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Measurement of PM_{10}, $PM_{2.5}$ and TSP Particle Concentrations in Tehran, Iran

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Abstract: Short-term exposure sampling of fine particle ($PM_{2.5}$), coarse particle (PM_{10}) and Total Suspended Particle (TSP) has been carried out at different located in Tehran, the capital of Iran. Samples were collected from summer, to winter of 2005, in North (N), South (S), West (W), East (E) and center of Tehran. The daily monitoring site was located 2 m above ground near highway and main streets. One hundred and seventeen simultaneous sampling of the airborne particle matter (MS) were collected using a direct-reading instrument, the TSI Inc. model 8520 Dusttrack aerosol monitor. The 24 h average PM_{10}, $PM_{2.5}$ and TSP concentrations during the sampling period were 122.1, 24.3 and 239.8 μg m^{-3} respectively. Daily PM_{10} and TSP concentrations exceeded the National Ambient Air Quality Standard (NAAQS) of USA, for approximately 25.7 and 38.9% of the sampling days, respectively. Compared with NAAQS, the average $PM_{2.5}$ measured concentration (24.3 μg m^{-3}) in Tehran was lower. The results also showed that for north of Tehran, the average particle matter concentrations (153.1 μg m^{-3} for PM_{10}, 32.4 μg m^{-3} for $PM_{2.5}$ and 269.6 μg m^{-3} for TSP) were higher than other area. The average $PM_{2.5}/PM_{10}$ ratio for the five area were 0.19 compared to 0.15 to 0.25 reported by EPA. Three season monitoring data indicated that the average concentrations of PM_{10} in the winter (December to March), summer (Jun to July) and fall (November) were 116.4, 101.9 and 150.9 μg m^{-3}, respectively. $PM_{2.5}$ levels in the seasons also were 10.9, 21.32 and 12 μg m^{-3}, respectively. These results clearly confirmed the non-parametric analysis (Kruskal-Wallis test) PM_{10} ($p<0.001$), $PM_{2.5}$ ($p<0.001$) and TSP ($p = 0.114$).

Key words: Fine particle, coarse particle, particle matter, Urban air quality, Tehran, Iran

INTRODUCTION

Tehran with 7160097 population and a land area of 657 km^2, is the capital city of Iran and the center of Tehran province. The city is hemmed in by the Alborz Mountains to the north, causing the increasing volume of pollutants to become trapped, hovering over Tehran when the wind is not strong enough to blow the pollution away. Tehran's high altitude, ranging between 3300 and 5000 feet, also makes fuel combustion inefficient, adding to the pollution problem. Air pollution is the most serious of Iran' s environmental problems, especially in Tehran due to the combination of two natural and man-made factors. Research conducted in 1997 by the Tehran municipality involved the cooperation of two international organizations: the World Bank and Japan's international cooperation agency. The research provided an exact picture of the pollutant sources and their levels of responsibility for Tehran's notoriously poor air quality. The results of this research indicated that the densities of NO_2 and SO_2 in 1996 were below the standard limit determined by EPA, but reached twice that ceiling in 2000. The index of air pollution (PSI) also was reported as unhealthy for 252 days during 1999 and 282 days in 2002 (Anonymous, 1997). Thus, with regards to high volume of vehicular traffic and the industrialized area Suspended Particulate Matter (SPM) is a main pollutant and it may become a problem in cold seasons because of the topography of the city and meteorological conditions (Peimaneh, 2000). In urban areas, particulate air pollution is of particular interest for the possible delayed health effects associated with the continues exposure of a high-density population (Marcazzan *et al*., 2001; Harrison *et al*., 2001). High levels of Particulate Matter (PM) such as TSP and PM_{10}, have been reported during the period of 22 December 2001 to 20 April 2002 in the ambient air a general hospital district in Tehran (Kermani *et al*., 2003). Considering that 73% of air pollution in Tehran is produced by vehicle emissions. In recent years, several projects have been and are being, undertaken. Perhaps no other pollutants is as complex as particle pollution. Also called Particulate Matter (PM) that consists of a mixture of large materials, called coarse particles and smaller particles, called fine particles. The

