MEASUREMENT AND COMPARISON OF INHALABLE DUST BETWEEN PERI-URBAN FOREST AND URBAN ENVIRONMENT

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Abstract
Research has shown that urban and peri-urban vegetation is capable of retaining large amounts of atmospheric particles, thus bringing about substantial improvements in urban air quality.

For these suspended atmospheric particles, the term particulate matter (PM) is used referring to small-sized solid or liquid matter suspended in the air. The purpose of this paper was to examine the role of a peri-urban forest in mitigating dust levels in a neighboring urban area setting by measuring inhalable dust concentrations there and in the surrounding city. To get consistent data across the year's three seasons namely summer, autumn, and winter, we took three sets of inhalable dust readings using our personal SKC Button Sampler. Measurements were performed in three repeated time cycles so that PM10 data could be collected from three different seasons of the year.

Data were obtained from a total of 15 sites, 9 of which were located in the peri-urban forest and 6 in the urban fabric. Overall, data collection was carried out from July to early March and included 45 sampling days. A total of 45 samples were collected, 27 of which were obtained from a peri-urban Pinus brutia forest and 18 from an adjacent urban area (9 and 6 samples in each repeated sampling cycle, respectively).

Results obtained from both sampling areas show a significant increase in PM10 levels during the summer (8.86 mg·m^{-3}/24h) in comparison with the autumn and winter concentrations (3.71 mg·m^{-3}/24h and 4.12 mg·m^{-3}/24h, respectively). The PM10 concentrations in both sampling regions were found to be significantly higher in the summer than in the fall and winter.

Key words: *Air pollution; Button Sampler; peri-urban forest; PM10*

Introduction

The exposure of individuals to airborne particles is a subject of intense scientific interest due to their impact on both human health and the environment (climate change, reduced visibility, deterioration of archaeological monuments, etc.).

According to the World Health Organization (WHO), atmospheric pollution is the most significant environmental risk to health in the European Union (EU).

The rapid development of technology, which has led to the escalation of industry on a global scale, has contributed to this. A primary result of all this activity is the creation of increasingly more anthropogenic airborne particles (Michailidis, 2015). Particulate matter (PM) of various diameters, such as PM2.5, PM10, and PM1.0, is extremely hazardous, both for human health and for the environment and climate on the planet. The Environmental Protection Agency (EPA) of the United States ranks PM as one of the most significant pollutants along with ozone (O_3), nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), and lead (Pb) (Esworthy, 2013).

Particulate Matter (PM) refers to all solid and liquid particles dispersed in the atmosphere. Characteristic examples of particulate matter include dust, airborne ash, and smoke. Some particles are large enough and visible with a dark color, perceived as smoke. Others are so small that they are only visible under special microscopes (Samet et al., 2007).

Initially, the measurements of suspended particulate matter referred to total suspended particulate (TSP), without any differentiation based on their size, which is the most significant parameter for characterizing their behavior, along with their chemical composition and morphology.

The characterization of the size of particulate matter has predominantly been based on diameter since they typically have complex shapes ranging from entirely irregular to geometric. Thus, the concept of 'aerodynamic diameter' has been introduced. With the advancement of technology, a separation is now made into PM10, which pertains to particulate matter with aerodynamic diameters between 2.5 and 10 μm (coarse particles), and PM2.5 with an aerodynamic diameter smaller than 2.5 μm (fine particles). Aerodynamic diameter is defined as the diameter of a sphere of unit density (ρ= 1mg/cm^3) that has the same terminal settling velocity in still air as the particle under consideration (Krewski, 2000; Dockery et al., 1993).

Coarse particles are typically generated through mechanical means and have many different sources, such as wind-blown dust, vehicle movement on unpaved roads, industrial machinery compression, etc. Their formation is mainly attributed to mechanical forces like friction and crushing. In the environment, larger particles, with a diameter of 10 μm, can travel up to 20 to 30 kilometers, while smaller particles with diameters ranging from 0.1 to 1 μm can be transported several hundred kilometers away from their emission point. A small percentage of particulate matter can reach the upper troposphere (8-15 kilometers altitude). These particles can remain suspended for long periods (up to 1 year) (Vlachidis, 2015).

