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On-Road Vehicle Emissions Forecast Using IVE Simulation Model

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ABSTRACT: During the recent decades, rapid urbanization growth has led to even faster growth of motor vehicles and especially in large cities. Hence, evaluation of the actual level of traffic emissions has gained more interest. This paper, for the first time, presents a bottom-up approach for evaluation of vehicular emissions in Tehran- the capital of Iran- using the International Vehicle Emission (IVE) model. The IVE model uses local vehicle technology levels and its distributions, power based driving factors, vehicle soak distributions and meteorological parameters to tailor the model for specific evaluation of emissions. The results of this study demonstrate that carbon monoxide (CO) emission with 244.45 ton/hr during peak traffic hour is the most abundant criteria pollutant. About 25% of this quantity is emitted during start-up periods. Other pollutants such as NO_X, VOCs, PM, VOC_{evap} and SO_X are ranked after CO accordingly. Also, carbon dioxide (CO_2) emissions of 1744.22 ton/hr during the study period indicate that light vehicles are responsible for more than 82% of this amount. Based on IVE's evaluation, about 25% of the total vehicle emissions in Tehran come from districts 2, 4 and 6 respectively. It has further been inferred that the development of public transportation systems and proper land-use and urban spatial planning for various centers in these districts are essential.

Key words: Air Pollution, Vehicular Emission Forecasting, IVE Model, Tehran

INTRODUCTION

Human being's exposure to air pollutants has received much attention for many years (Montero Lorenzo *et al.*, 2011; Cui *et al.*, 2011; Alipour *et al.*, 2011; Fotouhi and Montazeri, 2012; Nejadkoorki and Baroutian, 2012; Chianese *et al.*, 2012; Barrera *et al.*, 2012; Ataei *et al.*, 2012) . A large number of people around the world are inflicted with heart and respiratory diseases related to air pollution (Katsura, 2012; Lee *et al.*, 2012; Rashidi *et al.*, 2012; Quesada-Rubio *et al.*, 2011; Sekhavatjou and Zangeneh, 2011; Zou *et al.*, 2011; Wang *et al.*, 2011). An average 70 kg adult person takes about 15 breaths a minute and inhales about 20 m^3 of air per day (Curtis, Rea *et al.*, 2006). Some groups of people such as asthmatics, atopic patients, people with emphysema and bronchitis, heart and stroke patients, pregnant women, the elderly and children are more at risk of outdoor air pollution and toxicants (ALA, 2005). In addition, people spend the majority of their time indoors, and indoor air quality is dependent to outdoor air quality to a large degree (Curtis, Rea *et al.*, 2006; Shafie-Pour, Ashrafi *et al.*, 2010). Population growth and urban development on the one side and improving living standards on the other, causes exponential growth of vehicles, especially in large cities. Transportation is one of the major contributors of hazardous air pollutants emissions and vehicles are the dominant source of many air pollutant emissions in urban areas (Zhang, Batterman *et al.*, 2011).

Economic impacts of air pollution are another side of this dilemma. Accurate estimate for economic cost of air pollution is so difficult (Levy, 2003; Curtis, Rea *et al.*, 2006). Furthermore, combinations of air pollutants cause an increase in mortality, morbidity, absenteeism and lost productivity which create major economic costs. Some adverse health effects of air pollution such as human suffering is hard to measure in monetary term (Curtis, Rea *et al.*, 2006). Environmental economists commonly use the direct medical cost (DMC), contingent valuation (CV) and value of statistical life (VOSL) in order to evaluate morbidity and mortality of environmental changes such as air pollution (Karimzadegan, Rahmatian *et al.*, 2008). The other groups of damages are related to non-human health related economic costs. For example reduced visibility, global warming, harm to animal and plant types, vehicle and building damage and invaluable items maintained in museums and galleries are impossible to be estimated.