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impact of particulate air pollution on human health has been known since the early 1950s (Lippman, 1989). Evidence from epidemiologic studies have shown that ambient concentrations of airborne Particulate Matter (PM) to increased respiratory and cardiovascular mortality and morbidity (USEAP, 2001; Katsouyanni *et al*., 1997; Norris *et al*., 1999; Schwaretz and Dokery, 1992; Pope *et al*., 1995; Goldberg *et al*., 2001). This implies an association between community exposure to PM of ambient origin and adverse health effects. The Environmental Protection Agency (EPA) adopted, in 1997 both 24 h and annual average PM_{10} and $PM_{2.5}$ standards, on the basis that $PM_{2.5}$ is the best currently available surrogate hazard index for the health effects associated with ambient air PM (USEPA, 2001). With the development of economy of Tehran in recent years, its particle pollution has increasingly become sever to the emissions from traffic vehicles and paved roods. Due to the particulate air pollution importance and its consequence especially in large cities like Tehran, we have carried out daily PM_{10}, $PM_{2.5}$ and TSP sampling, from summer to winter of 2005, in the 5 area of Tehran. Furthermore, in this study we gathering the data of meteorological variables from Islamic Republic of Iran Meteorological Organization (IRIMO). Finally, we use non-parametric analysis such us kruskal valis test and regression models to identify of particle concentrations and distribution of Particulate Matter (PM) in the areas and season.

MATERIALS AND METHODS

Sampling and analysis: PM_{10}, $PM_{2.5}$ and TSP was conducted in the five area of Tehran at the 24 sampling site. These airborne particulate sampling station were located on the busy street and nearby the traffic highways. Sampling was done for winter, fall and summer. The Particulate Matter (PM) was collected in the sampling station at a height of about 2 m above ground. Twenty-four hour particulate matter sampling were collected daily from summer to winter of 2005. A total of 117 the PM valid samples were taken during the study. Two kinds of samplers have been used during the 24 h simultaneous sampling.

PM_{10} and $PM_{2.5}$ measurements were collected using a direct reading instrument. The TSP sampling was carried out by gravimetric method on Whatman membrane filter of 25 mm with a pore size of 3.0 μm, using SKC sampling pump, which operated at a nominal flow rate of 0.00 to 10.000 L min^{-1} (Anonymous, 1996). The TSP was determined gravimetrically on pre-weighed and pre-conditioned filters conditioning consisted of an exposure of filters for 24 h at about 25°C constant humidity (around 50%). Before and after exposure, the filters were weighed using an analytical balance with a readied precision of ±10 μg. The direct reading instrument used in this study was TSI Inc. model 8520 Dusttrak aerosol monitor, which is a light scattering laser photometer with a laser diode directed at continuous aerosol stream. The Dusttrak was factory-calibrated to the repairable fraction of the International Organization for Standardization (ISO) 12103-1, A_1 Arizona test dust (ISO, 1997).

Statistical analysis: Statistical analyses were performed using SPSS version 11.3. The relationships between the PM meteorological variables were investigated significance of the differences between distribution of PM and seasons and months were tested with the non-parametric kruskal-walis test. Regression analysis models also were used to identify determinates of particulate matter concentrations.

RESULTS AND DISCUSSION

Particulate matter concentrations: Non-parametric tests indicated that the PM (PM_{10}, $PM_{2.5}$ and TSP), concentrations were log-normally distributed ($p<0.05$). The concentrations of PM_{10} was ranged from 153.1 μg m^{-3} at north to 81.8 μg m^{-3} at east of Tehran while that of $PM_{2.5}$ was ranged from 32.4 μg m^{-3} at north to 13.3 μg m^{-3} at east. The TSP concentration was ranged from 289.6 μg m^{-3} at north to 173.7 μg m^{-3} at east. The ratio of coarse particles (greater than 2.5 μ) make up the majority of aerosol (Table 1, 2). The annual arithmetic

