Source Apportionment of Tehran's Air Pollution by Emissions Inventory

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ABSTRACT

The main environmental problem of Tehran is air pollution originating from natural topographic conditions as well as anthropogenic sources. The first step for managing Tehran's air pollution problems is to identify the main stationary and mobile sources and their relative contribution. Stationary sources include residential dwellings, power plants, and industrial complexes such as Tehran refinery. Mobile sources are comprised of public and private light and heavy vehicles.

There are several source apportionment procedures with different levels of complexity and data requirements which can be source-oriented and/or receptor-oriented. The classic source-oriented procedure is the use of emission factors to calculate pollutant generation based on the technology being employed and fuel usage. The receptor-oriented method consists of measuring and analysis of the prevailing pollutants' concentrations and back-calculating to identify the contributors. The above methods have been applied in this study to the available information of the data of the year 2002.

The results showed that 90% of total weight of the Tehran's air pollution is emitted from vehicles and the remaining 10% is from stationary sources. More than three fourth of the pollutants weight is CO with 98.7% being contributed from vehicles; about half from Light Duty Vehicles (LDVs) and 20% from motorcycles. Next in the line are HC and NO_x with 11.4% and 8.4% of total weight, with 70% and 67.5% contribution from mobile sources. SO_2 has 2.9% of the total weight, 85.8% of which is emitted from stationary sources. TSP comprises 2.4% of the total weight.

INTRODUCTION

Tehran and its vicinity with more than 11.5 million population with respect to: its topography, its unique regional setting, the presence of thousands of industrial units, the traffic flow of nearly two million active moving vehicles [1] and the daily [2] gas consumption of approximately nine million litres is considered as one of the most polluted mega cities in the world [3]. The air stability in fall and winter season creates the necessary condition for the air inversion phenomenon and pollution

accumulation to occur. The Tehran's air is polluted more than the standard limit in majority of the days on a yearly basis. In fact, the percentages of the days with clean air were 22% and 32% in the years of 2002 and 2003, respectively [3].

To find the most practical solution for this problem, the first step is to identify the pollutants sources and to classify them with the goal of determining the share of each source in various periods and locations of Tehran. Next step is: to determine the effectiveness of the solutions offered, to prioritize them and to execute the solution plans with respect to the obtained information.

For instance, one of the most important researches in the area of air pollution control and examination by the title of "Reduction of Air pollution caused by transportation" was carried out between 1994 and 1997 in Iran which the following points below can be pointed out. The result of this research revealed that the emission rate of stationary sources for the greenhouse gases with respect to the corresponding CO_2 was estimated nearly 41 million tons; moreover, 5300 tons for air floating particles. In fact, it was announced that 45% of the gases and 38% of the air particles were produced by the energy consumed in residential and commercial units.

This research estimated that the total emission from mobile sources was 9.4 million tons of greenhouse gases (corresponding CO2) and 20,500 tons of air floating particles. As a matter of fact, heavy duty vehicles produced 36% of greenhouse gases and 42% of air floating particles, respectively. However, the measured traffic flow for these heavy vehicles based on kilometre was computed as 8% of the total traffic flow [4].

Another comprehensive research was collaborated with Japan International Cooperation Agency (JICA). Based on the results obtained in this project, transportation produced 71.2% of the total pollutants. Furthermore, the stationary sources produced the remaining 28.8% of the pollutants which industry sector takes 18.2%, residential and public sector 4.6% and power stations and Tehran's oil refinery take 5.9% of the shares pollutants productions [5].

MATERIALS AND METHODS

To measure the pollutants emission for the stationary sources and their fuel consumption and emission factors, Iran's oil distribution products organization and Iran's national gas company provided the necessary information. This data which is available to public belonged to the year of 2002. The information related to the number of consumers in various regions was collected from organizations such as Statistics and Information Centre of Mayor's office (City Hall), and the Statistics Centre of Iran. In fact, to examine the periodic trend of pollutants production, the rate of pollutants production were measured in different months of a year in the city of Tehran.

To measure the pollutants emission for the mobile sources, the following data were measured and collected: the total kilometres travelled by the average speed for every type of vehicle in Tehran's avenues and streets, the emission factors of various pollutants for every type vehicles in different speeds and every single path, and the slope of streets in various conditions. Finally, by accumulating the total amount of a pollutant emission in streets, the production rate of that specific pollutant was calculated for every region in Tehran. The necessary traffic information was obtained from a travel demand model called EMME/2 provided by the comprehensive transportation studies company in Tehran. Moreover, to calculate the traffic volume for every region of Tehran, all data, models, territories and roads network were updated and utilized in 2002. Eventually, the monthly kilometres travelled as data for various vehicles in all streets was obtained.

