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# Temporal Variation of $PM_1$ on the Campus of the University of Patras, Greece †

**Aristeidis Bloutsos [1,2,*] and Panayotis Yannopoulos [1]**

[1] Environmental Engineering Laboratory, Department of Civil Engineering, University of Patras, 26504 Patras, Greece; p.c.yannopoulos@upatras.gr
[2] Hydraulics and Geotechnical Engineering Division, Department of Civil Engineering, University of West Attica, 12241 Athens, Greece
* Correspondence: arblouts@upatras.gr
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**Abstract:** Several scientific studies reveal that particulate matter that is smaller than 1 μm ($PM_1$) represents the main hazard for the cardiorespiratory pathological status of the population. The present study deals with the presentation of the long-term continuous measurements of $PM_1$ in the atmospheric environment of the University of Patras Campus (UPC) at Rion. The 1 h mean concentrations of $PM_1$ were recorded and presented in this study, covering a seven-year period (2012–2018) in a suburban area of Patras, with background characteristics. The results indicated that $PM_1$ levels were quite low, with significant differences between cold and warm periods. However, they did not show significant variations. This project aimed to identify and assess UPC air quality. Our findings may contribute to useful $PM_1$ concentration patterns based on the long-term recorded data.

**Keywords:** air pollution; air quality; $PM_1$; suburban; diurnal; weekly; annual; hourly; ultrafine



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## 1. Introduction

Previous epidemiological studies have focused on the adverse effects of $PM_{10}$ and $PM_{2.5}$ (particulate matter with an aerodynamic diameter $\leq$ 10 μm and $\leq$ 2.5 μm, respectively). Increased concentrations of $PM_{10}$ and $PM_{2.5}$ are associated with respiratory and cardiovascular diseases [1]. These adverse effects lead to increased incidences of hospitalization and mortality [2–4]. $PM_1$ (particulate matter with an aerodynamic diameter $\leq$ 1 μm—ultrafine particles) is a predominant component of $PM_{2.5}$ [5], although their physicochemical properties are different. While $PM_{2.5}$ can penetrate the lower respiratory system, $PM_1$ is even smaller, having the ability to diffuse more deeply, depositing in the alveoli [6]. Thus, PM size is negatively correlated to its adverse effects [7,8].

During the last decades, several campaigns have been conducted to characterize the air quality regarding $PM_{10}$ and $PM_{2.5}$ worldwide [9] and in Greece [10]. However, there are limited systematic or continuous experimental campaigns for $PM_1$ [11–14]. In addition, ultrafine particles have not been regulated in Europe or the United States as there is a significant lack of relative data [15].

The present study considered the temporal presentation of $PM_1$ concentrations measured continuously by the Environmental Engineering Laboratory (EEL) of the Civil Engineering Department from September 2012 to December 2018. These concentrations are comparable to other stations in Patras of limited campaign duration.

## 2. Materials and Methods

EEL conducted several air quality monitoring programs for gaseous pollutants and airborne particulates in the major areas of Patras (downtown and UPC) [16]. In April 2012,

a new fixed air pollution monitoring station started operating in continuous mode at the UPC under the responsibility of EEL.

### *2.1. Study Area*

The University of Patras has been installed in UPC since 1968. UPC includes an area of 2.66 km$^2$ at the foot of Panachaicon Mountain, 8 km NNE of the Patras center S of Rion Village, and approximately 3 km NW of the coastline. Nowadays, UPC includes more than 30 major building blocks, many secondary buildings in various sizes, and for different purposes, having a total area of more than 260,000 m$^2$. Details about the location and characteristics of the surrounding area are given by [17].

The station (Geographical Longitude: 21°47′22″, Geographical Latitude: 38°17′22″, Altitude: 60.6 m) is located at the western parking lot of the Building of the Department of Civil Engineering (Figure 1). The inclination of the ground surface of this area is 4–5% toward NW. Apart from asphalt-covered streets and parking lots, the major area consists of natural soil with low vegetation, bushes, and olive trees. The nearest building to the EEL station is the three-storey building of the Civil Engineering Department, which is about 15 m W away, while the other buildings or obstacles are even further away. Due to the topographical characteristics, the ventilation of the area around the station takes place mainly from the NW, N, ENE, and SSE directions. The UPC area is characterized as suburban with background concentration characteristics [18].