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In Tehran, the capital of Iran, rapid population growth in urban and rural areas, increasing per capita ownership of private vehicles, low technology level of produced vehicles and use of old vehicles with high fuel consumptions, have collectively led to excessive fuel consumption and air pollution. Tehran's way of life relies heavily on private cars, buses, motorcycles, and taxis, and is one of the most car-dependent cities in the world (Roshan, Zanganesh Shahraki *et al.*, 2010; Anonymous, 2011). Automobiles and motorcycles participate in production of large amount of pollutants and greenhouse gases such as CO, SO_X, HC, NO_X, PM, and CO_2. According to a study conducted by Iran's Department Of Environment (IDOE), the origin of the problem of air pollution- 80% of pollution emissions- in Tehran is the cars that flood the city main streets on a daily basis (IEPO, 2010). Table 1 show the proportion of different fossil fuel consumer sectors in emission of pollutants.

In Iran using Emission Factors (EF), recommended by US-EPA as AP 42 method (EPA, 2011), for calculation of air pollution emissions in transportation sector is popular. In this way the amount of different emissions can be estimated based on multiplying amount of vehicles' consumed fuels by the relevant emission factors. This method has many disadvantages. For example, spill or evaporative fuels during refueling or driving habits would not be considered. Fuels with special compositions are the only parameter of interest in this approach. But it is apparent that the compositions of fuels may be variable in different areas and it can affect the results. So evaluation of improved methods or different control strategies is ignored in this manner.

New vehicles have a higher technology level and consume less fuel. Several factors such as driving speed, scrolling and numbers of starts are issues which are involved in fuel consumption rate, but none of these details are considered in old EPA approach, AP 42.

This article focuses on application of International Vehicle Emissions (IVE) model for evaluation of emissions from mobile sources in a mega city such as Tehran. Greater Tehran Area has the population of 13.27 million which are distributed in an area of approximately 3500 square kilometers. Tehran has 4.9 million automobiles and 2.2 million motorcycles according to 2010 records. About 15 million trips are made daily in Tehran that only about 2.3 million of those are made by city buses. Therefore, application of preventive methods for high emission vehicles is very important and essential. On the other side, less than 70% of vehicles passed the Inspection and Maintenance (I&M) annual tests. Amongst the cars that do not pass the I&M tests, nearly 30% is due to high emissions of exhaust air pollutants (Mojabi and Navazi, 2008). IVE model is able to calculate emission of different pollutants and some greenhouse gases using VSP parameter (Vehicle Specific Power), fleet dispersion and pattern of vehicle activities, environmental and other parameters.

MATERIALS & METHODS

The International Vehicle Emissions (IVE) model, version 2.0, is designed by Office of International Affairs for calculation of mobile source air emissions, the U.S. Environmental Protection Agency. The aim of this model is to provide a background for evaluation of control strategies and effectiveness of different transportation planning. IVE as a bottom-up approach (Wang, Chen *et al.*, 2008), can predict how different strategies will affect local emissions and measure progresses of reducing emissions over time (ISSRC,

Table 1. Amount of pollutants and CO_2 emissions in Tehran from different sectors (RPC, 2007)

Pollutant	SO_x		HC		CO		NO_x		SPM		CO_2	
Consumer	ton	%	ton	%	ton	%	ton	%	ton	%	ton	%
Residential, Commercial & Other	10315	12.3	2282	1.4	13706	1.1	23268	19.4	5048	4.4	21540012	45.3
Industrial	35143	41.6	771	0.5	10302	0.8	13064	10.9	2989	2.6	6925142	14.6
Transportation	22924	27.2	152424	97.2	1239081	98.0	62642	52.1	105385	91.1	14236577	29.9
Agriculture	2126	2.5	32	0.0	174	0.0	455	0.4	354	0.3	445266	0.9
Power plants	13902	16.5	1319	0.8	914	0.1	20837	17.3	1937	1.7	4421097	9.3
Total	84410	100	156827	100	1264177	100	120265	100	115712	100	47568095	100

2008). The IVE model has the ability to predict local air pollutants, greenhouse gas emissions and toxic pollutants from different mobile sources. The emission estimates are delivered using the following parameters:

- Vehicle emission rates,
- Vehicle activity, and
- Vehicle fleet distribution.