Emission factors

The emission factor of every vehicle is the rate of every pollutant released in a kilometre travelled in a specific hour. In fact, various vehicles have different emission factors based on their manufacturing technology and their fuel type. In addition, these emission factors are calculated by considering the driving skills and the slop of the road. Due to the lack of accessibility to obtain the updated emission factors of various vehicles again, the data from the project of "The plan of air pollution reduction caused by transportation (GEF-1997)" was used. In addition, with respect to the change of various vehicles subgroups and calculation of the fuel consumption rate, the numbers were modified.

Table 1. The pollutants emission factors released by LDVs in city of Tehran.

speed	Street slant	THC	PM10	CO	NOx	SO2
Average speed 20 km/hr	Flat surface	6/980	464	107/461	2/108	15
	uphill	11/173	2/319	302/911	5/792	21
	downhill	6/968	464	92/931	2/087	13
Average speed 40 km/hr	Flat surface	4/001	359	100/048	1/981	12
	uphill	5/329	1/796	123/880	5/346	17
	downhill	3/650	359	73/333	1/188	9
Average speed 60 km/hr	Flat surface	2/883	289	49/996	1/772	9
	uphill	3/683	1/444	57/904	5/579	13
	downhill	1/903	289	22/534	885	7
Average speed 80 km/hr	Flat surface	2/471	332	44/541	2/256	11
	uphill	3/137	1/662	46/767	5/538	15
	downhill	1/744	332	33/407	1/127	7

Data is provided by: Air Quality Control Organization (units: mg/km)

To compute the emission rate for the stationary sources, the data were obtained by the Air Quality Control Company and used which collected the emission factors based on their comprehensive research plan for the air pollution control.

Table 2. The emission factors for the stationary sources released by combustion.

Row	Sector	Fuel	unit	Emission factors				
				SPM	HC	CO	NOx	SO2
1	Industry	Gas	g/L	1/44	10/48	272/34	5/80	1/30
		White oil	g/L	2/38	0/34	0/56	6/15	3/20
		Gasoline	g/L	2/50	0/35	0/50	6/32	12/94
		Furnace oil	g/L	2/72	0/37	0/49	7/11	51/49
		Liquid gas	g/Kg	0/40	0/10	0/35	2/61	3/06
		Natural gas	g/m3	0/25	0/04	0/29	3/00	0/04
		Solid fuel	g/Kg	2/34	0/00	5/37	7/90	18/65
2	Residential and commercial	White oil	g/L	0/82	0/41	0/56	2/31	3/20
		Gasoline	g/L	2/12	0/15	0/58	2/73	12/94
		Furnace oil	g/L	2/88	0/16	0/61	2/84	51/49
		Liquid gas	g/Kg	0/40	0/15	0/45	1/81	3/06
		Natural gas	g/m3	0/29	0/12	0/33	2/05	0/04
		Solid fuel	g/Kg	2/34	0/03	25/29	6/80	18/65
3	Transportation	Gas	g/L	20/22	28/13	311/06	10/59	1/30
		Jet fuel	g/L	0/84	2/29	4/37	8/16	4/70
		Furnace oil	g/L	353/98	21/53	29/47	32/01	13/29
		Liquid gas	g/Kg	5/63	0/15	0/75	6/63	3/06
4	Power station and Refinery	Gasoline	g/L	2/54	0/58	0/58	10/94	12/94
		Furnace oil	g/L	2/84	0/65	0/65	13/20	66/48
		Natural gas	g/m3	0/25	0/66	0/29	9/60	0/04

Data is provided by: Air Quality Control Organization

RESULTS AND DISCUSSION

Pollutants emission by mobile sources

Table 3 presents the production of air pollution percentage share of every type of vehicles in 2002. The total pollutant produced by mobile sources was 1,708,802 tons which means by average 4,700 tons of air pollutants are emitted by vehicles in Tehran.

Table 3. Total emission of pollutants by mobile sources in 2002.

