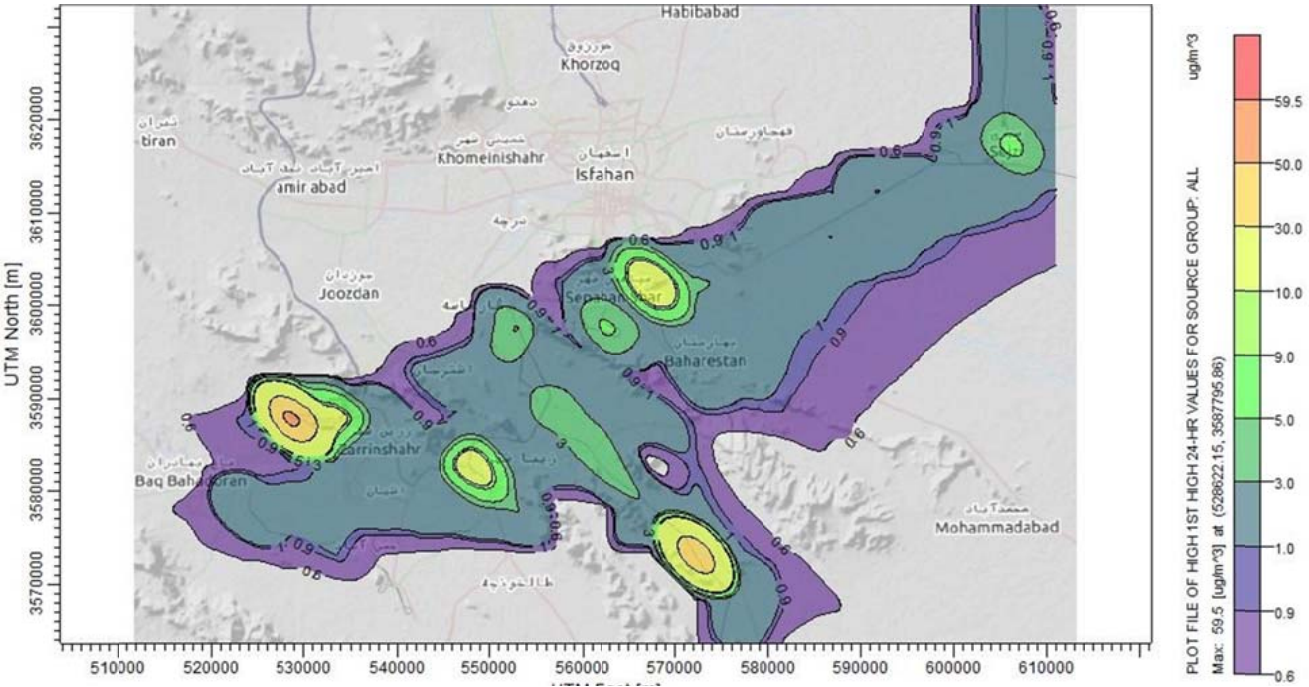

Fig. 14. The CO emissions caused by passing trains in Isfahan in 2016

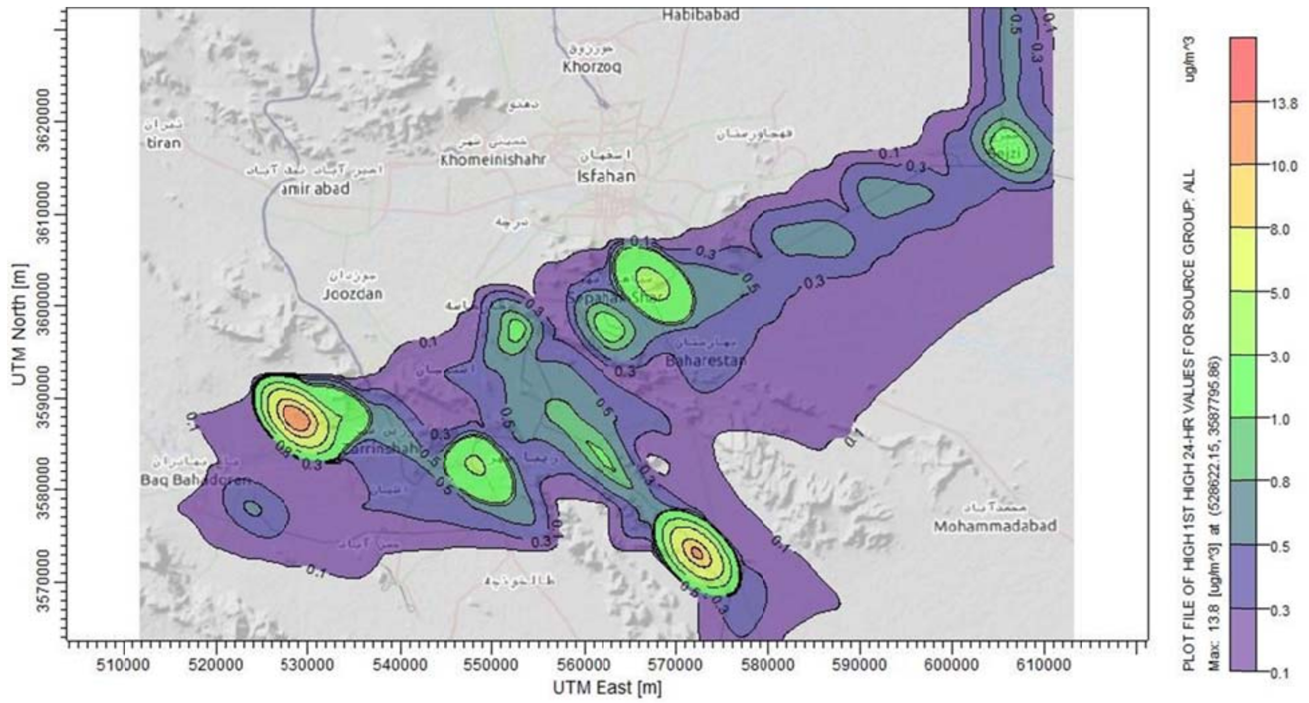

Fig. 15. The $PM_{2.5}$ emissions caused by passing trains in Isfahan in 2016

The airplane emission inventory

Although Isfahan Airport is located outside of the city limits, the aircraft are moved from one side of the city to another during each fly. This is one of the reasons of transferring of pollutants from Isfahan airport to the city of Isfahan. In addition, seasonal winds can disperse the pollutants into the atmosphere and they can occasionally reach the city. Eleven types of airplanes are usually travelling in and out of the Isfahan airport as revealed in Table 5. The amount of fuel consumption per landing/take-off for each type of aircraft has been taken from EASA [25]. On average, 33 take-offs and landings happen daily in this airport. The number of take-offs and landings happening on a monthly or annual basis is 229 and 2748, respectively. This information shows that Isfahan airport does not have heavy traffic compared with other airports in Iran [26].

The annual amount of CO_2, HC, NO_x, CO and SO_x generated by all airplanes types in Isfahan airport is presented in Table 6. The total amount of pollutants produced by the airplanes in the Isfahan airport is shown in Table 7. The calculated dispersion of every type of pollutant is shown in Figs. 18 and 22. As can be seen, the produced pollution by airplanes is dispersed on a wide scale over Isfahan. The highest amount of pollution is gathered around the Isfahan airport, where the airplanes are moving on the surface or at low altitude. As can be seen in Figs. 16 to 20, the eastern parts of Isfahan receive the highest amounts of pollutants that are released into the atmosphere by airplanes. Based on the modeling, the concentration of carbon monoxide, carbon dioxide, nitrogen oxides, hydrocarbons and sulfur oxides around Isfahan airport are 0.003, 0.0004, 0.002, 0.0005 and 0.0003 μ/m^3, respectively. These pollutants concentrations are only calculated for pollutants released from aircrafts in Isfahan city. Other pollutant sources such as cars, industries, etc., have not been considered. According to Fig. 18, nitrogen oxides with concentration of 0.002 μ/m^3 have, among others pollutants, the highest concentration around Isfahan airport. Based on Fig. 20, carbon monoxide with a concentration of 0.003 μ/m^3 is found to be the second important pollutant around Isfahan airport. Since Isfahan airport is located out of Isfahan city limits, therefore, only small amounts of pollutants released from aircrafts can reach residential areas of this city.