**Figure 1.** Map of the major area of Patras.

### *2.2. Data*

The EEL Station is equipped, among others [17], with an automatic analyzer (model Grimm 180) of particulate matter ($PM_{10}$, $PM_{2.5}$, and $PM_1$) based on the 90° scattering light measurement principle. The specific sampler is certified (TÜV CERT) and the factory calibrations were maintained for the measurement to follow relative European regulation (EN 12341/EN 14907). A flow and a zero check were performed every month to ensure the reliable operation of the device. The continuous monitoring campaign started on 7 September 2012 and lasted until 19 December 2018. The analyzer recorded data every five minutes. In addition, meteorological data are available from the meteorological station installed on the roof of the EEL Station chamber.

### *2.3. Methodology*

The 5 min $PM_1$ data are used to calculate the mean hourly $PM_1$ concentrations. It must be noted that a 1 h record is constructed when its completeness is more than 67% (i.e., more than eight 5 min records during an hour). Thus, hourly values that did not meet the above criterion were excluded from further analysis. Therefore, the overall dataset completeness was 85.6% for the monitoring period, while the degree of completeness achieved for the period 2012–2018 was 76.8%. Hereafter, the completeness will refer to the worst-case duration of 2012–2018 (1 January 2012–31 December 2018). Based on mean hourly values, the diurnal, monthly, weekly, and yearly $PM_1$ variations were obtained.

## 3. Results and Discussion

During the monitoring period, the mean hourly $PM_1$ concentrations at UPC ranged from 0.1 to 106.4 μg $m^{-3}$, with an average value of 7.4 ± 51.4 μg $m^{-3}$ and a median of 6.4 μg $m^{-3}$. These findings are comparable to corresponding average values of 8.6 μg $m^{-3}$ [19] and 7.7 μg $m^{-3}$ [11] from a monitoring station nearby to EEL's station referring to much shorter monitoring campaigns. The 98% percentile was estimated to be equal to 21.4 μg $m^{-3}$. The completeness of the dataset was 76.8%. During the cold period (October–March) of the monitoring period, the mean hourly $PM_1$ concentrations at UPC ranged from 0.1 to 106.4 μg $m^{-3}$, with an average value of 8.0 ± 6.2 μg $m^{-3}$ and a median of 6.6 μg $m^{-3}$. The 98% percentile was estimated to be equal to 24.3 μg $m^{-3}$. The completeness of the corresponding 2012–2018 dataset was 76.4%. During the warm period (April–September) of the monitoring period, the mean hourly $PM_1$ concentrations at UPC ranged from 0.3 to 61.5 μg $m^{-3}$, with an average value of 6.9 ± 3.7 μg $m^{-3}$ and a median of 6.3 μg $m^{-3}$. The 98% percentile was estimated to be equal to 16.3 μg $m^{-3}$. Regarding the warm period, the completeness of the dataset was 77.3%.

The diurnal variations of $PM_1$ during the whole period and the warm and cold periods are shown in Figure 2. During 2012–2018, the hourly mean values ranged from 6.6 to 8.7 μg $m^{-3}$, while the $PM_1$ ranges during the cold and warm periods were 6.2–10.2 μg $m^{-3}$ and 5.6–7.6 μg $m^{-3}$, respectively. Regarding the diurnal cycle, $PM_1$ concentrations had an average value of 7.4 ± 0.6 μg $m^{-3}$ during the study period, 8.0 ± 1.2 μg $m^{-3}$ during the cold periods and 6.9 ± 0.7 μg $m^{-3}$ during the warm periods. The variation of hourly mean values was more significant for the values of the cold period than for the warm period values. For all the cases, a significant variation occurred after 09:00. Regarding the cold-period variations during 2012–2018, two peak values appeared: one during the morning hours 11:00–12:00, and another one during the evening hours 18:00–21:00. The evening peak was higher than the morning peak. Regarding the warm period, one peak value appeared during 20:00–22:00. During 00:00–09:00, although the concentration values varied insignificantly, the $PM_1$ concentrations during the cold period were lower than the corresponding values during the warm period. The above-discussed patterns indicate that traffic and human activities have a significant impact on PM1 concentrations. Additionally, central heating and/or wood burning during the cold periods, respectively, explain the peaks observed.

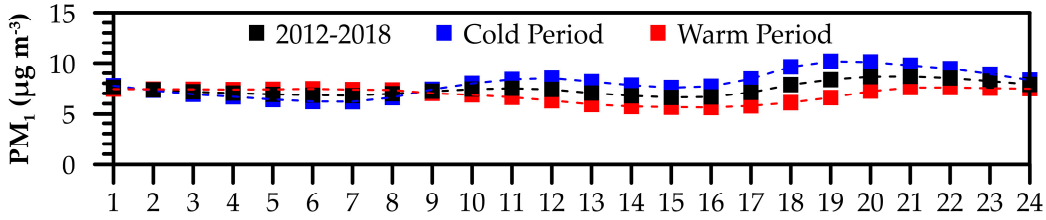


**Figure 2.** Diurnal variation of $PM_1$ mean concentration values at the UPC monitoring station during the cold period and warm periods of 2012–2018.