As indicated formerly, the IVE model requires three input files including vehicle fleet, vehicle activity (i.e. driving behavior) for the location of interest and base adjustments.

For preparing the Fleet file, six types of data are needed:

1) Classification of Fleets,
2) Fuel type (Petrol, NG, Propane, Ethanol, Diesel, CNG/LPG and special),
3) Fuel delivery system (Carbureted, Single Point Fuel Injection, Multi Point Fuel Injection, Pre-Injection, Direct Injection, 2-cycle and 4-cycle),
4) Vehicle type and feature,
5) Percentage distribution of the desired vehicle, and
6) Distribution of Air Condition system.

Based on these data, the total of 1417 technologies are contained in IVE model that 1372 of them are predefined and remains can be defined by user.

In 2010, more than 15 million daily trips were made in Tehran. This value is expected to increase to over 18 million by 2025. Table 2 lists distribution of daily trips and proportion of different groups in transportation sector within the Greater Tehran Area.

Selection of appropriate classification is the first step for preparing Fleet files. In current study three groups of Light vehicles, Heavy vehicles and Motor cycles were selected as Fleet groups. The desired fuel types for intended vehicles were set amongst various types of fuel in the IVE model; realistically only three types of Petrol, Diesel and CNG/LPG have been used in this study. After selection of fuel types, the classes of fueling system for desired group have been determined. Carburettor, Fuel Injection, Multi Point Fuel Injection and Carburettor/Mixer for Light Duty vehicles and vans, Fuel Injection for Heavy vehicles and 4-cycle/Carburetor for motorcycle, are cases most used in Tehran.

Preparation of the ‘Fleet file’ continued by entering the details of each group among 1372 proposed technologies in IVE model. The details included are: description of vehicle type, weight, air/fuel control system, exhaust control system, evaporative control systems and age which defines the age of the vehicles in terms of odometer reading in thousands of kilometers travel (K km).

Travel fraction for each technology type and the fraction of the technology that is equipped with air conditioning form another part of the information required for this model. The results of this assessment for Tehran are shown in Table 3.

It should be noted that although some light vehicles can use petrol and CNG as a fuel simultaneously, but due to lack of information about the distance traveled by CNG, these systems are ignored.

Table 2. Distribution of daily trips and vehicle displacement performance, Tehran (TCTTS, 2007)

System	vehicle	Residents travel		Nonresidents travel		Total daily trips		Relocation factor	Daily relocation	
		Total	%	Total	%	Total	%		Total	%
Personal	motorcycle	900,000	7.2	40,000	1.6	940,000	6.3	1	940,000	4.9
	Motorcar & Passenger vans	4,300,000	34.4	1,100,000	44	5,400,000	36	1	5,400,000	28.4
General	Urban Train	600,000	4.8	170,000	6.8	770,000	5.1	1.5	1,155,000	6.1
	Bus	2,300,000	18.4	280,000	11	2,580,000	17.2	1.5	3,870,000	20.3
	Minibus	230,000	1.8	260,000	10	490,000	3.3	1.8	882,000	4.6
Mid general	Van	80,000	0.6	10,000	0.4	90,000	0.6	1.8	162,000	0.9
	Taxi & Passenger car	3,000,000	24	210,000	8.4	3,210,000	21.4	1.6	5,136,000	27
	Automotive Service	1,050,000	8.4	370,000	15	1,420,000	9.5	1	1,390,000	7.3
	Other	40,000	0.3	60,000	2.4	100,000	0.7	1	100,000	0.5
Sum		12,500,000	100	2,500,000	100	15,000,000	100	-	19,035,000	100

