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MASS CONCENTRATIONS OF TSP, PM_{10} AND $PM_{2.5}$ IN ERZURUM URBAN CENTER, TURKEY

Hanefi Bayraktar[1*], F. Sezer Turalioğlu[1] and Gürdal Tuncel[2]

[1] Atatürk University, Engineering Faculty, Department of Environmental Engineering, 25240, Erzurum, TURKEY, e-mail: hanefib@atauni.edu.tr (H. Bayraktar)
[2] Middle East Technical University Department of Environmental Engineering, 06531 Ankara, TURKEY, e-mail: tuncel@metu.edu.tr (G. Tuncel)

ABSTRACT

Impact of atmospheric particles on human health and visibility degradation in urban areas is well documented in the literature. We have initiated a program in Erzurum to measure Total Suspended Particles (TSP), PM_{10} and $PM_{2.5}$, simultaneously at one point for one year period. Sampling was started in February 1, 2005 and will continue to the end of January 2006. Data generated in the first six months of the study were presented.

Average TSP, PM_{10} and $PM_{2.5}$ concentrations measured during sampling period (February to July 2005) are 114.7 ± 103, 31.4 ± 24 and 14.2 ± 14 μg m^{-3}, respectively. The ratios of $PM_{2,5}$/TSP, PM_{10}/TSP, $PM_{10\text{-}2.5}$/TSP, $PM_{2.5}/PM_{10}$ and $PM_{10\text{-}2.5}/PM_{10}$ are 0.13, 0.29, 0.16, 0.42 and 0.58 respectively. With the 0.13 value, $PM_{2.5}$/TSP ratio is the lowest one and also the lowest value of the literature. When attributing the correlations of PM values measured during sampling period (February to July 2005), the correlations between TSP and PM_{10} and $PM_{10\text{-}2.5}$ are observed higher and the moderate correlation is found between TSP and $PM_{2.5}$ ($p<0.01$). This higher correlation is mostly seen between soil-sourced coarse particles and shows the same source of origination, however fine fraction ($PM_{2.5}$) has different source and therefore found as a moderate correlation ($p<0.01$).

Key Words: Air pollution, atmospheric particle, Total suspended particle, PM-10 fraction, PM-2.5 fraction, Erzurum

1. INTRODUCTION

Anthropogenic emissions leading to atmospheric aerosols which have been synonymous of modern industrial and technological development, have been implicated in human health effects; visibility reduction; acid deposition and in altering the Earth's radiation balance (Morawska, et.al., 1998).

Airborne particles vary in size form and chemical composition. They range in size from a few nanometers (10^{-9}m) up to tens of micrometers (10^{-6}m). The size of

particles can be described by means of their aerodynamical diameter. The aerodynamical diameter is the diameter of a spherical particle with a density of 1 g/cm³, which moves in relation to atmospheric air in a gravitational field at the same speed as the particle in question (Arya, 1999).

Generally, particles found in the air range in size from 0.001 μm to 100 μm. The size of the particles is of decisive importance to their physical behavior. Particles of less than 0.2 μm in diameter are normally called ultra fine particles. They consist of combustion products, sea salt nuclei, and end products from chemical reactions in the atmosphere involving ozone and VOCs. The smallest particles approach the size of large gas molecules. Particles that range from 0.2 μm to 2.5 μm in diameter and consist of fumes and dust are normally called fine particles. Particles larger than 2.5 μm are generally called coarse particles. They mainly consist of fungal spores, pollen and particles generated through natural processes such as wind erosion and volcanic activities. In principle, particles with an aerodynamic diameter below 5 μm follow the motion of the air and may remain suspended for days in ambient air.

Larger particles, with an aerodynamic diameter of over 10 μm, are removed within a matter of hours either by settling or by rain. Particles may be measured based on weight, numbers or chemical content. Total suspended particles (TSP - $\mu g/m^3$) is the total weight of particles per volume of air and $PM_{2.5}$ and PM_{10} (particles with a diameter less than 2.5 μm and 10 μm, respectively) are the total weight of particles with diameters less than indicated by the subscripts per volume of air (EPA, 1996).

