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Comparative Measurements of Air Pollution Using Low-Cost Sensors in the Center of Athens and the Mt. Hymettus Aesthetic Forest †

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Abstract: Air pollution is a global environmental issue that primarily affects the health of city residents. The purpose of this study was to comprehensively assess air pollution levels in the center of Athens and compare them with those in the peri urban Mt. Hymettus Aesthetic Forest. To achieve this, two low-cost sensors, namely, the "PurpleAir PA-II-SD," were combined with the employed methodology. The first sensor was stationed at a fixed central point in the Mt. Hymettus Aesthetic Forest, whereas the second one captured measurements along a specific route among six points in the historic center of Athens during the summer of 2021. The pollutants measured included PM_{10}, $PM_{2.5}$, and PM_1, as well as temperature and humidity. The research findings indicated that all pollutant values were significantly higher in the center of Athens, particularly in terms of $PM_{2.5}$, which exceeded the permissible limits set by the European Commission. Furthermore, notable variations in temperature were observed in both areas.

Keywords: air pollution; air quality; low-cost sensors; PM; measurements; periurban green spaces

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1. Introduction

Cities will host most of the population by 2050, with air pollution and high temperatures being significant environmental concerns. Cities globally face environmental challenges such as water preservation, wastewater management, and park and tree provision, with clean air remaining one of the most significant challenges [1]. According to the World Health Organization [2], air pollution has a negative impact on urban residents' health. Prolonged exposure to pollutants increases the possibility of developing cardiovascular and respiratory diseases and lung cancer. Furthermore, in both emerging and developed countries, technological advancements and urbanization result in an increase in air pollution, and a larger dust contribution is observed due to local soil dust re-suspension from traffic. Cities worldwide use air quality monitoring networks to measure pollutant concentrations in areas that represent population exposure. Low-cost air pollutant sensors provide high-resolution data and a significant improvement in air quality monitoring [3]. This technology can answer scientific questions and provide solutions for end-users, ultimately leading to better air quality management and public health protection [4].

Peri-urban parks and forests play an important role in the urban environment by modifying the microclimate and air quality and reducing atmospheric greenhouse gas levels [5]. Periurban parks and forests are diverse natural ecosystems that provide crucial services for the well-being and quality of life of nearby inhabitants. In addition to their role in conserving biodiversity, they play a strategic role in urban climate change adaptation and mitigation. Periurban parks can help decrease the urban heat island effect, protect cities from flooding, and sequester carbon. Periurban Parks gather a great number of visitors who come to participate in outdoor activities and to get in touch with nature for their well-being and health. In light of the ongoing climate crisis, periurban parks have become even more critical for creating sustainable cities [6].

The main objective of this research is to investigate and identify the quality of air in the Center of Athens in comparison with the Mt. Hymettus Aesthetics Forest; this is due to the fact that high rates of air pollution occur mainly in the city center due to increased traffic [7], the settlement of the population in the urban center, and the lack of greenery, and this is one of the most important environmental problems. Citizen's benefit from a variety of ecological services provided by urban and peri-urban forests. While their capability to remove carbon dioxide and other gaseous molecules from the atmosphere has been evaluated, their ability to sequester particles (PM) has not. The Mediterranean Forest ecological system is frequently found close or within big cities [8]. For this reason, the aim is beyond the theoretical part of the importance of the peri-urban green spaces to prove their practical significance through the measurements of air pollution.