Table 3. Defined technologies in the transport system of Tehran

Description	Fuel	Weight	Air/Fuel Control	Exhaust	Evaporative	Age	Index
Auto/ Truck	Petrol	Light	Carburetor	None	PCV	<79K km	0
Auto/ Truck	Petrol	Light	Carburetor	None	PCV	80-161K km	1
Auto/ Truck	Petrol	Light	Carburetor	None	PCV	>161K km	2
Auto/ Truck	Petrol	Light	Multi-Port FI	None	PCV	<79K km	99
Auto/ Truck	Petrol	Light	Multi-Port FI	None	PCV	80-161K km	100
Auto/ Truck	Petrol	Light	Multi-Port FI	None	PCV	>161K km	101
Auto/ Truck	Petrol	Light	Multi-Port FI	3-Way	PCV	<79K km	117
Auto/ Truck	Petrol	Light	Multi-Port FI	3-Way	PCV	80-161K km	118
Auto/ Truck	Petrol	Light	Multi-Port FI	3-Way	PCV	>161K km	119
Auto/ Truck	Petrol	Light	Multi-Port FI	3-Way/EGR	PCV	<79K km	126
Auto/ Truck	Petrol	Light	Multi-Port FI	3-Way/EGR	PCV	80-161K km	127
Auto/ Truck	Petrol	Light	Multi-Port FI	3-Way/EGR	PCV	>161K km	128
Truck/Bus	NG	Medium	FI	3-Way/EGR	PCV	<79K km	993
Truck/Bus	NG	Medium	FI	3-Way/EGR	PCV	80-161K km	994
Truck/Bus	NG	Medium	FI	3-Way/EGR	PCV	>161K km	995
Truck/Bus	NG	Heavy	FI	3-Way/EGR	PCV	<79K km	996
Truck/Bus	NG	Heavy	FI	3-Way/EGR	PCV	80-161K km	997
Truck/Bus	NG	Heavy	FI	3-Way/EGR	PCV	>161K km	998
Truck/Bus	Diesel	Medium	FI	Euro I	None	<79K km	1119
Truck/Bus	Diesel	Medium	FI	Euro I	None	80-161K km	1120
Truck/Bus	Diesel	Medium	FI	Euro I	None	>161K km	1121
Truck/Bus	Diesel	Heavy	FI	Euro I	None	<79K km	1122
Truck/Bus	Diesel	Heavy	FI	Euro I	None	80-161K km	1123
Truck/Bus	Diesel	Heavy	FI	Euro I	None	>161K km	1124
Truck/Bus	Diesel	Medium	FI	Euro II	None	<79K km	1128
Truck/Bus	Diesel	Medium	FI	Euro II	None	80-161K km	1129
Truck/Bus	Diesel	Medium	FI	Euro II	None	>161K km	1130
Truck/Bus	Diesel	Heavy	FI	Euro II	None	<79K km	1131
Truck/Bus	Diesel	Heavy	FI	Euro II	None	80-161K km	1132
Truck/Bus	Diesel	Heavy	FI	Euro II	None	>161K km	1133
small Engine	Petrol	Med	4-Cycle, Carb	None	None	0-25K	1209
small Engine	Petrol	Med	4-Cycle, Carb	None	None	26-50K	1210
small Engine	Petrol	Med	4-Cycle, Carb	None	None	>50K	1211

Another requirement of the IVE model is ‘Location file’. This section actually represents status and driving patterns and should contain the following information:

1) Driving behavior,
2) Start patterns,
3) Environmental variables, and
4) Fuel Characteristics.