Types of vehicles	Pollutants (ton/yr)										Total	%	% of the total
	PM10	%	THC	%	CO	%	NOx	%	SO2	%			
Light personal cars	8,841	45/5	60,268	38/9	673,501	47/5	54,881	51/3	204	2/6	797,694/7	46/7	41/97
Pick ups	2,621	13/5	17,833	11/5	357,573	25/2	9,994	9/3	47	0/6	388,067/7	22/7	20/42
Taxi cabs	140	0/7	7,301	4/7	91,852	6/5	10,323	9/6	21	0/3	109,637/0	6/4	5/77
Minibuses	2,031	10/5	2,135	1/4	5,068	0/4	6,596	6/2	2,829	35/4	18,658/1	1/1	0/98
Private buses	656	3/4	1,196	0/8	2,461	0/2	3,931	3/7	1,510	18/9	9,753/5	0/6	0/51
Public buses	1,887	9/7	3,845	2/5	7,408	0/5	10,597	9/9	282	3/5	24,019/5	1/4	1/26
Motorcycles	1,971	10/1	60,270	38/9	276,563	19/5	628	0/6	60	0/7	339,492/1	19/9	17/86
Trucks	1,289	6/6	2,185	1/4	4,900	0/3	10,067	9/4	3,039	38/0	21,479/1	1/3	1/13
Total	19,435/3	100	155,033	100	1,419,326	100	107,016	100	7,991	100	1,708,802	100	89/90
%	1/14		9/07		83/06		6/26		0/47		100		-
Total stationary and mobile pollutants	27,308	71/17	219,840	70/52	1,438,654	98/7	158,547	67/50	56,448	14/16	1,900,799	89/90	-

As it is evident, personal vehicles take a significant share in the pollution production of mobile sources and they include 42% of the total pollutants in Tehran. Nearly 83% of the air pollution belongs to Carbon monoxide (CO) production caused by mobile sources which 47.5% of this compound is produced by personal automobiles. The LDVs are the leading polluters except in producing SO_2. Pick up vehicles and motorcycles take the shares of 19.9% and 22.7% as the next top polluters. It is noteworthy that motorcycles produce 40% of hydrocarbon and pick up vehicles produce 13.5% of PM_{10}.

Taxi cabs produce 6.5% of the hydrocarbons which take the share of 6.6% in the total pollutants production; moreover, buses, minibuses, and trucks all together take the share of 4.3% of the air pollution production of the moving vehicles.

Examining the pollutants

SO_2. By reviewing the SO_2 emission results released by various transportation vehicles, the highest rate of **SO_2** belongs to trucks, private buses and minibuses. Since they all consume gasoline with high sulphur content, they produce the highest rate of sulphur dioxide among the moving vehicles. However, although there are numerous public buses, they use low sulphur content gasoline. Thus their SO_2 production is low.

NO_x. The emission factor of NO_x in an identical kilometre distant is normally higher by several times. This pollutant is the significant part of air pollution produced by gasoline consumers' vehicles. However, there are a great number of gas consumption vehicles and more than half of the NO_x is produced by personal LDVs.

CO. Considering the emission factors production of CO in identical distances among gas consumers' vehicles are 10 times higher than THC and NO_x and nearly 100 times higher than PM_{10} and SO_2. Furthermore, among gasoline users, the production CO is much higher except for the NO_x. In fact, pick up vehicles produce CO (carbon monoxide) 2.5 times more than LDVs in similar distances and motorcycles are the major CO producers. The numerous personal cars have allocated nearly 50% of CO production.

THC. The production of THC for gasoline consumers' vehicles is higher than gas users' vehicles in identical distances. However, motorcycles which consume gas produce higher THC in similar distances.

The THC production in two divisions of LDVs and motorcycles allocate nearly 40% of the total THC production.

PM_{10}. Considering the table of air pollution emission factors of cars, the production of air floating particles in gasoline vehicles are several times higher compared to gas users. The amount of PM_{10} produced by the majority taxi cabs is frequently low due to the fact that they consume gas. However, based on the high gas consumption, the production of $PM_{10}$is high in LDVs compared to other vehicles.

Examining the periodic changes

The rate of monthly air pollution production is the lowest in March 20th till April 20th. The reason can be due to minimal traffic flow during Norouz national holidays. It is noteworthy that the

pollution production of vehicles is lower in spring and fall seasons compared to the monthly average along a year. Moreover, this rate is higher during summer and winter. The month of July has the highest pollution rate with 4.1% more than the average monthly along a year. The reason for this condition is due to high gas consumption as a result of high gas evaporation rate in summer. In fact, these three central regions are located in highly populated, busy area with high volume of traffic flow.

