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STATISTICAL ANALYSIS OF INHALABLE (PM_{10}) AND FINE PARTICLES ($PM_{2.5}$) CONCENTRATIONS IN URBAN REGION OF PATRAS, GREECE

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ABSTRACT

In this study, the relationship between inhalable particulate (PM_{10}), fine particulate ($PM_{2.5}$), coarse particles ($PM_{2.5-10}$) and meteorological parameters such as temperature, relative humidity, solar radiation, wind speed was statistically analyzed and modeled for the urban region of Patras during winter-spring of 2005-2006. Ambient air quality was monitored with a sampling frequency of twenty-four hours at three monitoring sites ("A", "B", "C") , covering a period of four months from December 2005 to March 2006. The monitoring sites were located near highly trafficked and congested areas. The 24-h average PM_{10} were measured using a FH 62-I-R in the fixed station "A", and "B", and a Teccora low-volume samplers in the site "C". The 24-h average $PM_{2.5}$ was measured in "A", "B", "C" sites using Teccora low-volume samplers. Meteorological parameters such as temperature, relative humidity, solar radiation, and wind speed were also recorded during the sampling period. It was found that approximately 36% of PM_{10} concentrations were exceeding the standard value of 50 $\mu g\ m^{-3}$. The ratios between $PM_{2.5}$ and PM_{10} were found to be in the range of 0.49 to 0.86 and the highest ratio was found in the most polluted urban site. Concentrations of PM_{10}, and $PM_{2.5}$ showed temporal and spatial variations during winter-spring. Statistical analyses have shown a strong positive correlation between PM_{10} and $PM_{2.5.}$ The highest correlation (0.98) was obtained between PM_{10} and $PM_{2.5}$ at station "A" followed by 0.97 at station "B" and 0.54 at station "C". The negative correlation was observed between particulate matter (PM_{10} and $PM_{2.5}$) and wind speed. Finally, a regression equation for PM_{10} and $PM_{2.5}$ and meteorological parameters were developed.

KEYWORDS: PM_{10}, $PM_{2.5}$, $PM_{2.5-10}$, statistical analysis, correlation, urban air pollution.

1. INTRODUCTION

The atmospheric aerosol is a highly dynamic system that affects our lives in multiple ways. Recently, adverse health effects of high atmospheric particle loading have been in the focus of scientific interest (Wallace, 2000).

Health effects are biologically expected to be associated with particles less than 10 µm, which are passing the nose and entering lung alveoli (Monn Ch. *et. al.*, 1995, Dockery *et al.*, 1992, 1993, Pope *et al.*, 2002). The impact of ambient particles on human health has been known since the early 80s (Lippmann, 1989). Over the last two decades many epidemiological studies have been conducted around the world that observing associations between ambient particle concentrations and excesses in daily mortality and morbidity (Katsouyanni *et al.*, 1997).

The health effects range from increased incidences of pneumonia and asthma, exacerbation of chronic obstructive pulmonary diseases, increased respiratory symptoms and decreased lung function, to an increased mortality rate (USEPA, 1995). The findings of the epidemiological studies around the world have underlined the importance of ambient particles and the need for monitoring PM_{10} (inhalable particles) and $PM_{2.5}$ (fine particles). It is assumed that PM_{10} represents anthropogenic pollutants, while the origin of the coarser ones (>10μm) are mainly natural.

The objectives of the present study were to collect baseline data of PM_{10} and $PM_{2.5}$ from a selected area of study, to assess the fraction of $PM_{2.5}$ within PM_{10} and its temporal and spatial variation and to analyze correlation, in terms of regression analysis, between air pollutants and meteorological parameters in the urban region of Patras city.

2. MONITORING AND ANALYSIS

2.1. Description of study area

Patras (alt. 12 m from the sea level, N $38^{0}14.785'$, E $21^{0}44.180'$) is one of the highest in traffic density cities in Greece. It is surrounded by sea from SSW to NNE clockwise and by high mountains on the remaining sides. The population of the city and surrounding area counts more than 200.000 inhabitants.