Table 1: Summary of the PM loading at five area in Tehran

Area	N	PM_{10}	$PM_{2.5}$	TSP
		------------------ Mean±SD (max) (μg m^{-3})	----------------------	
N	117	153.1±64.7 (265)	32.4±13.5 (73)	289.6±144 (682)
S	117	120.4±47.0 (243)	24.6±14.7 (67)	242.3±120.4 (702)
E	117	81.8±19.8 (140)	13.3±8.8 (43)	173.7±70.2 (457)
W	117	119.3±58.8 (250)	23.1±20.4 (92)	244.7±157.4 (890)
C	117	133.0±52.1 (242)	27.4±11.9 (44)	243.2±68.8 (380)

N: North; S: South; E: East; W: West; C: Center; SD: Standard Deviation

Table 2: Particle matter distribution according to seasons in Tehran

Season	PM	Mean (μg m^{-3})	SD	Statistical significant (Kruskal walis test)
Winter	PM_{10}	116.45	45.10	S
	$PM_{2.5}$	19.35	10.90	S
	TSP	212.51	67.80	NS
	$PM_{2.5}/PM_{10}$	0.15	0.05	S
Summer	PM_{10}	101.96	54.00	S
	$PM_{2.5}$	38.59	21.30	S
	TSP	307.91	225.90	NS
	$PM_{2.5}/PM_{10}$	0.37	0.10	S
Fall	PM_{10}	150.98	65.80	S
	$PM_{2.5}$	24.35	12.00	S
	TSP	246.99	78.10	NS
	$PM_{2.5}/PM_{10}$	0.15	0.04	NS

SD: Standard Deviation; S: Significant; NS: Non-Significant; PM: Particle Matter mean PM_{10} concentration was 122.1 μg m^{-3}. This concentration is considerably higher than the NAAQS (1997) of 50 μg m^{-3} and the European Union air Quality annual PM_{10} standard of 40 μg m^{-3}, respectively. The non-parametric analysis of krus-wallis is indicated that distribution of PM_{10} in the seasons was significant ($p<0.011$). $PM_{2.5}$ concentrations also were log-normally distributed. The mean concentrations of $PM_{2.5}$ obtained for the locations was 24.3 μg m^{-3}, that very difference was found between the mean concentration for the winter and summer, 19.6 and 38.5 μg m^{-3}, respectively. Compared with the NAAQS of USA for particulate matter (65 μg m^{-3} for $PM_{2.5}$ over a 24 h period), the $PM_{2.5}$ concentration in Tehran were lower. The non-parametric test also indicated that distribution of $PM_{2.5}$ in the area of Tehran and the seasons were significant, $p<0.001$, $p<0.001$, respectively. The mean concentration of TSP obtained for the area of Tehran was 239.8 μg m^{-3}. TSP levels were found to be 212.5 and 307.9 μg m^{-3} in winter and summer, respectively. Similarly to PM_{10} and $PM_{2.5}$, distribution of TSP in the 5 area of Tehran was significant ($p<0.001$), but this distribution with regards to seasonal or monthly was not significant ($p<0.114$). Compared with the NAAQS of USA that know as the USEPA (2001), for total suspended particulates (260 μg m^{-3} for TSP over a 24 h period), the TSP levels in Tehran are clearly lower than the 24 h standards. But these high levels of TSP, especially in winter (307.9 μg m^{-3}), may be due to high density of road traffic in the Tehran.

Type of site: Previous studies indicated that particulate air pollution monitoring through a few fixed sites cannot give accurate exposure data of population (Han and Naeher, 2006; Kulkarni and Patil, 1999). Kulkarni and Patil (1999), studied the integrated exposure to respiratory particulate matter ($PM_{2.5}$) among 24 outdoor workers in India and found that indicated by single monitoring site data. Similarly, in the netter lands, both PM_{10} and $PM_{2.5}$ concentrations measured at a background site were 1.3 times lower than those observed near a busy road (Jansen *et al*., 1997).