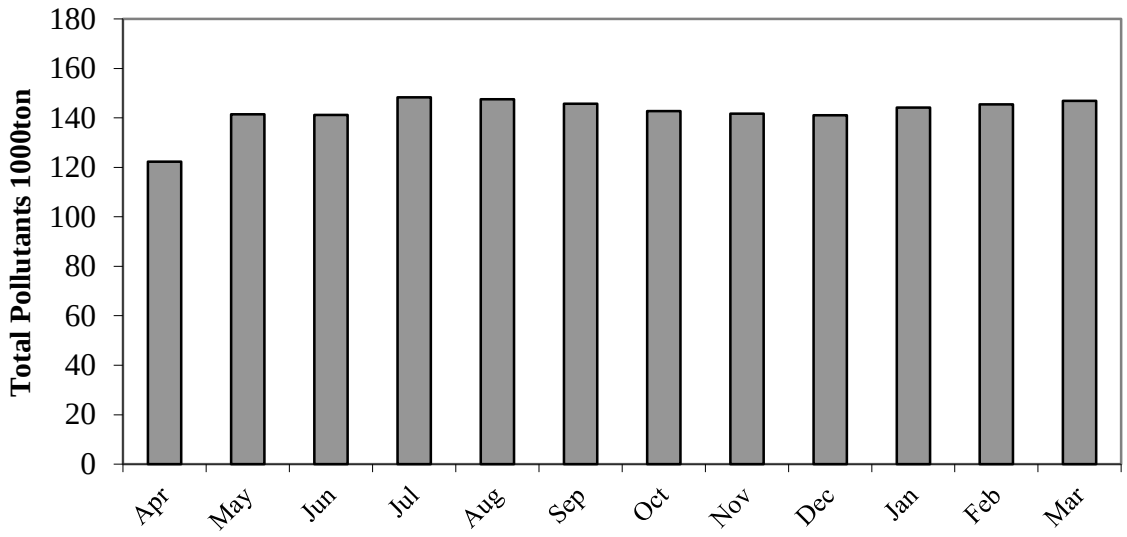

Figure 1. The total pollutants caused by mobile sources in Tehran in various months of 2002.

Examining regional changes

With respect to Figure 2, the regions of 2, 6, and 4 have the highest share of pollution production by the mobile sources; however, the with respect to the difference in regions level, the rate of pollution is higher in the regions of 6, 12, and 11 compared to other zones, respectively.

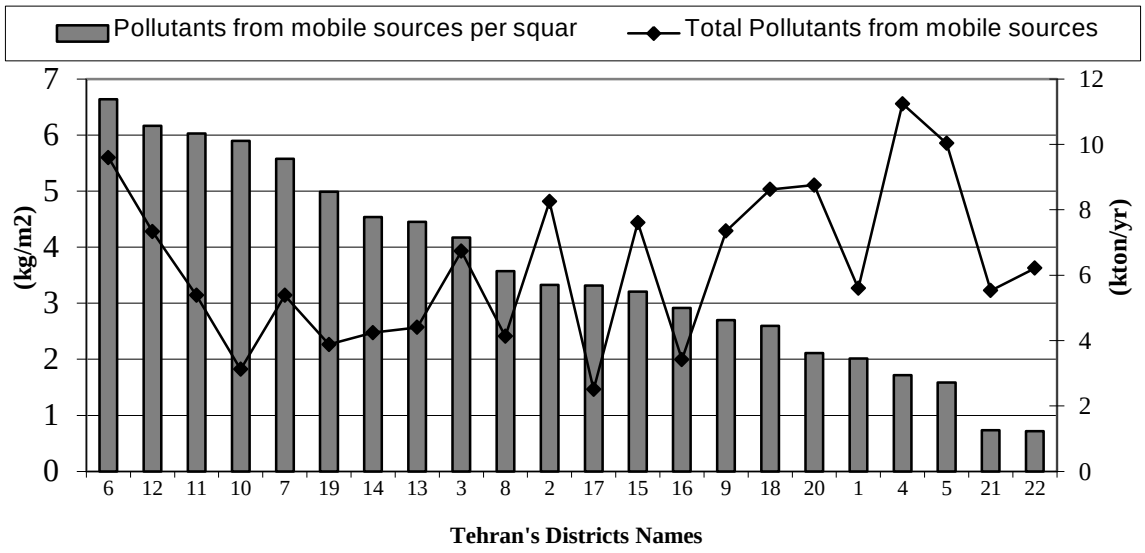

Figure 2. The share of pollutants of each region caused by mobile sources in 2002 according to City hall regional plan.