The climate of Patras is Mediterranean with hot, dry summer and wet, mild winter. Patras city is located in coastal area and influenced by sea-based disturbances. The sea-breeze tends to stratify the atmosphere, mainly, above the south side of the city, trapping air pollutants in a relatively small height above ground. Significant chemical transformations of photochemical precursors may also occur on the course of circulation.

The main pollution sources in the city of Patras are traffic, central heating, emissions from harbor and the relatively small number of industries operating in suburban areas. The central heating, if only the cold period (11th to 4th) is considered, becomes the most important pollution source of sulfur dioxide (SO_2). Most of the industrial units are located in the industrial area (~18 km south-southwest of Patras), while a major cement factory operates at a distance of ~16 km in the north-east of Patras.

Three monitoring sites (A, B, C) were selected (in the busiest urban agglomeration) in order to measure PM_{10} and $PM_{2.5}$ concentration. The air quality monitoring stations are shown in Figure 1. The station in the Sq. Drosopoulou (Loc.“A”) and Sq. George (Loc.“B”) are installed in the frame of “Integration of the Infrastructure of the Greek National Monitoring Network of Atmospheric pollution”. The stations operated continously, taking measurements (every ten minutes) of the key pollutants (e.g. CO, SO_2, NO, NO_2, O_3, PM_{10}). In the table 1 the reasons for selecting these areas are better explained.

The meteorological station (“D“) was located in the county building which is very close to the air quality monitoring stations. The station operated continuously taking measurements (every ten minutes) of temperature, relative humidity, solar radiation, wind speed and wind direction. The location of meteorological station (“D”) is shown in Figure 1.

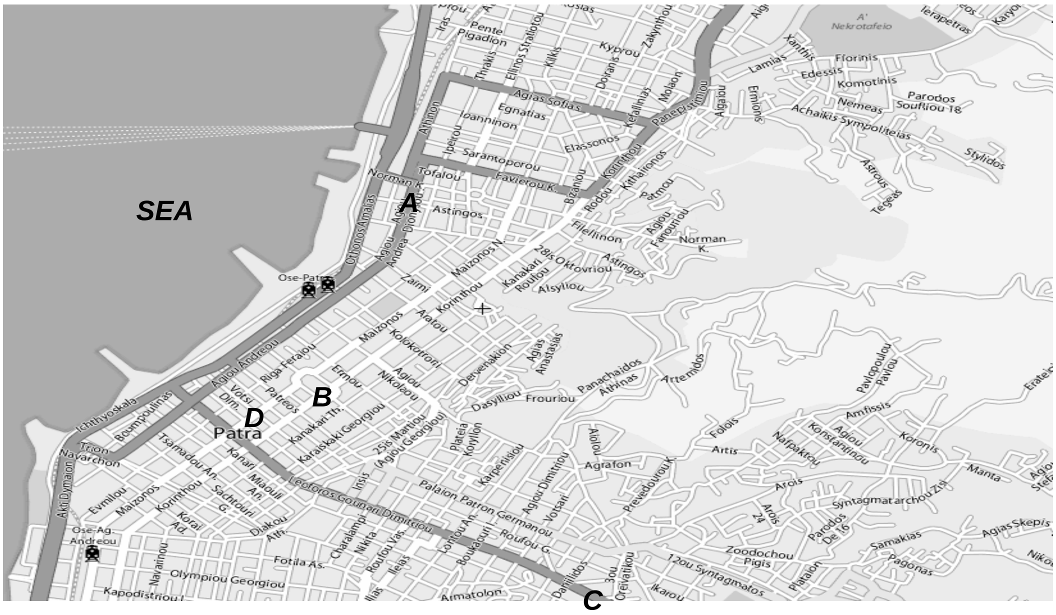

Figure 1. Location of monitoring sites in the study area (“A”: Square Drosopoulou, “B”: Square George and “C”: Square Marouda) and the meteorological station “D”

Table 1. Justification of air quality monitoring stations.