Figure 3 shows the monthly variation of $PM_1$ concentrations during 2012–2018. $PM_1$ monthly concentrations ranged from 6.1 to 9.9 μg $m^{-3}$ with an average value of 7.5 ± 1.1 μg $m^{-3}$. Higher values were recorded during the months of November–April (7.6–9.9 μg $m^{-3}$), while a significant decay was observed during May to October (6.1–7.2 μg $m^{-3}$). Similar $PM_1$ concentrations were reported by [19] at another station near EEL's.

The weekly variations of $PM_1$ during the whole period and warm and cold periods are shown in Figure 4. Weekly $PM_1$ concentrations had an average value of 7.4 ± 0.4 μg $m^{-3}$ during the study period, and 8.0 ± 0.5 μg $m^{-3}$ and 6.9 ± 0.3 μg $m^{-3}$ during cold and warm periods, respectively. The weekly mean values ranged from 6.9 to 7.9 μg $m^{-3}$ during 2012–2018, while the corresponding ranges were 7.4–8.9 μg $m^{-3}$ and 6.4–7.2 μg $m^{-3}$ during cold and warm periods, respectively. The variation of $PM_1$ during the week was rather

small. The variation was more significant during the cold period where a slight increase appeared during the weekend.

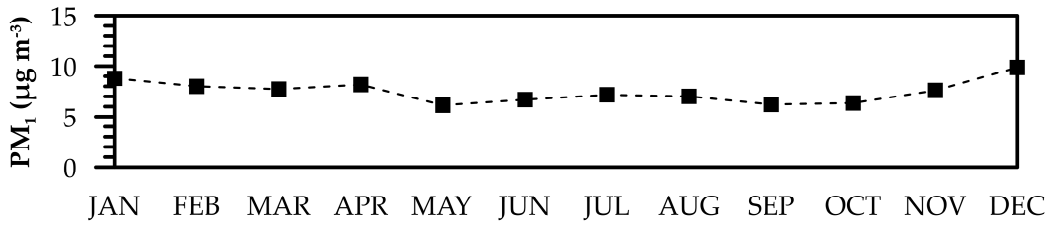


**Figure 3.** Monthly variation of $PM_1$ mean concentration values at the UPC monitoring station from 2012 to 2018.

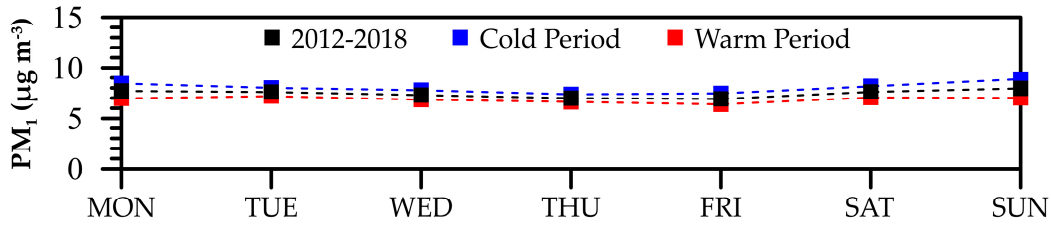


**Figure 4.** Weekly variation of $PM_1$ mean concentration values at the UPC monitoring station during the cold period and warm periods of 2012–2018.