Each of these parameters has a noticeable and potentially significant impact on the amount of emissions. In order to calculate the emission rate of mobile sources by IVE, it is necessary to consider specific locations based on common characteristics of each district. In this study, Tehran has 22 districts and considering the rural areas as a separate district, in total †23 areas are defined. For the first location, the file needs to be completed by information such as date, altitude, base adjustment, I&M class and percentage of time that the fleet equipped with air conditioning, would use it at temperature 27°C or higher. This study focused its activities on March 1, 2011, between 8-9 AM. Due to cool weather, the percent of vehicles which use Air Conditioning is considered zero. Fuel characteristics that point to the amount of contaminants and additives, include overall fuel quality, sulfur content for diesel and gasoline, lead, benzene, and oxygenate levels for gasoline fuel. Studies show the sulfur content of diesel in Iran is about 7-10 thousands ppm and this amount is about 1000 ppm for gasoline. For the next step of the model, other parameters such as environmental parameters (humidity and temperature), Distance/Time that point to the total distance traveled by the fleet of interest, the total number of starts for the fleet and include both cold and warm starts, average velocity and driving characteristics would have to be defined. For period of interest in this study, these data are calculated for every fleet, separately.

In the IVE model, driving patterns can be monitored by two concepts of Vehicle Specific Power (VSP) and Engine Stress. Both of these parameters can be obtained from general knowledge of the vehicle type and instantaneous velocity trace. Equations 1 and 2 show how to estimate VSP and engine stress (ISSRC, 2008):

$$VSP = v\left[1.1a + 9.81(a\tan(\sin(grade))) + 0.132\right] + 0.000302v^{3} \tag{1}$$

Where,

Grade: $(h_{t=0}- h_{t=-1})/v_{(t=-1 \text{ to } 0 \text{ seconds})}$

v: velocity (m/s)

a: acceleration (m/s^2)

h: Altitude (m)

$$\text{Engine Stress (unitless)} = \text{RPM Index} + (0.08\ \text{ton/kW})*\text{Pre average Power} \tag{2}$$

Pre average Power: Average $(VSP_{t=-5\text{sec to } -25 \text{ sec}})$ (kW/ton)

RPM Index: Velocity $_{t=0}$/Speed Divider (unit less) Similar to driving patterns, different kinds of starts can have a profound impact on tailpipe emissions. For example the engine soak period (the length of time that a warmed-up engine has been shut off before starting) has the most predominant effects on emissions. In contrast, cold start that point to condition that engine is completely cold and there is a period more than 18 hours between the last operations to next start, typically has the most emissions because, the engine must warm up and the catalyst, if one exists, will take longer to heat up to operating conditions (ISSRC, 2008; Schifter, Diaz *et al.*, 2010). A completely warm start is when a warm engine is shut off for five minutes or less before starting again and the amount of emissions from start-up is the least. In this study it is assumed that for emission evaluation in morning peak hours, each vehicle starts only once with soak period of 8 hours. Emission rates that have been considered in the IVE model for Tehran have been based on specific studies and dynamometer testing on a specific cycle at standard conditions. So this feature is provided for the user to modify the models' base emission rates in other locations. The IVE model has capability of using correction factors to calculate actual emission rates in each location corresponding with selected technologies.

Calculation of base emission rates in IVE model are based on the US Federal Test Procedure (FTP) driving cycle (ISSRC, 2008; Zervas and Bikas, 2008) and running emissions are from the LA4 cycle (Enns and Brzezinski, 2001). To run the model for Tehran based on the amount of sulfur content of fuel and existent values †in table of fuel characteristics, sulfur dioxide concentration should be multiplied in an appropriate correction factor.

RESULTS & DISCUSSION

In this study, the objective was set to evaluate the vehicle emissions for three groups of criteria pollutants, air toxics and global warming components in different districts of Tehran. To achieve this goal, common types of vehicle technologies, driving patterns, distance traveled by fleet of interest, soak times and other parameters that may affect the emission rates, have been considered. The results of this study show that during this period of evaluation, carbon monoxide with 244.45 tones has the most emissions amongst criteria pollutants. About 25% of this amount is related to start-up and the rest of it is released during driving.