Site Index	Location	Land use	Road Gradient	Type
“A”	Square Drosopoulou	Residential / Port	Flat	High traffic density
“B”	Square George	Commercial / Residential	Flat	High traffic density
“C”	Square Marouda	Residential	Flat	High traffic density

2.2. Collection and analysis of particulate matter

PM_{10} (inhalable particles) and $PM_{2.5}$ (fine particles) were measured in the three monitoring stations from December 2005 to March 2006. FH 62-I-R and portable Teccora low-volume Sampler were used for collecting PM_{10} in “C” and $PM_{2.5}$ in “A”, “B”, “C” at average flow rate of 38.0 l m^{-1}. The PM_{10} and $PM_{2.5}$ samples were collected on pre-weighed glass fiber filters (GF/A), as per the most widely recommended (IS 5182 – Part IV, 1999) technique. The measurements PM_{10} in site “C” and $PM_{2.5}$ at each monitoring site “A”, “B”, “C”, have been covered at least once in a week and the sampling period was twenty-four hours.

3. RESULTS AND DISCUSSION

75 samples were collected during the study period from December 2005 to March 2006 from three different sites (“A”, “B”, “C”) for $PM_{2.5}$ and 25 from “C” for PM_{10}. A blank control procedure for particulate sampling was performed, the result of which showed high accuracy of sampling in most cases. The initial and final weights of the blank sampler mounted at one of the sites were almost the same and within the permissible measurement error. Only in few cases final weight was slightly higher, with maximum difference of 0.15%.

3.1. Frequency distribution of PM_{10} and $PM_{2.5}$ concentrations

The frequency distributions of PM_{10} concentrations in intervals of 10 µg m^{-3} are shown in Figure 2. A peak in the distribution of PM_{10} concentrations occurred at 30 to 60 µg m^{-3}. Approximately 34.7% of PM_{10} concentrations (n=75) were below 40 µg m^{-3}, 64% below 50 µg m^{-3}, and 93.3% below 70 µg m^{-3}. Approximately 36% of PM_{10} concentrations were exceeded the standard value of 50 µg m^{-3}, as compared with the standard given in Table 2.

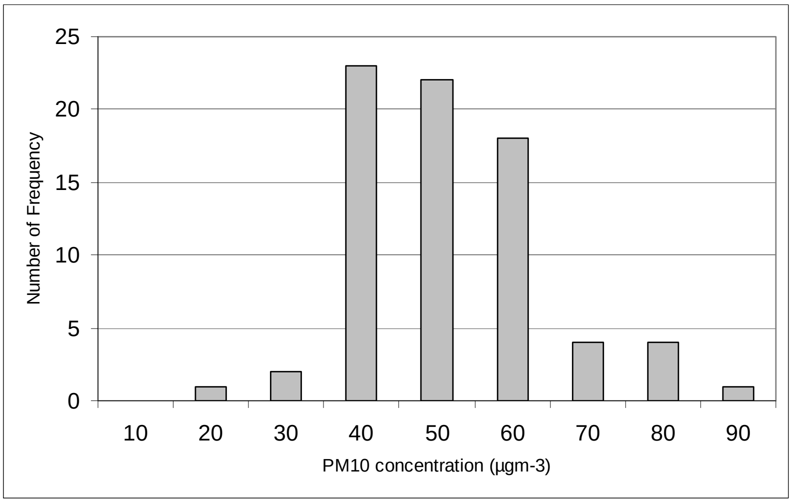

Figure 2. Frequency distribution of PM_{10} concentration (µg m^{-3})

Table 2. National Ambient Air Quality Standards *(1999/30/EK)*

Time weighted average	**PM_{10}**
Annual average	40 μg m^{-3}
24 h average	50 μg m^{-3}

On the other hand, the peak for the $PM_{2.5}$ concentrations was between 20 to 40 μg m^{-3} and is shown in Figure 3. Approximately 20 % of $PM_{2.5}$ concentrations (n=75) were below 20 μg m^{-3} and 86.7 % below 40 μg m^{-3}.