Given that PM is emitted into the atmosphere by a number of anthropogenic and natural sources, the physical and chemical patterns may vary considerably. Both natural and anthropogenic emissions supply primary (direct emission of PM) and secondary (formed from gaseous precursors) PM. On a global scale, PM emissions reach 3400 million tones/yr. Anthropogenic sources account for only 10% of total PM emissions, whereas the natural primary PM emissions reach 85% (2900 million tones/yr).

Although these figures change drastically on a local scale, natural emissions may interfere considerably in the PM monitoring around large natural PM emission sources (mainly arid and semiarid regions) such as the Mediterranean basin (Querol et.al., 2001).

Airborne particulate matter influences Earth's radiative balance, visibility, and human health. A number of epidemiological studies (Schwartz et al., 1996) have demonstrated that atmospheric particulate matter (PM) in urban areas has a clear correlation with the number of daily deaths and hospitalizations as a consequence of pulmonary and cardiac disease responses.

These studies show that measurements of thoracic and alveolar particles (PM<10 and <2.5 mm, respectively) correlate better with morbidity and mortality than total suspended PM (TSP). Recent establishment of $PM_{2.5}$ standards in the US have attracted everyone's attention to these fine fraction particles. If the new $PM_{2.5}$

standards prove themselves worthy, EU and other countries around the world will probably switch from PM_{10} to $PM_{2.5}$ standards in the near future.

Turkey, in the process of accession to EU will have to adopt and enforce EU air quality directives. Fair amount of information on the levels of PM_{10} and $PM_{2.5}$ in Turkish cities is necessary to be able to foresee the problems that will arise when new standards are adopted. However, such data is extremely scarce in most Turkish cities.

2. EXPERIMENTAL

2.1. Sampling site and period

Erzurum is located in the eastern part of Turkey and is one of the most important winter tourism centers in the country. It is surrounded by high mountains: the Gavur-Dumlu mountains (3200 m) to the north, Dumanlı-Palandöken (3125 m) to the south and Eğerlidağ (2974 m) to the east. The latitude of the city is 1950 m and it has a population of 402570 inhabitants. Since Erzurum is one of the coldest cities of Turkey, residential heating continues for at least six months in a year. With limited industrial activity, the main sources of air pollution are domestic heating and urban traffic. Average wind speed decreases from 3.3 m s^{-1} in summer to 2.2 m s^{-1} in winter.

Unfavorable topographical and meteorological conditions result in frequent inversions and subsequent pollution episodes in Erzurum, particularly during long and cold winter season.

In this study, 354 daily PM samples of TSP, fine (<2.5 μm) and coarse (2.5-10 μm) particles were collected at the garden of Erzurum Regional Directorate of Highways (see Figure 1), according to a new approach for sampling location, during February to July 2005 (Bayraktar et.al., 2005).

The sampling site is appropriate for the EPA criteria, and referred as the point reflecting the profile of the city pollution, because of its homogenous structure similar to the basic pollution sources of the city, such as the exhausted gases and the emissions of the fossil fuels used in domestic heating; and its distances far enough away from both local pollution sources and more than 150 m from main roads at north. It has also 1955 m altitude closer to the average city altitude (1950 m).