Coarse particles, also known as inhalable particles, are suspended particles that enter the upper respiratory system (nose and throat). This fraction of total suspended particles includes particles with diameters smaller than 10 micrometers, as the vast majority of particles with diameters larger than 10 micrometers are retained in the oral and nasal cavities (Vlachidis, 2015).

In Greece, the limits and targets set by the directives of the European Union apply. Specifically, the pollutants monitored include sulfur dioxide, suspended particles (PM10 and PM2.5), nitrogen dioxide, ozone, carbon monoxide, benzene, lead, arsenic, cadmium, nickel, and benzo[a]pyrene (EEA, Special Report 2018).

Threshold values refer to concentration levels above which it is scientifically documented that harmful effects on human health and the environment can occur. Specifically, for the concentration of inhalable particulate matter (PM10), which is also the focus of this study, the current European legislation (Directive 2008/50/EC) stipulates that the limit of 50 μg/m^3 should not be exceeded more than 35 times per year (daily exceedances), while the annual average should be below 40 μg/m^3 (PHE, 2012, Chrysikou et al. 2008). For fine particulate matter (PM2.5), the average annual value should not exceed the threshold of 25 μg/m^3. No daily threshold value has been established for this fraction of particulate matter (EEA, Special Report 2018).

The European Environment Agency (EEA, 2007) found that from 1997 to 2004, 23% to 45% of the urban population was exposed to PM10 concentrations higher than the exposure limit of 50 μg/m^3/24 hours. Since 1997, when PM10 concentrations were systematically studied for the first time, their levels remained stable until 2004 (EEA, 2007), despite the fact that precursor and primary PM emissions decreased by approximately 45% between 1990 and 2004.

Several studies have reported on air particle quantities. Eeftens et al. (2012) found that PM10 concentrations were higher in Southern Europe compared to Western and Northern Europe after controlling for various critical air quality variables such as population density, traffic intensity, and altitude.

Despite the differences between Southern and Northern Europe, particulate matter levels continue to be a major concern throughout Europe. Governments must immediately implement various mitigation measures. Tree planting or creating suburban forests can contribute to reducing PM levels in cities because their leaves can trap and store large quantities of pollutants (Uni and Katra, 2017). So far, studies have mainly focused on PM measurements in urban areas, but there is remarkably little information on best practices for shielding cities from dangerous PM levels or implementing programs to reduce PM in cities.

According to studies within the scientific community, individuals with respiratory problems, particularly Chronic Obstructive Pulmonary Disease (COPD), are more sensitive to the short-term effects of air pollution. It is known that mortality among patients with airway diseases increases during periods of high atmospheric pollution concentrations. The need for a deeper understanding of the effects of atmospheric pollution on humans necessitates the measurement of their levels in the environment where they move and reside, with the aim of further analyzing the factors influencing these levels (Pirozzi and Scholand, 2012).

The primary objective of conducting this study was to better understand the rates of human exposure to particulate matter (PM10) in a representative daily urban environment compared to a suburban forest environment, as well as the contribution of the suburban forest to reducing atmospheric pollution in the adjacent urban environment.

For this reason, the differences in particulate matter (PM10) levels between urban and suburban forest environments have been investigated during the seasons. Additionally, we compared the concentrations of PM10 in the urban area and the suburban forest in three different seasons of the year.

The urban environment from which we took measurements was the city of Alexandroupolis, a medium-sized city in northern Greece with a population of approximately 60,000 residents. The suburban forest from which we took PM10 concentration measurements was a nearby public forest of *Pinus brutia*, located to the north-northeast of the city of Alexandroupolis, approximately 3.5 kilometers away from the city center.

To acquire PM10 data for all three seasons of the year, measurements were conducted in three separate temporal cycles. Specifically, the first measurement cycle took place in the summer, the second cycle in the autumn, and the third cycle in the winter.

Furthermore, to collect the data, a total of 15 sampling locations were selected. Nine sampling locations were in the suburban forest, and six sampling locations were in the urban area. Measurements began in July and were completed by the end of February of the following year. A total of 45 sampling days were used to collect the data.