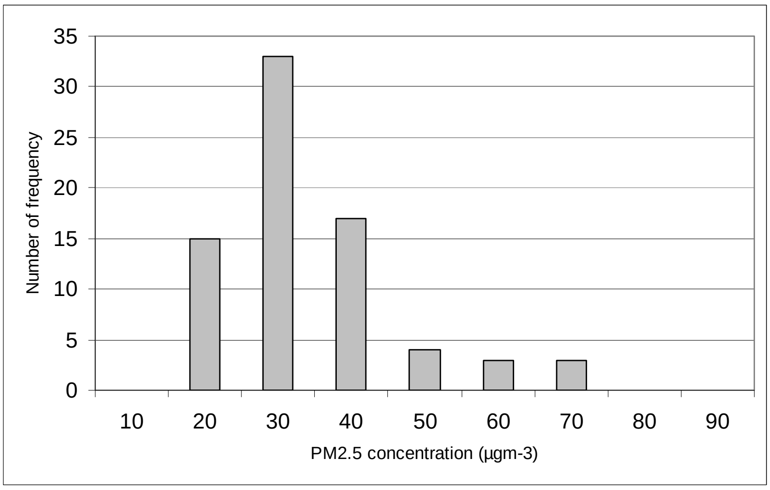

Figure 3. Frequency distribution of $PM_{2.5}$ concentration

3.2. Temporal Variation of PM_{10} and $PM_{2.5}$

The daily PM_{10} and $PM_{2.5}$ average concentrations for all the sites are presented in Figure 4 and 5 respectively. The average concentrations of PM_{10} and $PM_{2.5}$ for all the sites during the study period were 46.9±12.4 μg m^{-3} and 30.02±12.01 μg m^{-3}. The maximum and minimum concentration of PM_{10} was 84.31 μg m^{-3} and 14 μg m^{-3} in the month of March. The maximum and minimum concentration of $PM_{2.5}$ was 67.82 μg m^{-3} and 12 μg m^{-3} in the month of March and February.