For better understanding of the emissions from Tehran vehicles, Tables 4, 5 and 6 show the results of this study for morning peak traffic hour in Tehran. These results show that criteria pollutants emission for the period of the study are about 4.450, 257.842 and 26.684 tones for heavy, light vehicles and motor cycles, respectively.

Table 4. IVE estimated vehicle criteria pollutant emissions- Tehran (kg)

Vehicles type	CO	VOC	VOC $_{evap.}$	NO_x	SO_x	PM
Heavy	967.79	202.23	5.09	2250.78	262.16	762.22
Light	221958.63	14087.99	2545.98	18630.60	546.38	72.12
Motor cycle	21523.45	2571.81	406.23	1933.53	28.53	220.24
Total	244449.87	16862.04	2957.29	22814.91	837.07	1054.58

Table 5. IVE estimated vehicle toxic emissions- Tehran (kg)

Vehicles type	1,3 Butadiene	Acetaldehydes	Formaldehydes	NH_3	Benzene
Heavy	0.908	4.334	12.220	4.223	2.126
Light	33.237	70.421	173.931	677.233	1484.874
Motor cycle	14.578	70.310	281.235	128.369	120.677
Total	48.723	145.065	467.385	809.824	1607.677

Table 6. IVE estimated vehicle related GHG's emissions- Tehran (kg)

Vehicles type	CO_2	N_2O	CH_4
Heavy	215641.627	4.852	6.374
Light	1430327.943	47.826	2833.294
Motor cycle	98253.522	0.118	567.018
Total	1744223.091	52.796	3406.686

As shown in Table 5, Benzene as a toxic pollutant has emission of 1.6 tones during one hour. Breathing high level of benzene causes drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness.

From the greenhouse gas emissions perspective, carbon dioxide released from mobile sources during one peak hour in Tehran is about 1744.223 tones that light vehicles contribute about 82% of emissions and contribution of heavy vehicles and motor cycles are 12.36% and 5.63%, respectively.

Another feature of IVE model is calculation of start-up and running emissions. The principal of vehicular start emissions appear between 7-9 AM, which is consistent with morning vehicle starts. Figures 1 and 2 illustrate these emissions for criteria and toxic air pollutants.

According to the defined locations in the IVE model for Tehran, emission levels in each district may be determined. Hence, Tehran's map and distribution of pollutants in different districts are shown in Figs 3 to 5.

In fig. 4 it may be observed that the highest emissions occurred in districts 2 and 6. Districts 17 and 20 have lowest emissions and since the areas reviewed are not alike in terms of area, it is suggested to consider emissions and areas of every district together for individual evaluation. On this basis it can be seen that district 6 still has the most emission per unit area and districts 10 and 11 are ranked in the next positions. According to a study for Tehran (Karimzadegan, Rahmatian *et al.*, 2008), the total daily health damage cost of air pollution in the Greater Tehran Area has been evaluated about 16224, 28816, 1927 and 7739 US$ for each unit increase of PM_{10}, CO, NO_2 and SO_2, respectively. If the indirect effects and chronic effects are added to the above figure, the total costs will become significantly higher.