Table 5. The number of trips taken in 2016 by all airplane types at Isfahan airport

Aircraft type	Saturday	Sunday	Monday	Tuesday	Weekday	Thursday	Friday	Number of flights in month	Number of flights in year
BAE 146	3	3	2	4	2	1	0	15	180
MD 80	6	0	3	3	3	2	3	20	240
F100	5	6	10	7	4	8	6	46	552
MD83	3	3	2	4	3	2	0	17	204
MD 88	9	12	7	11	11	4	3	57	684
A320	2	2	4	0	2	7	2	19	228
RJ	1	0	0	2	1	1	1	6	72
ART72-500	1	5	2	1	1	3	1	14	168
F50	1	0	0	0	1	0	0	2	24
B737	2	1	3	5	3	3	3	17	204
M80	0	1	0	1	0	0	0	2	24
CRJ-100ER	0	1	0	0	0	0	0	1	12
A319	0	1	0	0	0	0	0	1	12
A 300	1	1	0	0	1	3	1	12	144
Total number of flights	34	36	33	38	32	34	20	229	2748

Table 6. The annual pollutants emission rates in 2016 from all airplane types in kg/year

Aircraft type	CO_2	HC	NO_x	CO	SO_x	Fuel consumption per LTO* [20]
BAE 146	981000	225	365.4	2664	309.6	290
MD 80	763200	448.8	2872.8	1550.4	242.4	1010
F100	1319280	789.36	3174	7639.68	419.52	760
MD83	648720	381.48	1719.72	820.284	206.04	1010
MD 88	2175120	1279.08	3149.136	2750.364	690.84	1010
A320	585960	129.96	2054.28	1411.32	175.56	770
RJ	68400	48.24	156.24	403.92	21.6	300
ART72-500	104160	48.72	305.76	391.44	33.6	200
F50	22296	4.8	69.6	67.2	1.416	297
B737	505920	171.36	1466.76	2658.12	159.12	870
M80	76320	44.88	287.28	155.04	20.88	870
CRJ-100ER	12720	7.56	27.24	80.4	3.96	330
A319	27720	7.08	104.76	76.2	8.76	730
A 300	784800	180	3723.84	2131.2	247.68	1720

* Landing/Take-Off (LTO) cycle

The total number of flights at Isfahan airport in 2016 was 2748 landing/take-offs, while it was reported that this number at Tehran Mehrabad international airport was nearly 110,000 landing/take-offs [26]. In other words, Isfahan airport can be categorized as a small airport in Iran. It was reported that nearly 197,100 kg sulfur dioxide, 2,737,500 kg carbon monoxide, 1,204,500 kg nitrogen oxide and 657,000,000 kg carbon dioxide are yearly released into the Tehran atmosphere by Tehran Mehrabad international airport [26]. Isfahan airport emissions are negligible in comparison with Tehran's airport. Since Isfahan airport emissions are widely dispersed into the Isfahan atmosphere due to the fast movement of aircraft, it can be less harmful on Isfahan habitants' health.