The pollutant emission by the stationary sources

The rate of pollution production by each stationary source in city of Tehran in 2002 is presented in Figure 3.

In the first group, the pollutants caused by defective fuels combustion and in the last four columns, the rate of hydrocarbon evaporation from the total fuel are illustrated. As it is evident, the rate of hydrocarbon evaporation from vehicles is assumed to be as stationary sources which play the

most significant role in the pollution production by the stationary sources. It can be stated that the speed of gas scape, high number of cars in the city and the low price of gas are among the reasons for the air pollution.

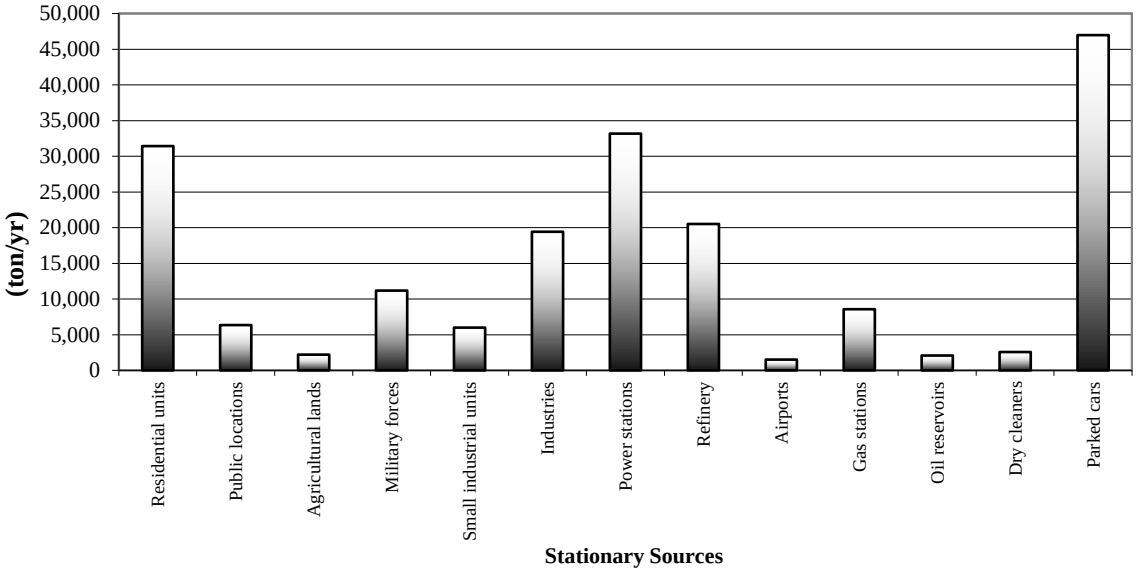

Figure 3. The rate of pollution emission by the stationary sources in Tehran in 2002.

The next causing factors in pollution production are the power stations. The high gasoline, furnace oil consumption and releasing high volume of NO_xandSO_2 by using these fuels play such a role in the pollution production. In fact, they rank the 1st in the production of NO_x and 2nd in SO_2 production.

The residential units allocate the next ranking in pollution production by the stationary sources. The residential units are the leading consumers of white oil, gasoline, natural gas and liquid gas as the stationary sources; thus they play a significant role in the production of the air floating particles.

Tehran's oil refinery with respect to its central situation is one the greatest air polluter. The specific pollutant produced by this refinery is SO_2. The consumption of the furnace oil in Tehran's refinery with 32% of the total white oil consumed by the stationary sources is higher compared to other sources; furthermore, based on the high emission rate of SO_2 from this type of fuel (66.48 g/L), the share of the refinery is higher in the production of SO_2.

Table 4. Total emission of pollutants by stationary sources in 2002.