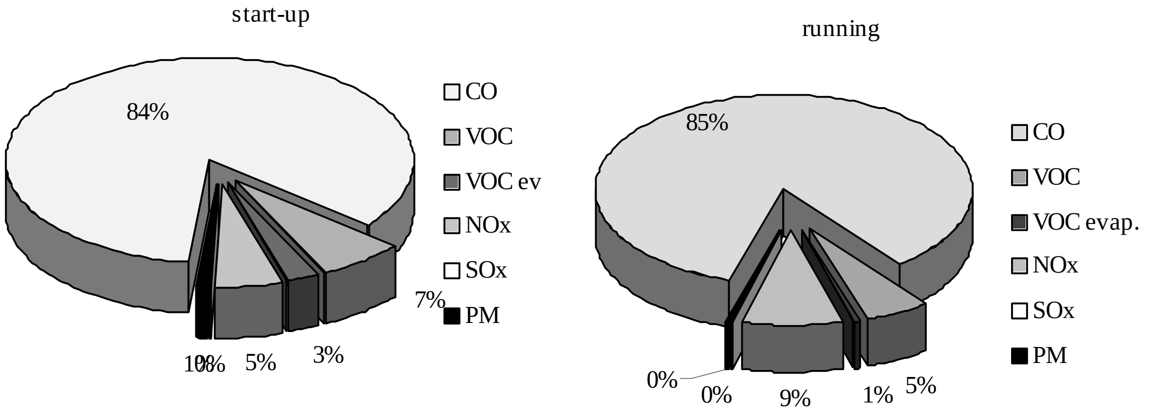

Fig. 1. Vehicle "Start" and "Running" criteria emissions, Tehran (%)

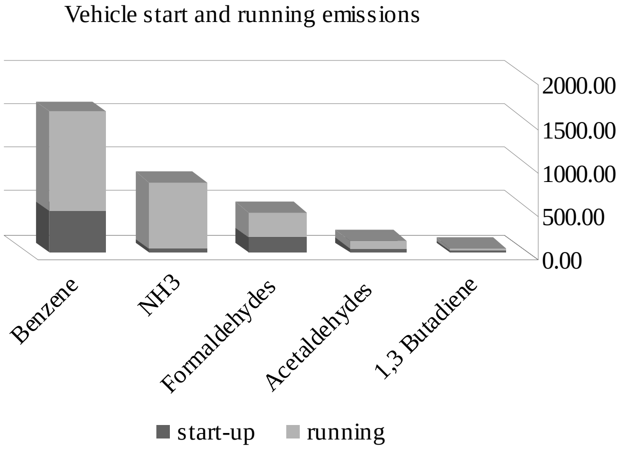

Fig. 2. Vehicle "Start" and "Running" toxic emissions, Tehran (kg)