Table 7. The total annual pollutants emission in 2016 from Isfahan Airport by kg/year

CO_2	HC	NO_x	CO	SO_2
8076	3.766	19.477	22.8	2.541

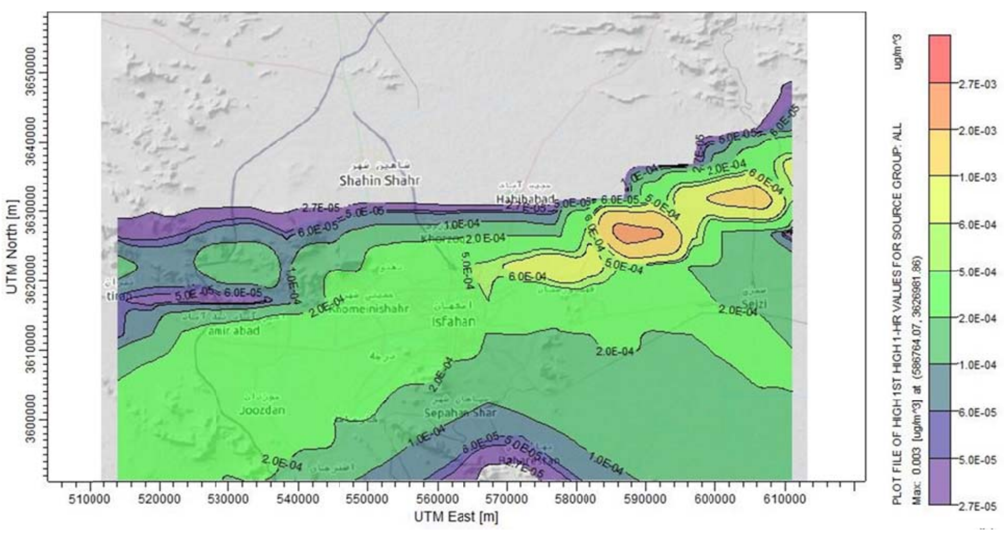

Fig. 16. NO_x emissions caused by airplanes from Isfahan airport

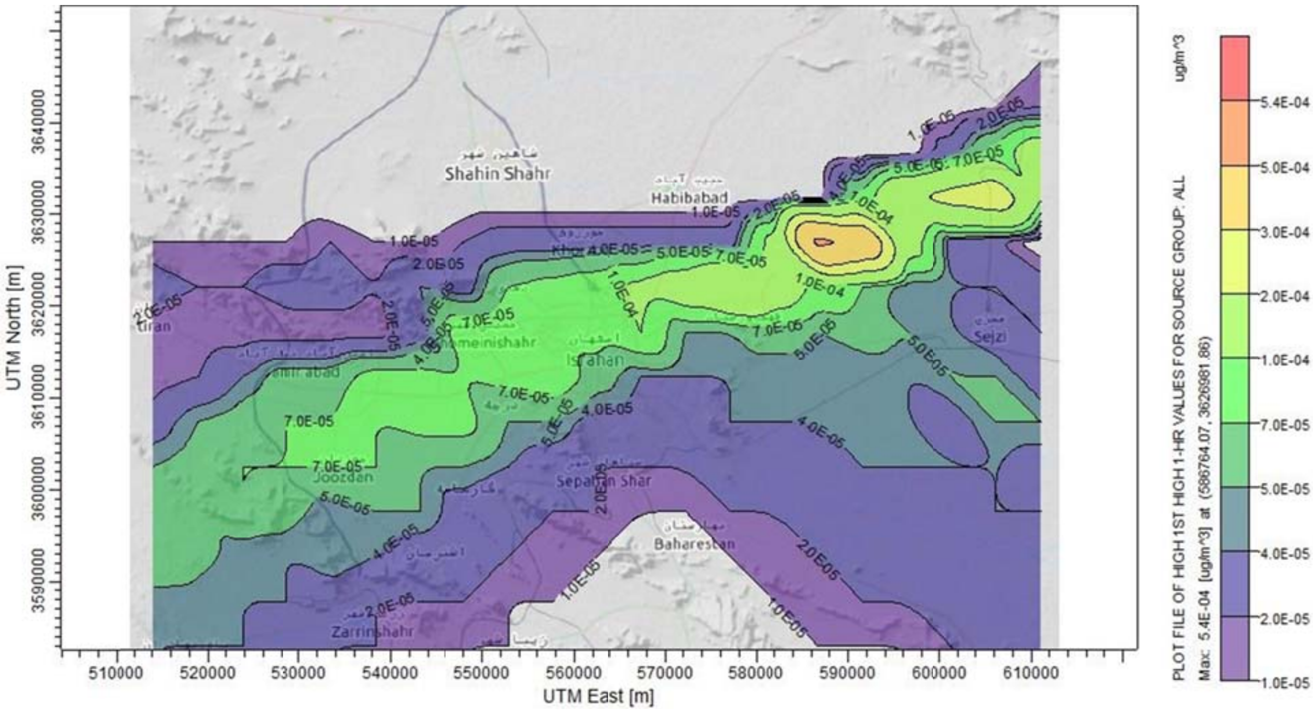

Fig. 17. CO_2 emissions caused by airplanes from Isfahan airport

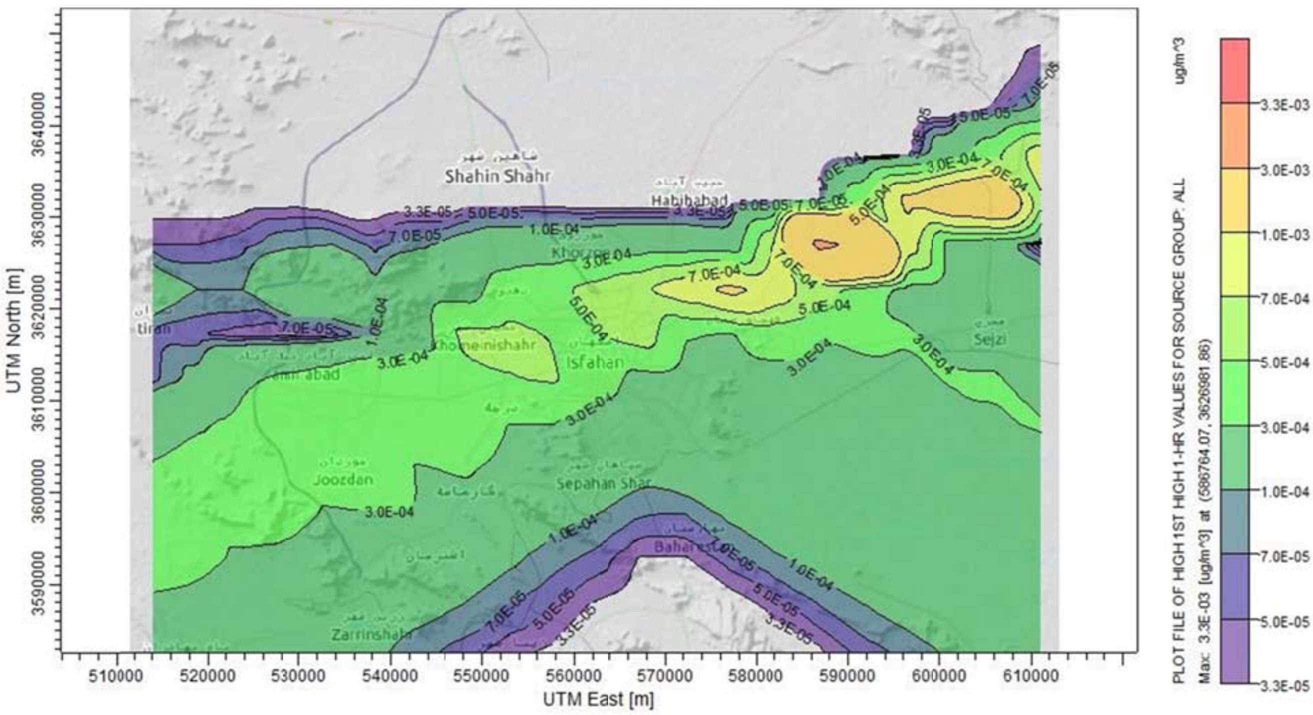

Fig. 18. CO emissions caused by airplanes from Isfahan airport

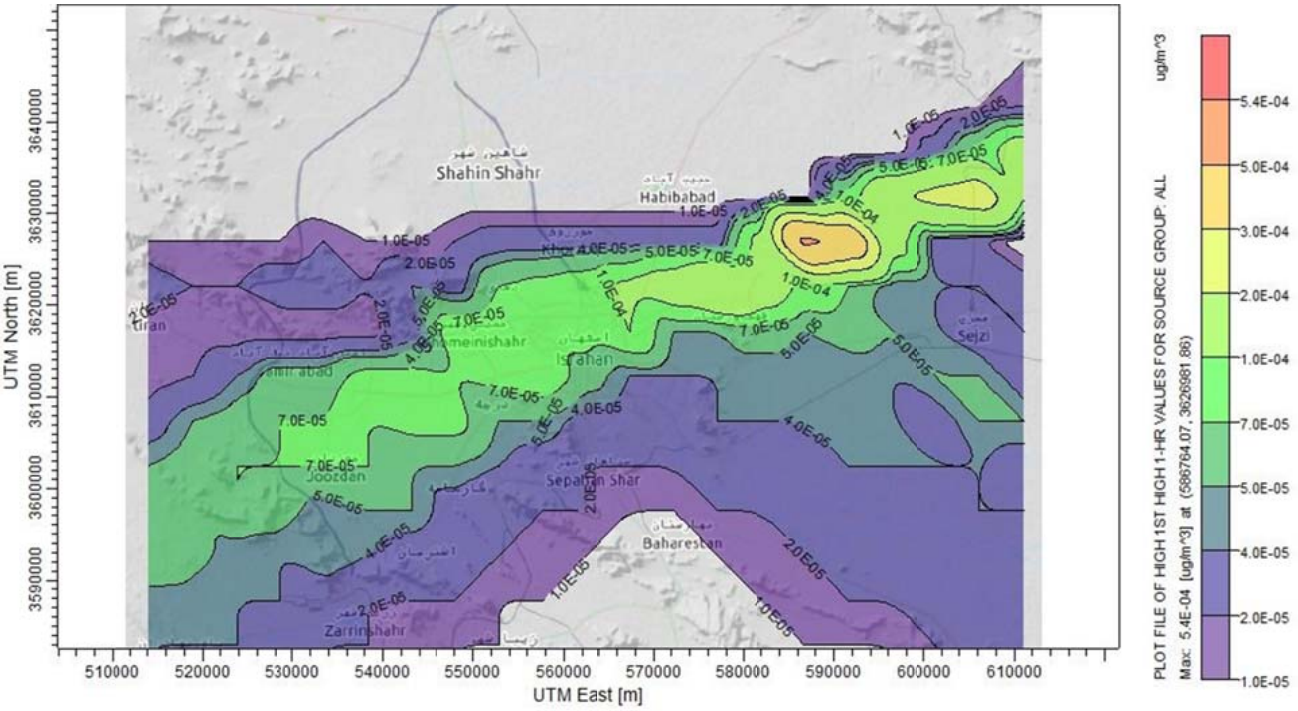

Fig. 19. HC emissions caused by airplanes from Isfahan airport

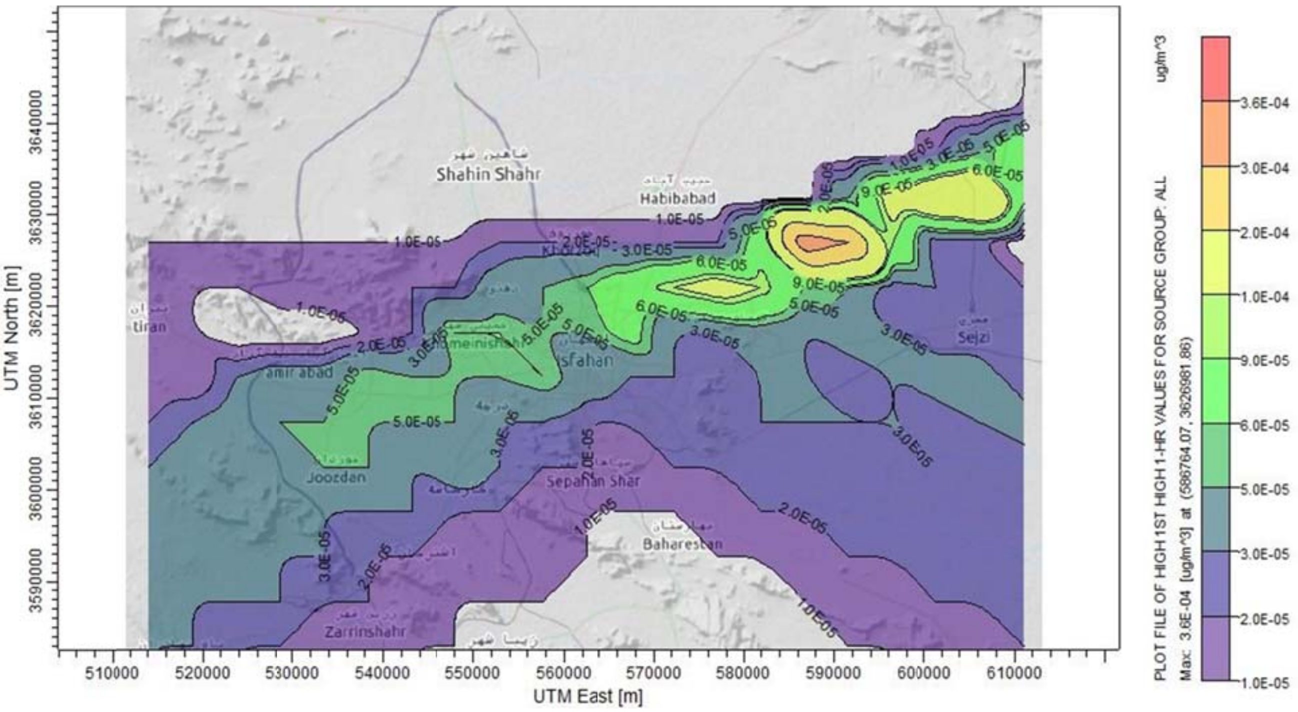

Fig. 20. SO_x emissions caused by airplanes from Isfahan airport

CONCLUSIONS