2. Methodology

2.1. Instruments

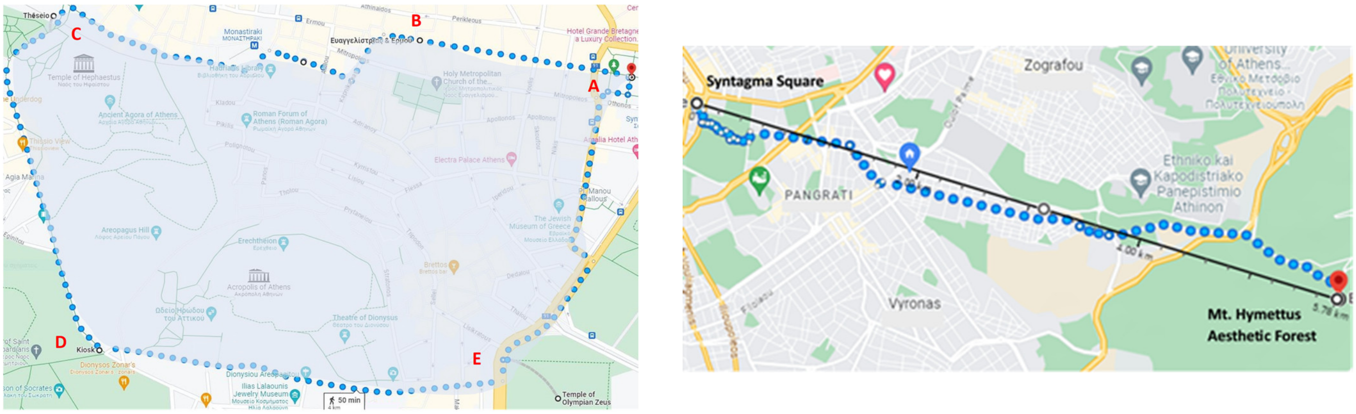
Two types of instruments were used to conduct the present research, which were two particulate matter sensors of the same type and a reference instrument. Recent developments in particle sensor technology have led to the growth of low-cost solid-particle (PM) monitors. These devices can enhance the identification of spatiotemporal variability at the environmental and exposure levels, but their accuracy requires thorough performance evaluation and calibration against standards [9].

The sensor that was used was PurpleAir PA-II (PurpleAir, Inc., Draper, UT, USA), monitor and its PA-II-SD model, which included a pair of PMS5003 laser optical particle counter sensors to detect the number of particles with particle sizes of 0.3, 0.5, 1, 2.5, 5, and 10 μm. Then, we utilized the count data to determine mass concentrations of PM_1, $PM_{2.5}$, and PM_{10}. Also, it contained a temperature sensor, relative humidity, and barometric pressure sensor, which were all coupled to a microprocessor with a wireless network connection module. The device recorded and transmitted data over Wi-Fi to a web platform (PurpleAir map).

The PurpleAir PA-II sensors have been used recently in many studies for long-term and short-term research on PM concentrations. Corresponding research using this kind of sensor has been performed in Greece [10,11] but also abroad [12,13]. Furthermore, the TSI DustTrakTM DRX Aerosol Monitor 8533 (TSI, Shoreview, MN, USA), which leads the industry in real-time dust tracking, will be used as a reference instrument and can calculate both mass and size fraction at the same time.

2.2. Measurements Areas

As mentioned above, the measurements were comparative between two areas: the historic center of Athens and the Mt. Hymettus Aesthetic Forest. Initially, the center of Athens was chosen as a popular place to visit every day by many citizens as well as having a lot of traffic. Through the historic center of Athens, six specific points were selected, where the measurements were made. These were the Syntagma Square, Corner of Ermou and Evangelistrias, Monastiraki, Thissio, Acropolis, and Columns of Olympian Zeus. Regarding urban planning, Athens consists of tall buildings and narrow streets affecting air flows and air currents. In this way, the microclimate of the city is affected. In Figure 1, it appears that the specific points were chosen because they cover the perimeter of the historic center of Athens. Therefore, the data of the measurements are representative of the center of Athens.



(**a**) (**b**)

Figure 1. (**a**) The measurements points of the center of Athens, and (**b**) the distance between the two study areas.

Distances from one point to another (A, B, C, D on Figure 1a) in the center of Athens were about 10 min on foot, and the total of a complete route was approximately 4 km. The way the measurements were carried out between these points was on specific days of the week and at specific times. The second area, as already mentioned, was the Mt. Hymettus Aesthetic Forest (Figure 1b), which was located on the west side of Mount Hymettus in Attica. There, the sensor was permanently placed in a spot, receiving data 24 h a day. The purpose was to be placed in a spot where there was a frequent passage of people inside the forest. This particular area was chosen because it was a peri-urban forest with great influence of the city and was only 6 km from the center of Athens. It was also an innovative idea because such a comparison between in these two specific areas has never been observed before.

2.3. Data

This research followed an adopted methodology of low-cost sensor measurements [14]. In order to obtain the data with the purpose to receive the results, four main steps were followed. First was the registration in the real-time air quality monitoring system of PurpleAir, then the trial measurements, followed by the official conduct of the measurements, and, finally, the processing of the results.