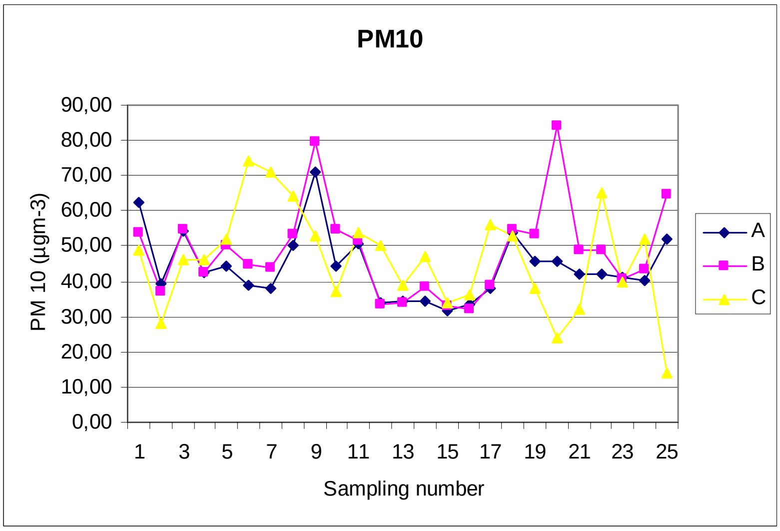

Figure 4. Daily PM_{10} average concentration for all the sites

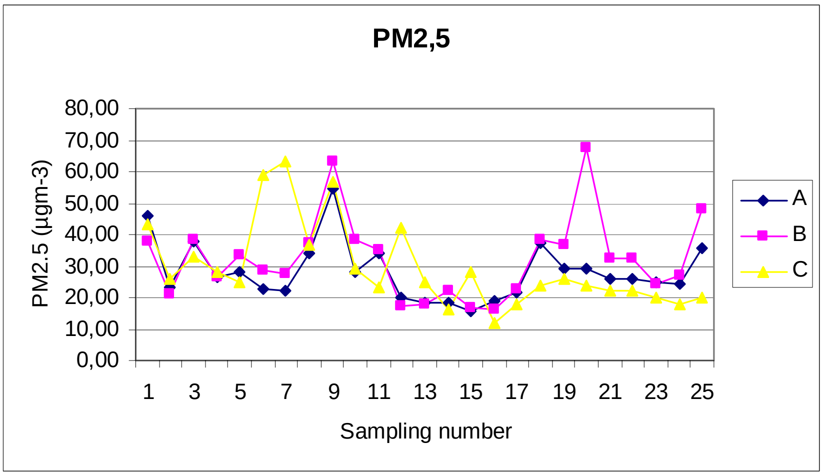

Figure 5. Daily $PM_{2.5}$ average concentration of all the sites

3.3. Spatial Variation of PM_{10}, $PM_{2.5}$ and $PM_{2.5-10}$

Figure 6 presents the average concentrations of PM_{10} and $PM_{2.5}$ at all the three monitoring sites during the study period. The ratio of highest to lowest concentration of all sites varies from 2.0 to 5.3 for PM_{10} and 3.5 to 5.25 for $PM_{2.}5$. The ratio of $PM_{2.5}/PM_{10}$ was the highest at the site A (0.85). This may be due to the heavy and general operations of the port. The ratio of $PM_{2.5}/PM_{10}$ was lowest at the site C (0.32). The concentration of $PM_{2.5-10}$ was about 39% of PM_{10} concentration. The ratio of $PM_{10-2.5}$ /PM_{10} was highest at C (0.68) in the month of February, while the lowest was at B (0.21) during the month of December.

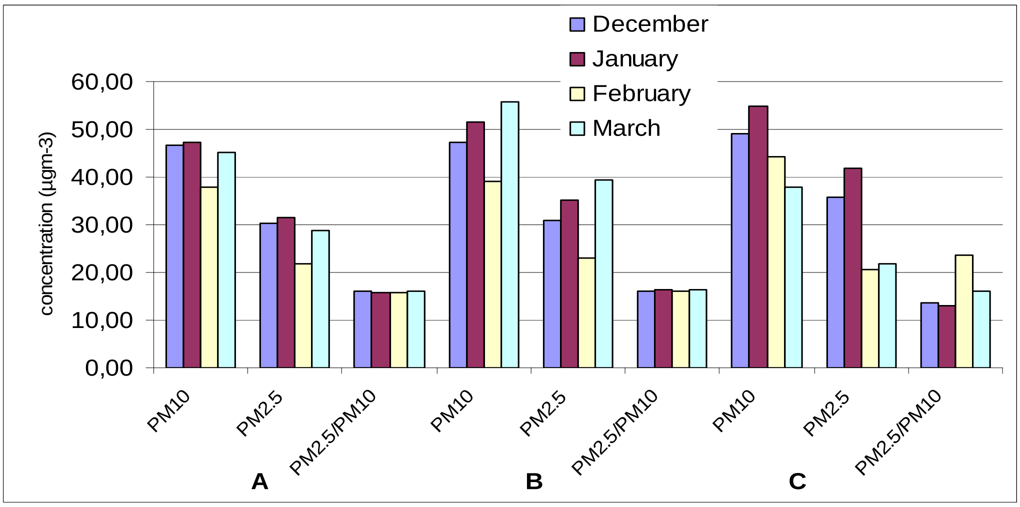

Figure 6. Concentrations of PM_{10}, $PM_{2.5}$ and $PM_{2.5-10}$ at all the three monitoring sites

3.4 Relationships between PM_{10}, $PM_{2.5}$ and $PM_{2.5-10}$

Results from recent studies have shown that PM_{10} in urban locations is mainly composed of fine particles. The particle size analysis shows that concentration of $PM_{2.5}$ is about 62% of PM_{10} concentration for all the three sites. That is in agreement with previous studies, such as Harrison *et al.* (1997) that found that in Birmingham approximately 60% of PM_{10} was $PM_{2.5}$ and Clarke *et al.* (1999) reported that 60-70% of urban PM_{10} mass is typically in the $PM_{2.5}$ fraction and 50% in the $PM_{1.5}$.

The $PM_{2.5}/PM_{10}$ value had shown large variability, and ranged from 0.32 to 0.85. This suggests that the contributions of $PM_{2.5-10}$ (coarse particle) and $PM_{2.5}$ (fine particles) to PM_{10} are not similar. Similar results have been reported in a large number of urban and semi-rural US areas where annual mean $PM_{2.5}/PM_{10}$ ratios varied between 0.3 and 0.7 (USEPA, 2001).