Materials and Methods

For the collection of the fraction of inhalable dust PM10, a portable air sampling instrument, specifically the Air Sampling SKC, was used. The inhalable dust sampler was of a specialized design, known as the IOM sampler (Institute of Occupational Medicine), which makes it less susceptible to the effects of air movement around it. Such a personal monitor can provide a detailed picture of an individual's short-term exposure at a specified location (Kalatoor et al., 1995). The pump (Button Sampler Sidekick) of the portable dust collection instrument had a flow range of 5-3000 ml/min. The IOM cassette allowed for the placement of special PM10 collection filters, with a diameter of 25 cm. For each new measurement, corresponding to a different sampling day, a new sampling filter was placed in the IOM sampler cassette (Dimou et al., 2020; Marchi et al., 2017).

The filters were pre-conditioned for 24 hours at a temperature of 20±1°C and relative humidity of 48±2% in a climatic chamber before being used in the sampling tests (Chrysikou et al., 2008; Dimou et al., 2020). Additionally, before and after each sampling, the filters were weighed on a precision balance with an accuracy of 0.0001g to measure the mass of inhalable dust PM10. Each daily sampling lasted a total of 8 hours. Time-weighted average (TWA) 24-hour mean values were ultimately used to express the sampling data. Furthermore, three temperature and humidity measurements were taken per sampling day, and the average temperature and humidity were determined. These measurements were conducted using a digital thermometer and hygrometer (HUM DC-103) on each day of data collection. The Meteorological Station of Alexandroupolis Airport (www.wunderground.com) provided the data for the average daily wind speed during the sampling period.

As for the measurements in the suburban forest, the equipment was securely fastened to the trunk of each selected tree at a height of approximately 1.70 m from ground level. In the urban environment, the instrument was anchored at fixed points at a corresponding height, in positions chosen to provide a representative measurement of dust from across the entire urban area of Alexandroupolis.

At the end of each sampling period, another airflow rate measurement was taken to account for the possibility of reduced performance, so the average of the two airflow readings (initial and final) was calculated for each sampling event.

Daily exposure to dust was determined according to the EN481:1993 standard of the British Health and Safety Executive (HSE) using the MDHS 14/4 method (Methods for the Determination for Hazardous Substances), titled 'General methods of sampling and gravimetric analysis of respirable, thoracic, and inhalable aerosols' (Pirozzi and Scholand, 2012).

The sampling locations in the suburban forest were a total of nine and were chosen to be relatively close to the perimeter of the respective forest. Six of the sampling locations were along a frontal line located 3500 meters away from the city, while the remaining three were along a zone (130 meters wide) at a distance of 3450 meters from the urban area of Alexandroupolis.

In the urban area, there were a total of six sampling locations, of which five were in the city center and one in a nearby suburb. The sampling locations were distributed to capture data on PM10 dust concentrations across the entire city, not just from the downtown area. Thus, points in the city were selected that were heavily populated, and had high traffic volume, as well as points that attracted fewer people with moderate vehicle traffic.

Sampling location per cycle	1st Cycle		2nd Cycle		3rd Cycle	
	Peri-urban forest	**City**	**Peri-urban forest**	**City**	**Peri-urban forest**	**City**
	1	*2*	*3*	*4*	*5*	*6*
Mean PM10/8h ($mg \cdot m^{-3}$), SD	0.68 (±0.70)	2.27 (±2.26)	0.32 (±0.26)	0.91 (±0.26)	0.67 (±0.20)	0.70 (±0.34)
Min-Max PM10 ($mg \cdot m^{-3}$)	0.10-2.49	0.10-5.33	0.10-0.96	0.60-1.35	0.30-1.02	0.18-1.17
Mean PM10/24h ($mg \cdot m^{-3}$), SD	2.04 (±2.11)	6.81 (±6.79)	0.96 (±0.79)	2.73 (±0.79)	2.01 (±0.60)	2.10 (±1.03)
Rainfall height RH	45	45	81	81	32.33	32.33

Results

Table 1. Mean concentrations of PM10 ($mg \cdot m^{-3}$) per day; minimum and maximum concentrations per cycle and location; SD: Standard Deviation

The three sampling cycles corresponding to different seasons of the year are depicted in Figure 1. The concentrations of inhalable PM10 dust per sampling location are also shown. The results are reported as time-weighted average (TWA) concentrations of PM10. The average concentrations of PM10 in peri-urban forest and urban environments during the three sampling periods were 4.42 $mg \cdot m^{-3}$, 1.84 $mg \cdot m^{-3}$, and 2.05 $mg \cdot m^{-3}$/24h, respectively.