Sources	Pollutants (tons/yr)										total	%	% of Pol
	SPM	%	HC	%	CO	%	NOx	%	SO2	%			
Residential units	3,333	42/3	995	1/5	2,624	13/6	15,499	30/1	8,978	18/5	31,429	16/4	1/65
Public locations	540	6/9	196	0/3	1,600	8/3	2,540	4/9	1,474	3/0	6,350	3/3	0/33
Agricultural lands	143	1/8	142	0/2	1,548	8/0	108	0/2	268	0/6	2,209	1/2	0/12
Military forces	795	10/1	608	0/9	6,478	33/5	716	1/4	2,585	5/3	11,182	5/8	0/59
Small industrial units	361	4/6	105	0/2	1,018	5/3	362	0/7	4,149	8/6	5,995	3/1	0/32
Industries	919	11/7	252	0/4	3,569	18/5	4,936	9/6	9,749	20/1	19,425	10/1	1/02
Power stations	1,137	14/4	1,288	2/0	1,914	9/9	18,969	36/8	9,867	20/4	33,175	17/3	1/75
Refinery	626	8/0	489	0/8	276	1/4	7,775	15/1	11,349	23/4	20,515	10/7	1/08
Airports	20	0/3	529	0/8	301	1/6	627	1/2	37	0/1	1,514	0/8	0/08
Gas stations	0	0/0	8,571	13/2	0	0/0	0	0/0	0	0/0	8,571	4/5	0/45
Oil reservoirs	0	0/0	2,084	3/2	0	0/0	0	0/0	0	0/0	2,084	1/1	0/11
Dry cleaners Print shops Paint shops	0	0/0	2,574	4/0	0	0/0	0	0/0	0	0/0	2,574	1/3	0/14
Parked cars	0	0/0	46,974	72/5	0	0/0	0	0/0	0	0/0	46,974	24/5	2/47
Total	7,874	100/0	64,807	100/0	19,328	100/0	51,532	100/0	48,456	100/0	191,997	100/0	10/10
% rate of stationary sources	4.10		33.75		10.07		26.84		25/24		100.0		-
Total pollutants by stationary and mobile sources	27,308	28/83	219,840	29/48	1,438,654	1/34	158,547	32/50	56,448	85/84	1,900,799	10/10	-

Examining the pollutants

SO_2. With respect to theSO_2 emission factor compared to other fuels in each application, the emission factor of the furnace oil is several times higher. Therefore, the production of SO_2 by the sources which consume the furnace oil is higher than other sources. In addition, the lack of high consumption of the furnace oil in the mobile sources have caused higher share of SO_2 by the stationary sources compared to mobile ones.

NO_x.The emission factor of this pollutant is higher compared to the furnace oil, gasoline and even natural gas in power stations and refineries in other applications by the stationary sources. Hence, the power stations, residential units and Tehran's refinery are the major production sources of NO_x.

CO. The majority of the CO emission factors are caused by fuels which is lower than 1 g/L; while, the CO emission factor compared to gas in the industry is 272.3 g/L and 311.1 in the transportation sector. Therefore, the source with higher gas consumption produce higher CO as well which the 84% share of mobile sources in the production of CO is reasonable. With respect to the relatively high gas consumption in the military forces and the industry, the share of these sources is higher in CO production compared to the other sources.

HC. The emission factor of hydrocarbons by various fuels is much higher in the transportation sector compared to the emission factor of this pollutant in other groups. However, in the stationary sources after 10.5 g/L factor, the other emission factors are lower than 1. The highest emission factors are related to the gasoline and the natural gas in the power stations sector and the refineries. However, the emission factors caused by defective fuel combustion which are produced by the evaporation process of hydrocarbons in the stationary sources. The fuel evaporation by the vehicles are the 1st ranked and afterwards, the gas stations emit the highest rate of this pollutant which tales the highest share in the pollution production by the stationary sources.

SPM. With respect to the emission factor table by the stationary sources, the furnace oil, gasoline and white oil with the rate of 2.5 till 3 g/L have the highest emission factors of this pollutant. Moreover, the lowest factors are related to the natural gas and liquid gas with nearly 0.3% g/L.

Based on the 52% share of the residential units in gasoline consumption and their 93% share of white oil, they play a higher role in the production of SPM compared to others.

Examining the periodic changes

By using the statistics of the rate of fuel consumption prior to 2002, a comparison can be made within these years. With respect to the Figure 4, the pollutants productions by the stationary sources are reduced between 1998 and 2002. In fact, this reduction is remarkable in the industry sector which the reasons for this reduction is as follows: to reduce fuel consumption with high pollutants and the users' trend toward consuming natural gas; to stop issuing work permit to polluting industries inside the city; to improve the refining systems and pollution reduction from industrial chimneys.