Nowadays, having an appropriate transportation industry is a measure of well-being in any country. Because the Isfahan metropolis is an industrial area in Iran, it contains a vast system of air and railroad transportation. This may produce significant level of air pollution in Isfahan's ground-level atmosphere. All trains whose destination or origin is or even passes through the Isfahan metropolitan area use locomotives with diesel engines. The results of this study show that 13,297 tons of nitrogen oxides, 0.13 tons sulfuric oxides, 691 tons of hydrocarbons, 727 tons of VOCs, 329 tons of PM_{10}, 1374 tons of carbon monoxide and 319 tons of $PM_{2.5}$ on average are released into the atmosphere of Isfahan on an annual basis by railroad systems. It is concluded that the most important pollutants emitted from railroad systems in Isfahan are nitrogen oxides. Sepahan-Shar suburb, in the southern part of Isfahan, receives the majority of the generated pollutants by the passing trains. The study on emission inventory of produced pollutants by airplanes showed that in 2016 an average of 8076 tons of carbon dioxide, 3.8 tons of hydrocarbons, 19.4 tons of nitrogen oxides, 22.8 tons of carbon monoxide and 2.54 tons of sulfuric oxides are released into the atmosphere on annual basis. The eastern parts of Isfahan receive most of the pollutants that are released into the atmosphere by airplanes. The results obtained from this study demonstrate the significant impact of railroad and air systems to air pollution of Isfahan atmosphere.

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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.

AUTHOR CONTRIBUTIONS

It is certified that all of the authors have made the same contribution in the experiments and manuscript writing.

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ETHICAL CONSIDERATIONS

Authors are aware of, and have complied with, best practices in 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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