This is expected, since both fine (primary and secondary particles) and coarse particles (road dust re-suspension, which is enhanced in dry winter climates) are associated with local traffic.

3.5. Correlation between Particulate Data Sets

Figure 7 shows the scatter plots of $PM_{2.5}$ concentration against that of PM_{10} concentration. The Figure indicates that these two parameters are highly related to one another with a linear relationship. The least-square regression line for the daily data gave the following equation:

$$[PM_{2.5}]= 0.779[PM_{10}] – 6.0767 \qquad [R^2 = 0.6515] \qquad (1)$$

The regression Equation (1) obtained by using the data for all the monitoring sites. The above equation reveals that the PM_{10} concentration increases with increasing $PM_{2.5}$ concentration.

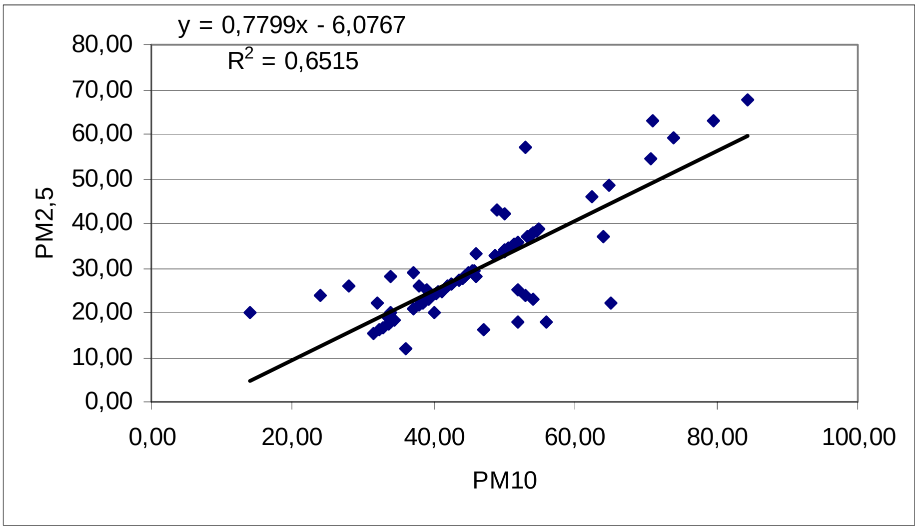

Figure 7. Scatter plots of $PM_{2.5}$ concentration against that of PM_{10} concentration

Correlation analyses of the data have been carried out using Spearman rank correlation coefficient from the commercial package SPSS (SPSS, 2003). Table 3 shows the correlation between PM_{10} and $PM_{2.5}$ data sets during the study period. The results showed that PM_{10} and $PM_{2.5}$ were strongly correlated for sites A and B while a satisfied correlation was found for site “C”. The highest correlation (0.98) was obtained between PM_{10} and $PM_{2.5}$ for the “A” site, while 0.97 for the site “B” and 0.55 for the site “C”.

Table 3. Spearman rank correlation coefficient for particulate data

	PM10-(“A”)	**PM10-(“B”)**	**PM10-(“C”)**	**PM2,5-(“A”)**	**PM2,5-(“B”)**	**PM2,5-(“C”)**
PM10-(“A”)	1.00					
PM10-(“B”)	0.76333	1.00				
PM10-(“C”)	0.04988	0.15677	1.00			
PM2,5-(“A”)	0,98741	0.75713	0.04900	1.00		
PM2,5-(“B”)	0.76333	0.97100	0.15677	0.75713	1.00	
PM2,5-(“C”)	0.31793	0.21407	0.54355	0.32395	0.21407	1.00

Correlation is significant at the 0.01 level.

PM_{10} refers to inhalable particle data sets, $PM_{2.5}$ refers to fine particle data sets at the square Drosopoulou (Loc. “A”) near the port, in central square George (Loc. “B”) and Square Marouda (Loc. “C”) (Figure 1).