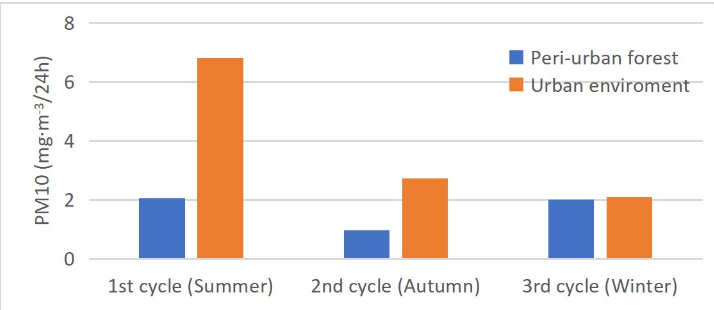

Figure 1. Concentration of PM10 ($mg \cdot m^{-3}$/24h) per sampling cycle

The maximum and minimum concentrations of PM10 measured during the 8-hour sampling periods are presented in Table 1 by season and sampling location. The highest mean concentration of inhalable dust, equal to 5.34 mg/m³/8h, was recorded during the summer months in the urban area of Alexandroupolis. Additionally, the maximum relative humidity (81 RH) was recorded during the 2nd sampling cycle, i.e., autumn, while in the other two cycles (summer and winter), the relative humidity was approximately the same. This is evident in the last row, which depicts the relative humidity by sampling cycle. The average PM10 concentrations in the city were 6.81 mg/m³ in summer, 2.73 mg/m³ in autumn, and 2.10 mg/m³/24h in winter. Meanwhile, the average PM10 concentrations in the suburban forest were 2.04 mg/m³, 0.96 mg/m³, and 2.01 mg/m³/24h for summer, autumn, and winter, respectively. The first and the third rows of the results show the average PM10 concentration values per 8-hour and 24-hour period. 24 respectively

The classification of PM10 concentrations was done into five categories for both the suburban forest and urban environment (classes a, b, c, d, e) (Table 2). The classes were created based on decreasing levels of PM10 as determined from the filter weights. More specifically: class e consists of PM10 concentrations above 5 $mg \cdot m^{-3}$, class d ranges from 2 to 5 $mg \cdot m^{-3}$, class c from 1 to 2 $mg \cdot m^{-3}$, class b from 0.5 to 1 $mg \cdot m^{-3}$, and class a below 0.5 $mg \cdot m^{-3}$. From the results, it is evident that classes a and b (very low and low concentration classes, respectively) encompass the majority of the sampling filters and the three sampling periods.

Specifically, for the suburban forest and the urban environment, approximately 92.5% and 61% of the sampling filters belong to the very low and low concentration classes, respectively.

Sampling Site	<0.5 mg/m³ *(%)*	0.5<x≤1.0 mg/m³ *(%)*	1<x≤2 mg/m³ *(%)*	2<x≤5 mg/m³ *(%)*	>5 mg/m³ *(%)*
	Classe a	Classe b	Classe c	Classe d	Classe e
Peri-urban forest	13 *(48.15)*	12 *(44.44)*	1 *(3.70)*	1 *(3.70)*	0 *(0.00)*
Urban environment	4 *(22.22)*	7 *(38.88)*	4 *(22.22)*	1 *(5.55)*	2 *(11.11)*

Table 2. PM10 concentration (%) per concentration class

Discussion

A difference in inhalable dust concentration was observed between the urban and suburban forest environments for all three sampling cycles, with higher inhalable dust concentration in the urban environment, which holds true for all three sampling cycles. Specifically, the difference in dust concentration between the two environments was greater during the summer months, relatively smaller during the autumn, and with minimal difference during the winter period. The highest dust concentration value was observed in the urban area during the summer period, equal to 5.34 mg·m^{-3} (Table 6).