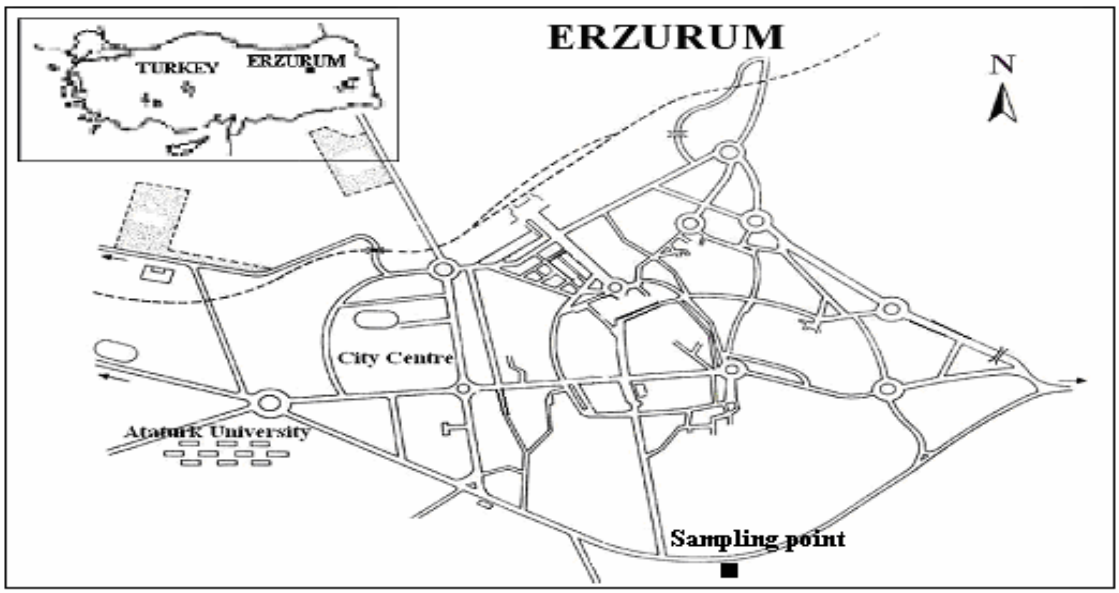

Figure 1. Study area

2.2. Sampling Method

A dichotomous 244 sampler (Anderson sampler) and low-volume sampler (Tecora TCR PM sampler) were used to collect three ranges of PM samples (TSP, PM_{10}, $PM_{2.5}$). Dichotomous sampler has an inlet with PM_{10} cut-off, which collects only particles smaller than 10 µm. The particles are then size-segregated by means of virtual impaction, into fine particles smaller than 2.5 µm and coarse particles between 2.5 and 10 µm ($PM_{2.5–10}$). The particles are collected on Ø37 mm Teflon membrane filters with a 2 µm pore size, which are recommended for gravimetric determination of particulate matter. The sampling flow rate used was 1 m^3/h. Before sampling, the Teflon membrane filters were placed into a desiccator at room temperature in open plastic Petri dishes for at least 24 h to reach a constant humidity. Afterwards, they were weighed with a five digit sensitive balance. The sample collection period was 24 h for all collected samples. After sampling, the filters were transferred to the laboratory. They were placed in the desiccator again for 24 h, and then weighted under exactly the same conditions as the empty filters. For each sample, three repeated weight determinations were performed and the average was reported.

3. RESULTS AND DISCUSSION

3.1. Mass Concentrations of $PM_{2.5}$, $PM_{2.5-10}$, PM_{10}, TSP

In the sampling period (from February to July 2005), the average concentrations of TSP, PM_{10} and $PM_{2.5}$ were 114.7, 31.4, 14.2 and standard deviations were 102.6, 24, and 13.8, respectively. Descriptive statistics of PMs measured in all sampling period are shown in Table 1.

Table 1. Descriptive statistics of PMs measured in sampling period

	N	Max	Min	Mean	Standard Dev.
TSP ($\mu g/m^3$)	102	435	16	114,7	102,6
PM_{10} ($\mu g/m^3$)	115	93	4,7	31,4	24
$PM_{10-2.5}$ ($\mu g/m^3$)	115	73	0,4	17,2	16
$PM_{2.5}$ ($\mu g/m^3$)	115	65	1	14,2	13,8

The descriptive statistic results of measured PM data at the heating period, between February and April, and at the non-heating period from April to July are also given at Table 2. As can be seen, all of the maximum values and maximum standard deviations of parameters are observed in winter months, however all minimum PM values and minimum standard deviations are seen in summer months. Some meteorological parameters (wind speed, temperature, precipitation etc.) are more effective during winter season, and so the standard deviations of PM values become higher at this season.