3.6 Influence of Meteorological parameters on Particulate matter

The air quality varies at any place from time to time, though the source emissions are constant, because the dynamics of the atmosphere and the meteorological conditions play a vital role in governing the fate of air pollutants. In this study, the relationship between ambient particulate matter data and meteorological factors, such as temperature, relative humidity, solar radiation and wind speed is statistically analyzed using the SPSS package (SPSS, 2003).

Table 4 shows the descriptive statistics of particulate matter and meteorological factors. Table 5 presents the relationship between particle concentrations (PM_{10} and $PM_{2.5}$) and meteorological parameters (temperature, relative humidity, solar radiation and wind speed). The PM_{10} and $PM_{2.5}$ is found to be strongly correlated with each other and inversely correlated with wind speed with correlation coefficient of -0.63 and –0.66, respectively. Very poor correlation was observed between particulate matters (PM_{10}, $PM_{2.5}$) and meteorological parameters including temperature, relative humidity and solar radiation.

Table 4. Descriptive statistics of particulate matter and meteorological factors

Parameters	Minimum	Maximum	Mean	Std. Deviation	N
PM_{10} ($\mu g\ m^{-3}$)	14.76	84.31	46.29	12.43	75
$PM_{2.5}$ ($\mu g\ m^{-3}$)	12.47	67.82	30.02	12.02	75
TEMP. (^oC)	0.10	19.70	10.92	3.57	75
RH (%)	22.00	92.00	64.26	13.68	75
SR ($W\ m^{-2}$)	41.00	1057.00	301.36	22.17	75
WS ($m\ s^{-1}$)	0.70	8.67	3.63	0.31	75

TEMP, RH, SR, WS refers to temperature, relative humidity, solar radiation and wind speed, respectively. Values were rounded to two places of decimal.

Table 5. Spearman rank correlation coefficient of particulate data and meteorological factors

	PM_{10}	$PM_{2.5}$	TEMP	RH	SR	WS
PM_{10}	1.000					
$PM_{2.5}$	0.90**	1.00				
TEMP	-0.10	-0.11	1.00			
RH	-0.07	-0.01	-0.11	1.00		
SR	0.04	0.01	-0.23	-0.63*	1.00	
WS	-0.63*	-0.66*	-0.13	0.30	0.06	1.00

** Correlation is significant at .01 level

* Correlation is significant at .05 level

Figure 8 shows the temporal variation of PM_{10} with wind speed, while Figure 9 shows the temporal variation of $PM_{2.5}$ with wind speed at all the monitoring sites. It was found that an inverse relationship exists between wind speed and particulate data, and therefore the predominance of local sources. In this case strong winds flush pollution out of the system whereas low winds allow pollution level to rise. The correlation studies of the daily average of PM_{10} and $PM_{2.5}$ concentration of all the sites with different meteorological factors have been conducted to establish their relationship.

The multiple regression equation obtained for PM_{10} is expressed as:

$$[PM_{10}] = 1098.0 - 253.6\ [WS] – 12.9\ [TEMP] \qquad [R^2 = 0.45] \tag{2}$$

According to this equation the level of PM_{10} decreases with increasing wind speed and temperature. The regression equation obtained for $PM_{2.5}$ is expressed as:

$$[PM_{2.5}] = 793.8 – 171.3\ [WS] - 12.17\ [TEMP]\ [R^2 = 0.42] \tag{3}$$

The above equation reveals that the $PM_{2.5}$ concentration is also decreasing with increasing concentration of wind speed and temperature.

$[PM_{10}]$ = Concentration of PM_{10} in μg m^{-3}
$[PM_{2.5}]$ = Concentration of $PM_{2.5}$ in μg m^{-3}
[WS] = Wind speed in m s^{-1}
[TEMP] = Temperature in ^{o}C.