Relationships between the PM concentrations: The monthly ratio of $PM_{2.5}/PM_{10}$ has little variability from 0.14 (February) to 0.3 (July). It indicates that coarse particles (greater than 2.5 microns) make up the majority of aerosol (Table 3). With regards to this results, the concentration of coarse particle (PM_{10}) in December was much higher than other months. Based on the, meteorological condition of Tehran, December is very importantly in inversion condition. In one study by USEPA (2001), the annual mean $PM_{2.5}/PM_{10}$ ratios measured in urban and semi-rural US areas were between 0.3 and 0.7. Similar to this study, low ratio of $PM_{2.5}/PM_{10}$ were observed in the semi-area western US, where a large fraction of PM_{10} consists of soil particles. Harrison *et al*. (2001) showed that $PM_{2.5}$ comprises about 80% of PM_{10} during the winter month (July), the $PM_{2.5}/PM_{10}$ ratio was high. We also evaluated the relationships between PM_{10}, $PM_{2.5}$ and TSP, respectively. During the study, the variations of 24 h simultaneous TSP and PM_{10} concentrations data were correlated ($R = 0.77$) and this correlation had statistically significant at confidence ($p<0.001$) (Fig. 1) The concentrations of PM_{10} were associated with $PM_{2.5}$ concentrations, with correlation matter, coefficient of 0.82. With regards to, levels of PM_{10} and TSP that exceeded the standard level such as WHO standards (WHO, 2000), these high levels of particle pollutant may be due to high density of road traffic in Tehran city.

Table 3: Monthly the PM concentrations and $PM_{2.5}/PM_{10}$ ratio in Tehran

Months	PM_{10}	$PM_{2.5}$	TSP	$PM_{2.5}/PM_{10}$
	Mean±SD (max)			
January	114.6±45.7 (217)	19.6±10.6 (49)	213.0±72.0 (380)	0.16
February	125.1±51.1 (242)	20.8±14.5 (47)	230.5±68.2 (321)	0.14
March	112.1±40.1 (242)	17.7±8.6 (38)	198.1±60.6 (319)	0.14
July	101.9±54.0 (250)	38.5±21.3 (92)	307.9±225.9 (890)	0.30
December	150.9±65.8 (265)	24.3±12.0 (44)	246.9±78.1 (380)	0.15

All concentrations expressed in μg m^{-3}

Relationships between the PM and meteorological parameters: The relationships between PM concentrations (PM_{10}, $PM_{2.5}$ and TSP) and wind speed indicated that the particle matters were negatively correlated with wind speed, $R = -0.3$, $R = -0.01$ and $R = -0.06$, respectively. As can be seen, the relationships between the PM_{10} concentrations and wind speed is not liner relationships (Fig. 2). In similar to this study, no relationship between wind speed and TSP concentration was also found in Hong Kong (Cheng and Lam, 1998). Investigators in Paris demonstrated lack of relationship between $PM_{2.5}$ concentrations measured near a highly trafficked road and wind speed values (Ruellan and Cachier, 2001). We also analyzed the PM data by the season and found significant differences between the periods (Table 2). As suggested by the results of the non-parametric test season is an important determinant of both PM_{10} and $PM_{2.5}$ and ratio of $PM_{2.5}/PM_{10}$, with season significant p-value of $p<0.011$, $p<0.001$ and $p<0.001$, respectively. The seasonal differences may be explained by either the higher PM_{10} emissions during the colder season (December), because this month having maximum inversion layers in Tehran. Similar observations have been seen in Santiago, Chile (Kavouras *et al*., 2001). In present study distribution of the PM (PM_{10} and $PM_{2.5}$) appeared in the kruskal-wallis test to be related to the