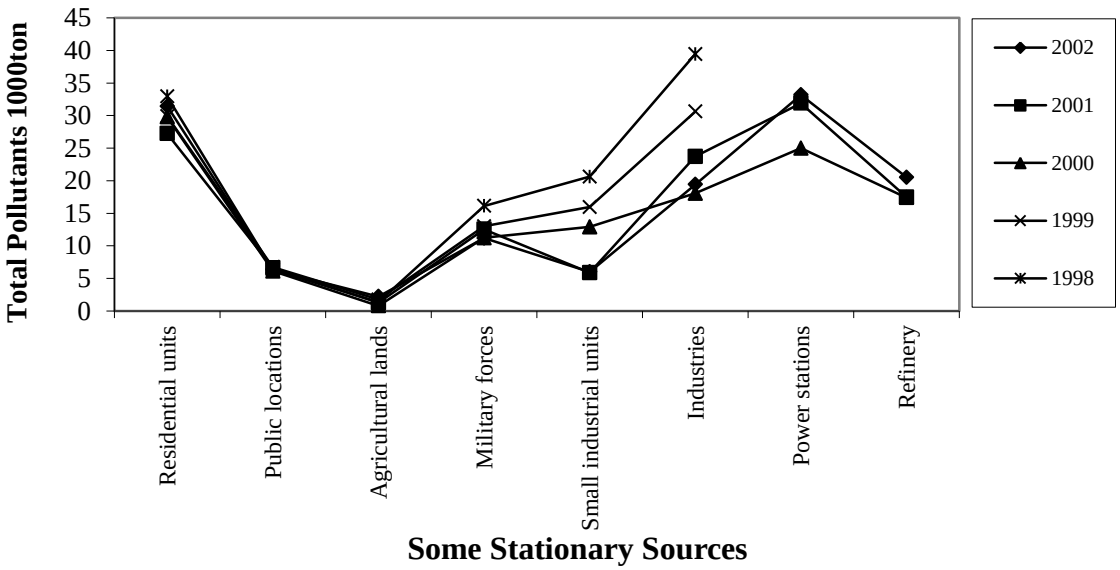

Figure 4. The rate of various pollutions released by the stationary sources in city of Tehran within 1998 and 2002.

The consumption of oil products are higher in cold months of a year; thus the air pollutants production is higher as well. As can be seen in Figure 5, the rate of pollution production is constant within the first six months of a year and then we are faced with a rising rate of pollution production until February. The pollution production is reduced a bit in March.

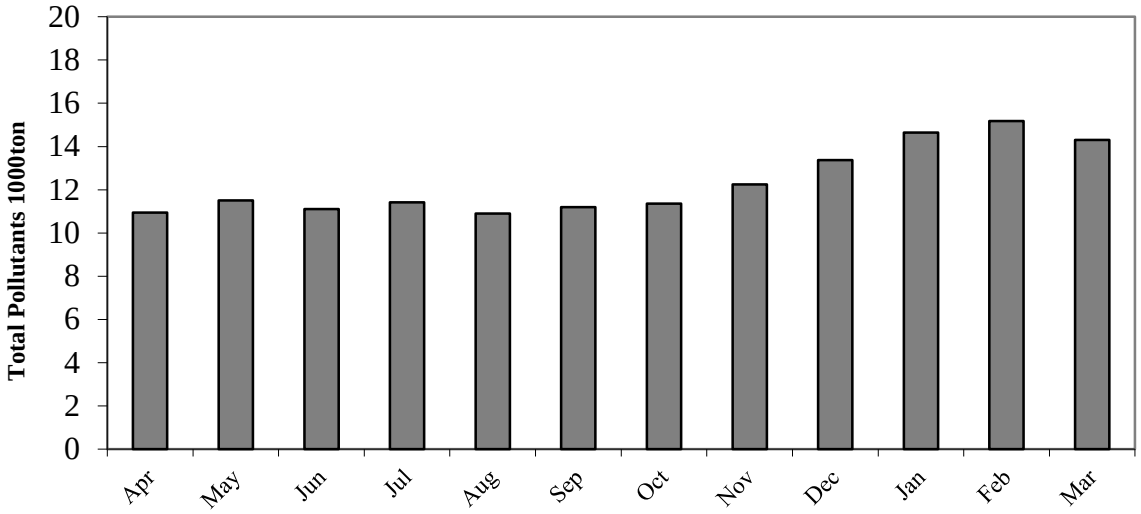

Figure 5. The total pollutants caused by stationary sources in Tehran in various months in 2002.

Examining the regional changes

As it can be observed in Figure 6, regions 20, 16 and 4 take the highest share of pollution production by the stationary sources among 22 regional planning in city of Tehran. Furthermore, with respect to the area of these regions and to obtain the rate of pollution, the regions of 20, 16 and 12 are identified as the most polluted zones. The main reason for these pollutions is the presence of power generation stations in these regions.