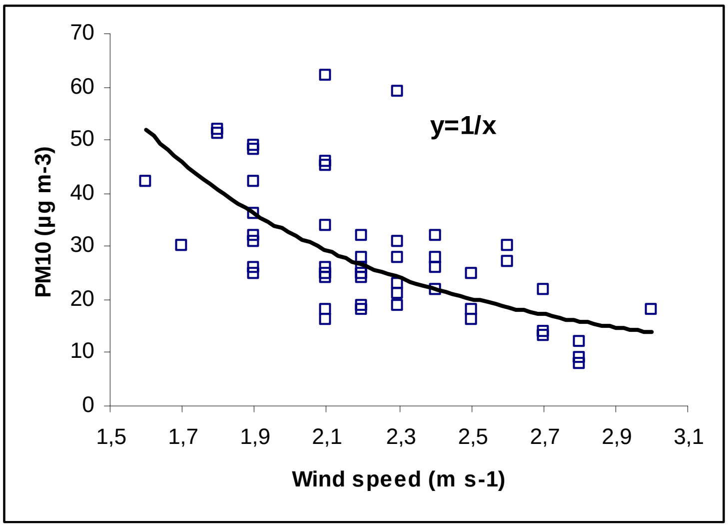

Figure 8. Temporal variation of PM_{10} with wind speed

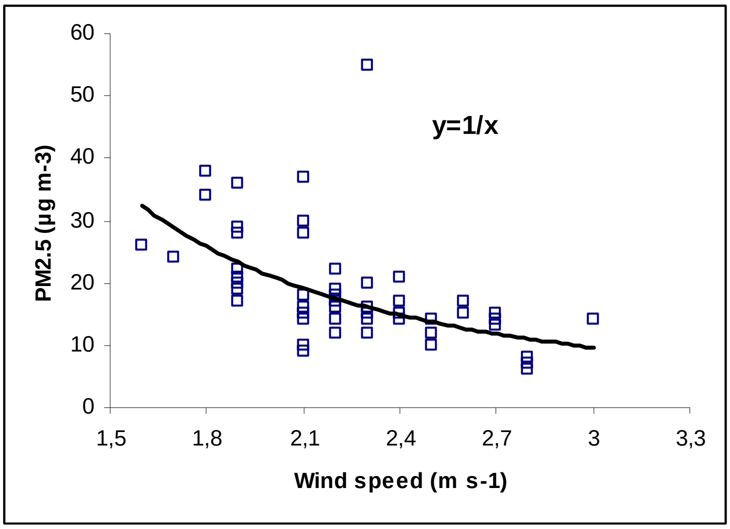

Figure 9. Temporal variation of $PM_{2.5}$ with wind speed

4. CONCLUSIONS

The study provides a valuable baseline data on PM_{10} and $PM_{2.5}$ levels and is the first of its kind in which such data has been collected in any urban region of Patras. Data capture rate was high and the precision of the results was good. The total data were analyzed to investigate spatial and temporal variation and correlation using the code SPSS in order to gain more understanding on their variability and interrelations.

The maximum PM_{10} concentrations at "A", "B", "C" sites were 70.81 μg m^{-3}, 84.31 μg m^{-3} and 74.0 μg m^{-3} and the minimum concentrations were 31.55 μg m^{-3}, 32.3 μg m^{-3} and 14.2 μg m^{-3} respectively. The maximum $PM_{2.5}$ concentrations at "A", "B", "C" were 54.4 μg m^{-3}, 67.7 μg m^{-3} and 63.2 μg m^{-3} and the minimum concentrations were 15.49 μg m^{-3}, 16.25 μg m^{-3} and 11.8 μg m^{-3} respectively. It was found that approximately 36% of PM_{10} concentrations were exceeded the standard value of 50 μg m^{-3}. In the central square George area the concentration showed higher value due to higher traffic congestion. $PM_{2.5}$ data appears to be a constant fraction (0.32 – 0.85) of the PM_{10} at all the sites, indicating common influences of meteorology and sources.

There are clear associations between PM_{10} and $PM_{2.5}$ data sets at all the measured sites. The highest correlation (0.98) was obtained between PM_{10} and $PM_{2.5}$ at Sq. Drosopoulou followed by 0.97 at Sq. George and 0.54 at Sq. Marouda. Considering the simplicity of the stepwise regression models, their performance was quite satisfactory, in predicting the observed values. Predictive models explain 65% of the variability in the $PM_{2.5}$ by the PM_{10} concentration variance respectively.

It was found that an inverse relationship exists between wind speed and particulate data, and therefore the predominance of local sources. In this case strong winds flush pollution out of the system whereas low winds allow pollution level to rise.

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