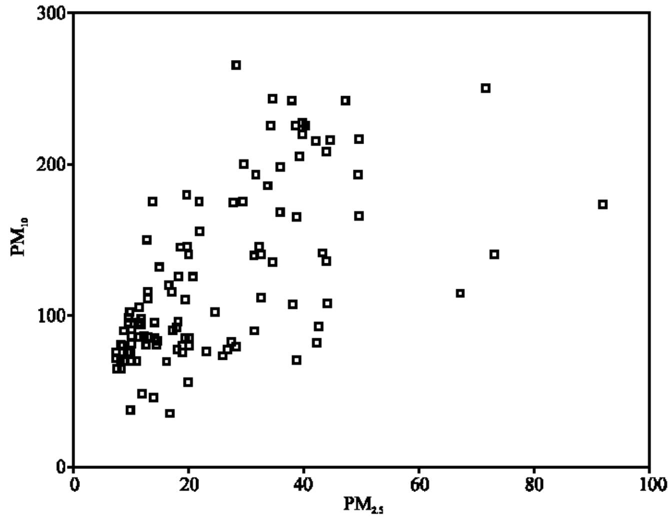

Fig. 1: Correlation of $PM_{2.5}$ and PM_{10} concentrations

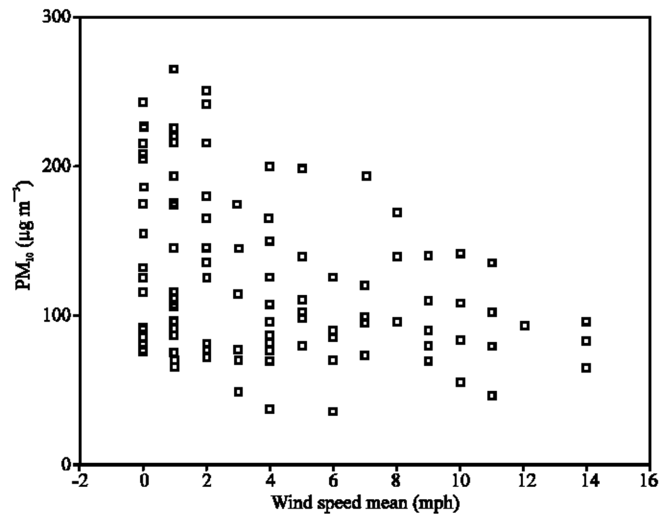

Fig. 2: Relationship between PM_{10} concentrations and wind speed

months (Table 3). The significant differences between the PM concentrations and months were found for PM_{10} ($p<0.05$), $PM_{2.5}$ ($p<0.001$) and $PM_{2.5}/PM_{10}$ ($p<0.001$), respectively.

CONCLUSIONS

The determination for the particle matter of PM_{10}, $PM_{2.5}$ and TSP during the winter, fall and summer 2005, in Tehran was conducted. Air sampling were collected at five area of Tehran. Compared with the NAAQS of the USA and European Union Air Quality Standard for PM, particle pollution of PM_{10} and TSP in Tehran was higher. Especially for PM_{10}, was more than two times the standards. The mean $PM_{2.5}$ concentration was considerably lower than the US EPA 24 h period $PM_{2.5}$ standard. With regards to results, TSP levels were found to be 239.8 $\mu g\ m^{-3}$ in the city areas. These high levels of pollutant may be due to high density of road traffic in the Tehran. It is important and we must keep in mind that particulate matter may have reached an alarming level considering many other streets with much higher traffic intensities than the street in which the fixed site was located. Prior studies also have suggested that air quality compliance measurements should be conducted at multiple monitoring sites within the city. In our study the average concentrations were based on measurements conducted at 24 sites located next to highly trafficked and frequently congested street. During the study the variation of 24 h simultaneous PM_{10} concentrations data with $PM_{2.5}$ and TSP concentrations were correlated and these correlation had statistically significant. On the basis of the results when the relative humidity and temperature were in the range of 38-49% and 46-53°F, respectively, especially on fall season and more importantly in inversion conditions of Tehran, the highest concentration of PM_{10} would be expected (Table 2, 3). The our results are in agreement with the fact that particulate matter especially the PM_{10} concentration above the Tehran basin during low wind periods.

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