In Figure 5, $PM_1$ annual average concentrations from hourly values are presented. Yearly $PM_1$ concentrations had an average value of 7.6 ± 1.3 μg $m^{-3}$ during the study period, 8.1 ± 1.3 μg $m^{-3}$ during cold periods and 7.1 ± 1.4 μg $m^{-3}$ during warm periods. The annual $PM_1$ concentrations ranged from 5.7 to 9.1 μg $m^{-3}$ during 2012–2018. $PM_1$ annual concentrations ranged from 6.3 to 9.6 μg $m^{-3}$ and 5.2 to 9.1 μg $m^{-3}$, regarding the cold periods and warm periods, respectively. The annual variation of $PM_1$ concentrations was rather stable through the period 2012–2015, while there was a significant decay during 2016–2018. $PM_1$ concentrations were higher during cold periods than warm periods. As neither EPA [20] nor EEA [21] have prescribed air quality standards for $PM_1$, nor has the WHO [22] recommended any guidelines, comparison was carried out by estimating an equivalent $PM_{2.5}$ or $PM_{10}$ concentration value, based on $PM_1/PM_{2.5}$ and/or $PM_1/PM_{10}$ ratios mentioned in bibliography. Gaidajis et al. [23] reported $PM_1/PM_{2.5}$ = 0.89–0.98 and $PM_{2.5}/PM_{10}$ = 0.84–0.85 for cold periods. Thus, equivalent $PM_{10}$ concentrations ranged from 6.4–10.8 μg $m^{-3}$. These values are similar to recorded values at UPC [24–26] and are lower than the limit values of EEA (20 μg $m^{-3}$) and EPA (12 μg $m^{-3}$). Equivalent $PM_{10}$ concentrations were estimated using $PM_{2.5}/PM_{10}$ [23] and $PM_{2.5}/PM_{10}$ = 0.74 ± 0.13 [25]. Thus, equivalent $PM_{10}$ concentrations ranged from 8.7–14.6 μg $m^{-3}$. These values are similar to recorded values at UPC [25,26] and are lower than the limit values of EEA (40 μg $m^{-3}$) and AQG of WHO (15 μg $m^{-3}$). Similarly, equivalent $PM_{10}$ concentrations were estimated using $PM_1/PM_{10}$ = 0.48–0.91 [27]. Thus, equivalent $PM_{10}$ concentrations ranged from 6.3–19.0 μg $m^{-3}$. These values are similar to recorded values at UPC [25,26] and are lower than the limit values of EEA (40 μg $m^{-3}$) and the maximum value slightly exceeds the AQG of WHO (15 μg $m^{-3}$).

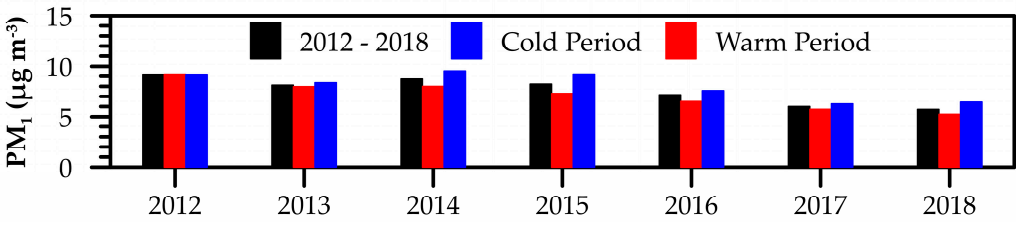


**Figure 5.** Annual variation of $PM_1$ mean concentration values at the UPC monitoring station during the cold period and warm periods of 2012–2018.

Figure 6 shows $PM_1$ concentrations with respect to the wind direction at the EEL's site. Wind directions, which are mainly in the N, NE, and ESE-SE sectors, are representative of the predominant wind directions at EEL. Figure 6 reveals that the most significant dependence of $PM_1$ concentrations on wind direction is the N, SE, and NW sectors during the cold period and SE during the warm period.

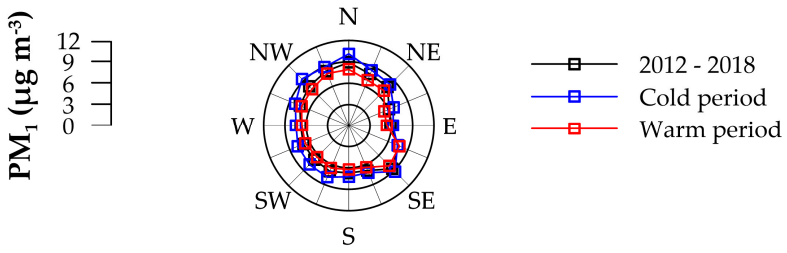


**Figure 6.** Hourly mean $PM_1$ concentrations for each wind direction sector at the EEL monitoring station of UPC during the cold period and warm periods of 2012–2018.

## 4. Conclusions

$PM_1$ concentrations were recorded continuously at the University of Patras Campus from September 2012 to December 2018. $PM_1$ concentrations were higher during cold period, showing that central heating and/or wood burning mainly affect the air quality. The mean hourly $PM_1$ levels of the cold period were up to 17% lower than the $PM_1$ levels of the warm period during 01:00–08:00, while the $PM_1$ concentrations of the cold period were up to 58% higher than the $PM_1$ concentrations of the warm period during 08:00–01:00. It seems that the weekly variation of $PM_1$ values was rather stable without having been affected by seasonality. The monthly variation showed that seasonality affected $PM_1$ concentrations as $PM_1$ levels increased during the cold period. There was a significant decay of the annual concentrations, though these concentrations were quite low, less than 10 μg $m^{-3}$. The equivalent $PM_{2.5}$ and $PM_{10}$ concentrations showed that the air quality was considerably good. The significantly low $PM_1$ concentrations can be characterized as background values.

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