Table 2. The descriptive statistic results of measured PM data at the heating period and at the non-heating period

	N		Max		Min		Mean		Standard Dev.	
	Feb-Ap	Ap-July	Feb-Ap	Ap-July	Feb-Ap	Ap-July	Feb-Ap	Ap-July	Feb-Ap	Ap-July
TSP ($\mu g/m^3$)	67	35	435	334	26	16	134,7	76,5	115,3	56,1
PM_{10} ($\mu g/m^3$)	79	36	93	70	5,4	4,7	37,8	17,5	25,4	12
$PM_{10-2.5}$ ($\mu g/m^3$)	79	36	73	61	0,4	1,4	19,2	13	17,8	10,3
$PM_{2.5}$ ($\mu g/m^3$)	79	36	65	21,1	3	1	18,6	4,5	14,4	3,7

PM correlations which are measured during sampling period are given in Table 3. When attributing the correlations of PM values during sampling period, the correlations between TSP and PM_{10} and $PM_{10-2.5}$ are observed higher and the moderate correlation is found between TSP and $PM_{2.5}$ ($p<0,01$). This higher correlation is mostly seen between soil-sourced coarse particles and shows the same

source of origination, however fine fraction ($PM_{2.5}$) has different source and therefore found as a moderate correlation.

Table 3. PM correlations measured during sampling period

	TSP	PM_{10}	$PM_{10-2.5}$	$PM_{2.5}$
TSP	1			
PM_{10}	0,938	1		
$PM_{10-2.5}$	0,906	0,837	1	
$PM_{2.5}$	0,583	0,769	0,293	1

On the other hand, in order to seen seasonal (heating period and non-heating period) correlations between TSP, PM_{10}, $PM_{10-2.5}$ and $PM_{2.5}$, Table 4 is created. It was observed that although the correlations during winter season are generally higher and that during summer season is lower.

Table 4. The seasonal correlations of PMs

	TSP		PM_{10}		$PM_{10-2.5}$		$PM_{2.5}$	
	Feb- Ap	Ap-July	Feb- Ap	Ap-July	Feb- Ap	Ap-July	Feb- Ap	Ap-July
TSP	1	1						
PM_{10}	0,956	0,870	1	1				
$PM_{10-2.5}$	0,918	0,937	0,869	0,963	1	1		
$PM_{2.5}$	0,567	0,394	0,735	0,737	0,304	0,527	1	1

3.2. Ratios between $PM_{2.5}$, $PM_{2.5-10}$, PM_{10} and TSP

Table 5 shows the maximum, minimum and mean ratio of PMs measured during sampling period. $PM_{2,5}$/TSP, PM_{10}/TSP, $PM_{10-2.5}$/TSP, $PM_{2.5}$/PM_{10} and $PM_{10-2.5}$/PM_{10} ratios are 0.13, 0.29, 0.16, 0.42 and 0.58 respectively. With the 0.13 value, $PM_{2.5}$/TSP ratio is the lowest one and also the lowest value of the literature

Table 5. Maximum, minimum and mean ratio of PMs measured during sampling period

	Mean	Max	Min
$PM_{2,5}$/TSP	0,13	0,45	0,01
PM_{10}/TSP	0,29	0,87	0,13
$PM_{10-2.5}$/TSP	0,16	0,55	0,01
$PM_{2.5}/PM_{10}$	0,45	0,93	0,07
$PM_{10-2.5}/PM_{10}$	0,58	0,93	0,07

The seasonal ratios of PMs are also given at Table 6. The ratio of the coarse fraction ($PM_{10-2.5}$) inside the PM_{10} is 0.49 in winter months, and increases to 0.68 in the summer period, while soil is uncovered from snow. $PM_{2.5}/PM_{10}$ ratio is averagely 0.51 and maximally 0.93 in winter months and this ratio is averagely 0.32 and maximally 0.70 in summer season. These ratios show that the main source of $PM_{2.5}$ is heating and there is only a small effect of traffic on $PM_{2.5}$. $PM_{2.5}$ which is commonly emitted by burning during winter season constitutes maximally 0.45 of TSP, whereas this value drops to 0.01 during summer periods. $PM_{10-2.5}$ and PM_{10} ratios inside TSP observed during winter season are 0.14 and 0.29, respectively. These values confirm that the main source of coarse fractions is not burning. The dominant size of atmospheric particles in Erzurum is in coarse mode (PM_{10}/TSP=0.29) and the ratio of fine fraction inside the total atmospheric particles only is15 %.