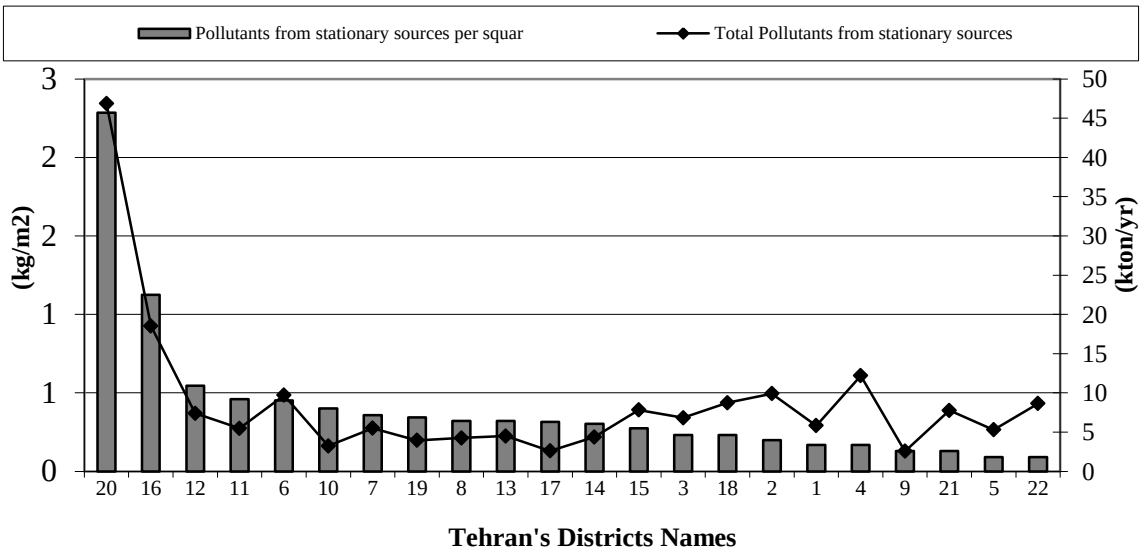

Figure 6. The share of Tehran's City Hall regions from the total pollutants caused by stationary sources in 2002.

CONCLUSIONS

The rate of production of solid particles is reasonably considered to be twice the particles smaller than 10 microns and the results can be compared between stationary and the mobile sources [7].

The rate of two kinds of pollutants produced was 1.920 kilotons in 2002 which 5.3 kilotons of pollutants are entered to the existing air of city of Tehran on a daily basis. By stationary sources, 526

tons of pollutants are emitted and 4735 tons daily by the mobile sources. In fact, 90% of the total weight of the pollutants is emitted by the vehicles in city of Tehran which means that the stationary sources include different kinds of applications in various regions, factories and industrial workshops, power stations and refinery include nearly 10% of the total air pollution caused by burning fuels.

Table 5. The percentage share of stationary and mobile sources in 2002.

Sources	Pollutants (ton/yr)					Total
	SPM	HC	CO	NOx	SO2	
Stationary sources	7,874	64,807	19,328	51,532	48,456	191,997
Mobile sources	38,871	155,033	1,419,326	107,016	7,991	1,728,237
Total	46,745	219,840	1,438,654	158,548	56,447	1,920,234
Production % by stationary sources	16/8	29/5	1/3	32/5	85/8	10/0
Production % by mobile sources	83/2	70/5	98/7	67/5	14/2	90/0
% share of the total pollution	2/4	11/4	74/9	8/3	2/9	100/0

Carbon monoxides form more than three forth of the weight of the air pollutants which 98.7% of that is related to vehicles and nearly half of this number belongs to LDVs and 20% emitted by motorcycles. The next pollutants are the hydrocarbons. More than 70% of this pollutant is released by the stationary sources which again both personal cars and motorcycles take equal share of 40% for the major parts of the air pollution production. Nitrogen oxides are next in this list that take the half of 67.5 % of the mobile sources produced by LDVs. The sulfuroxide take the share of 85.8% by the stationary sources higher than the mobile ones. The refinery, power stations, industry and the total residential units take a nearly 20% share of this major air pollution. The air floating particles are the last in this list with respect to the pollutants weight which in this case, the share of mobile sources is higher than the stationary sources. Nearly half the emitted floating particles of the mobile sources belong to LDVs.

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KEY WORDS

Source Apportionment
Urban Air Pollution
Emission Factors
Stationary and Mobile Sources