In more detail, during the 1st sampling cycle (summer), the average concentration of inhalable dust in the urban environment was 1.59 mg·m^{-3} higher than that in the suburban forest. Additionally, during the 2nd sampling cycle (autumn), the average PM10 concentration in the urban area was 0.59 mg·m^{-3} higher than that in the suburban forest, and during the 3rd sampling cycle (winter), it was higher by 0.02 mg·m^{-3}. The corresponding results in terms of 24-hour PM10 concentrations according to the European Environment Agency (EEA) are shown in the 3rd row of Table 1. Specifically, the maximum dust concentration during the summer months in the urban environment is 6.81 mg·m^{-3}/24h, while in the suburban forest during the same period, the maximum dust concentration is 2.04 mg·m^{-3}/24h. Therefore, there is a difference of approximately 4.77 mg·m^{-3}/24h. Additionally, the difference between the urban environment and the suburban forest for autumn (2nd sampling cycle) and winter (3rd sampling cycle) measurements, expressed in 24-hour concentration, was 1.77 mg·m^{-3}/24h and 0.09 mg·m^{-3}/24h, respectively.

In the present study, it was found that the concentrations of PM10 measured in the urban area varied significantly from summer (6.81 mg·m^{-3}/24h) to autumn (2.73 mg·m^{-3}/24h) and winter (2.10 mg·m^{-3}/24h). However, there was no statistically significant difference between the last two seasons. On the other hand, for the suburban forest, there was no statistically significant difference in PM10 concentrations among the three sampling seasons. Additionally, it should be noted that during the second sampling cycle (autumn), strong rainfall events with 81% relative humidity (RH) were recorded, significantly reducing the autumnal PM10 concentrations in the suburban forest (Table 1). As for the average PM10 concentrations in the city for autumn, the heavy rainfall did not have the same effect (Hellenic National Meteorological Service).

From similar studies, it was found that the average PM10 concentrations in Athens and Thessaloniki were much higher than in Alexandroupoli. Specifically, in Athens, PM10 concentrations were found to be 45.1 mg·m^{-3}/24h, while in Thessaloniki, PM10 concentrations were 75.5 mg·m^{-3}/24h. However, it should be noted that these measurements were taken at only one sampling point near the city centers (Chrysikou et al., 2008). The average PM10 levels, with reference to the center of Thessaloniki, were much higher than the recommendation of the European Environment Agency (EEA) in 2007 for 50 mg·m^{-3}/24h.

From the separation and classification of the sampling filters into the five PM10 classes, it appears that the highest percentage of filters in all three sampling periods regarding seasonal variability belongs to the class of very low inhalable dust concentration up to the class of low inhalable dust concentration. It can be concluded that the retention capacity of the suburban pine forest *Pinus brutia* was not significantly affected by the fact that the forest is only 30 years old (it was reforested at that time) and has a relatively small leaf type as a conifer species.

Conclusion

Mortality associated with atmospheric pollution is approximately 15% to 20% higher in urban areas, where high pollution levels are recorded compared to non-urban and less densely populated areas. In the European Union, according to the World Health Organization, the average life expectancy is estimated to be 8.6 months lower due to exposure to PM2.5 particles emitted from human activities (WHO, 2008). According to the British Committee on the Medical Effects of Air Pollutants (COMEAP), in the UK alone, PM10 particles may be responsible for 8,100 premature deaths and 10,500 emergency hospital admissions annually.

In the present study, a difference in dust concentration was observed between urban and suburban forest environments across the three sampling periods, with higher inhalable dust concentrations recorded in urban areas for all three sampling cycles. Specifically, the difference in dust concentration between the two environments was greater during the summer months, relatively smaller during the autumn, and minimal during the winter period. The highest dust concentration was observed in the urban area during the summer period, reaching 5.34 mg·m^{-3} (Table 1).

Regarding seasonal variation, concentrations were higher in summer both in urban and suburban environments, while values were lower during autumn and winter months.

During the summer months, PM10 concentrations in urban areas exhibited larger fluctuations compared to autumn and winter months. Specifically, PM10 levels during the autumn and winter periods were similar (0.91 mg·m^{-3}/8h and 0.70 mg·m^{-3}/8h). There was no statistically significant variation in particulate matter PM10 concentration levels in the suburban forest throughout the year. It is worth noting that heavy rainfall in the forest played a role in maintaining dust at low levels.

In any case, the average values of the measured inhalable dust were below the European Environment Agency's (EEA, 2007) threshold of 40 mg m^{-3} per 24 hours.

The results of this study demonstrate the positive contribution of a suburban forest in trapping suspended particles. This fact could support environmental strategies aimed at improving the quality of life in urban environments with severe atmospheric pollution problems or potential PM-related risks associated with airborne dust due to land use or climate change within the framework of urban centers' fortification by adjacent suburban forests (Uni, 2017).

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