Table 6. The seasonal ratios of PMs

	Mean		Max		Min	
	Feb- Ap	Ap-July	Feb- Ap	Ap-July	Feb- Ap	Ap-July
$PM_{2,5}$/TSP	0,15	0,11	0,45	0,32	0,03	0,01
PM_{10}/TSP	0,29	0,29	0,87	0,85	0,17	0,13
$PM_{10-2.5}$/TSP	0,14	0,18	0,55	0,41	0,01	0,08
$PM_{2.5}/PM_{10}$	0,51	0,32	0,93	0,70	0,18	0,07
$PM_{10-2.5}/PM_{10}$	0,49	0,68	0,82	0,93	0,07	0,30

Furthermore, when comparing the mean values of the literature and this study, the ratio of $PM_{2.5}/PM_{10}$ in Erzurum is averagely 0.45 and this ratio is 0.71 in Duisburg, Germany in 2001 and 0.47 at the same city in 1999. Another study done in Hong Kong in 2003 has found $PM_{2.5}/PM_{10}$ ratio as 0.61 averagely. The comparison of the observed values in this study with data in the literature are given at Table 7.

Table 7. The comparison of this study with the literature values

Study Area	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	TSP ($\mu g/m^3$)	$PM_{2.5}/PM_{10}$	$PM_{2.5}$/TSP
This study	14	31	114,7	0,45	0,13
Duisburg, Almanya (John et al. 2001)	32	45		0,71	
Duisburg, Almanya (Kuhlbusch, et al. 1999)	8	17		0,47	
Hong Kong, (Ho et al. 2003)	51	84		0,61	
Qalabotjha, Güney Afrika (Engelbrecht et al. 2001)	84	90		0,93	
Raahe, Finlandiya (Oravisjarvi et al. 2003)	10	17		0,59	
Buenos Aires, Arjantin (Bogo et al. 2003)	37	48		0,77	
Yellow Sea, South Korea (Lee et.al., 2002)	18,7		37,2		0,50
İstanbul, Turkey (Karaca et.al. 2005)	21	47		0,45	

As seen in Table 7, this study and other studies done in Istanbul and Europe have closer values, however, the values measured in Argentina and South Africa are different than Erzurum. This can be attributable to the selection of sampling location, green parks, contents of fossil fuels, exposure to the industrialization and traffic pollutions.

4. CONCLUSIONS

The arithmetic mean of PM_{10} (31.4 $\mu g\ m^{-3}$) in sampling period was found to be lower than Turkish air quality standard of 60 $\mu g\ m^{-3}$. On the other hand, this value was also found to be lower than the European Union air quality annual PM_{10} standard of 40μgm^{-3}. But the mean concentration of $PM_{2.5}$ in this study is higher than United States EPA annual $PM_{2.5}$ standard of 15 $\mu g\ m^{-3}$.

There are statistically significant relationship between $PM_{2.5}$, PM_{10} and TSP at the 99% confidence level. The correlations between TSP and PM_{10} and $PM_{10\text{-}2.5}$ are 0.938 and 0.906 respectively and the correlation between TSP and $PM_{2.5}$ is found as 0.583. This shows the dominant mode of Erzurum atmosphere as coarse mode. However, fine fraction ($PM_{2.5}$) emitted by burning during winter months are also important in Erzurum atmosphere. Other way, the ratios of $PM_{2.5}$/TSP and PM_{10}/TSP

in heating season (February-April) are 0.15 and 0.29 and, in un-heating season (April-July) are 0.11 and 0.29 respectively.

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