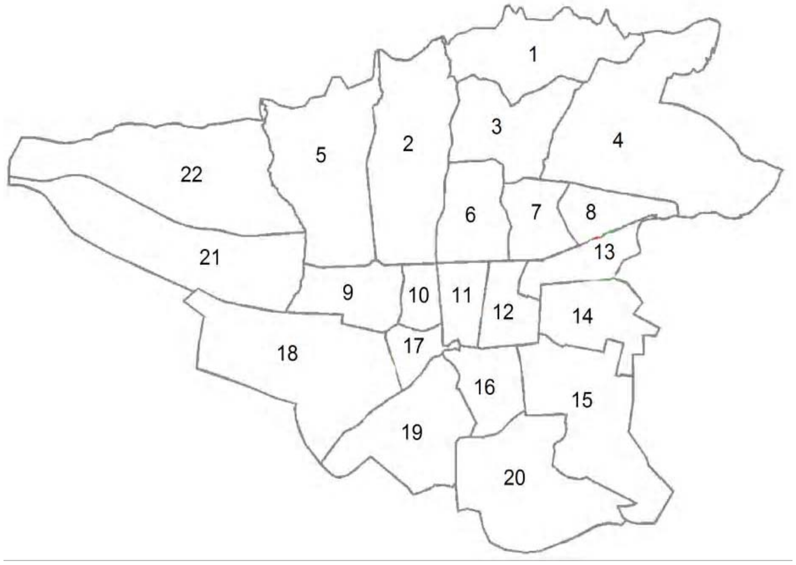

Fig. 3. Location of districts in Tehran city

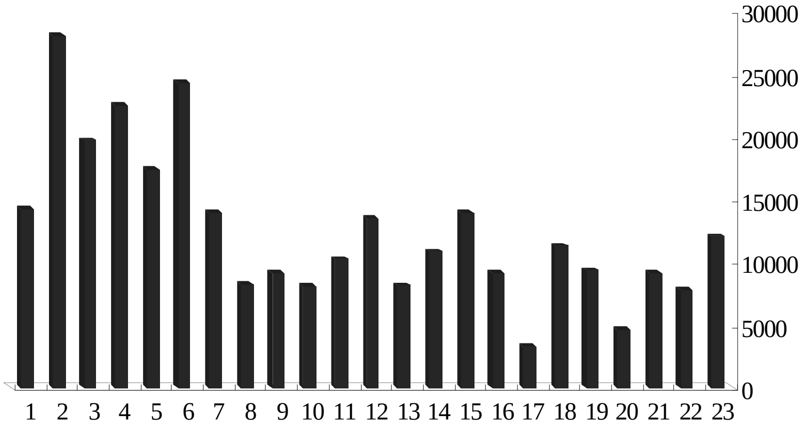

Fig. 4. Distribution of pollutants in different district, Tehran (kg)

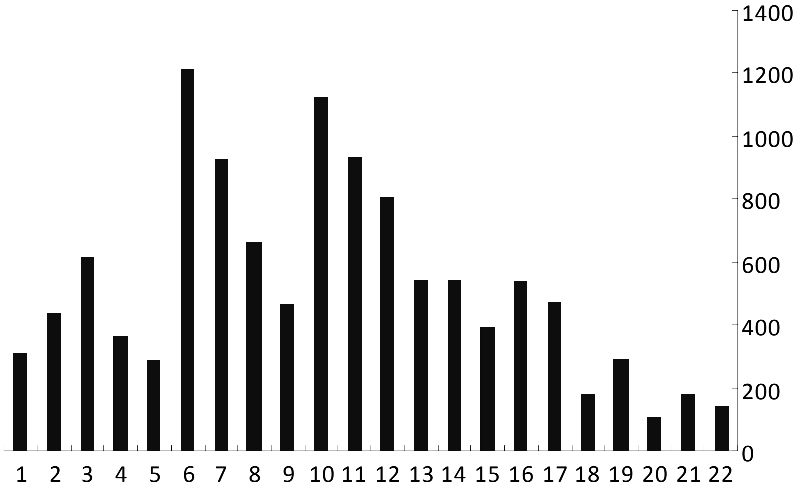

Fig. 5. Distribution of pollutants in different districts, Tehran (kg/km^2)

CONCLUSION

This article focuses on the evaluation of emissions from vehicles on March 1, 2011 in the AM traffic peak using the IVE model for a mega city such as Tehran. The results of this study show that contribution of light vehicles is about 90% of the total emissions (CO, VOC, VOC$_{evap}$, NOx, SO$_x$ and PM) emitted from mobile sources. This amount is equal to 82% emissions of carbon dioxide as the most important greenhouse gas.

Assessment of emission rates in different districts may be used as the base for management decisions. For example districts 2, 4 and 6 are responsible for more than 25% of total vehicular emissions in Tehran. Based on the results, in addition to low quality of consumed fuel and vehicle technology, driving cycle and driver's behavior have a significant effect on emissions of this sector. Therefore, in order to achieve broader and yet more accurate results, it is recommended to examine the most appropriate Compounded Driving Cycle (CDC) fit for Tehran so that individual testing for each portion of the CDC may be done accordingly. It is at this stage assumed that the closest driving cycle to that of Tehran may be best represented by the European Union adopted driving cycle that is ECE/EEC 15.04.

Economic benefits/costs of air quality improvement should be studied in more details for evaluation of human and non-human effects. Therefore, sound air quality management and proper positioning of administrative and commercial departments have effective role in improving the present situation.

As one might expect at the outset, the more developed public transportation systems coupled with the more updated fuels quality production for distribution and consumption, results in a radical change in the vehicular emissions estimated by the model.

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