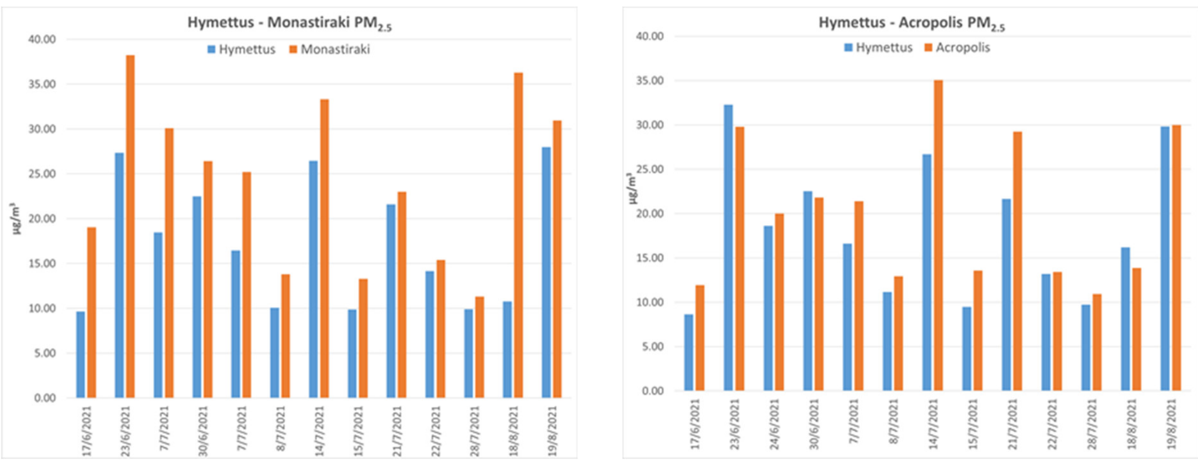
Moreover, a pre-processing stage started before the measurements. Initially, before using the sensors, it was necessary to register them with the real-time air quality monitoring system of PurpleAir and connect them to their map. In addition, a comparison was made between the sensors used for the measurements and the reference instrument. The two PurpleAir PA-II-SD sensors (ATH-ENV4 and ATH-ENV6) were placed in the same outdoor area together with the DustTrakTM DRX Aerosol Monitor 8533 high-cost and precision reference instrument for 12 days. The result of this comparison was that both PurpleAir sensors had a high degree of correlation of about 94% with the reference instrument for the value $PM_{2.5}$. Approximately the same results were obtained for the other parameters of PM_1 and PM_{10}.

Techniques used for processing the results were mainly based on the usage of Microsoft Excel and the PurpleAir platform. The sensor usually took measurements every two minutes. Moreover, in the center of Athens, there was a seven-minute stop at each point. As a result, the sensor recorded three distinct measurements. Consequently, for data classification in Microsoft Excel, only the data related to the hours during which the measurements were performed were selected. Using Microsoft Excel's data management capabilities, comparative charts were created and are presented in the results.

Some problems were encountered during this research, and they started in the summer of 2021 when, according to Dr. Dimitra Founta, Director of Research at the NOA Institute for Environment and Sustainable Development, the heatwave that hit Greece from late July to the first week of August was one of the worst in decades. It was definitely comparable to the historic heat waves of 1987 and 2007 [15]. According to the above, it was understood that the difficulty in conducting the measurements in the center of Athens was very big. In addition, hundreds of forest fires broke out in the summer of 2021 in Greece, many of which after 22 July, in the midst of unprecedented heat, which burned huge areas. Due to this, some measurements had to be excluded from the research to avoid distorting the actual data. On 4 August 2021, the National Observatory of Athens had appealed through social media to the residents of the Attica basin to stay in their homes with hermetically sealed windows and doors, and they should go outside only with a N95, KN95, or FFP2 mask, which provided protection against $PM_{2.5}$ particles [16].

3. Results

Regarding the main results of this research, the highest average values for PM_1, $PM_{2.5}$, and PM_{10} were observed at Monastiraki. In terms of $PM_{2.5}$, the biggest difference between the Mt. Hymettus Aesthetic Forest and the center of Athens (Monastiraki Point) in August was 25.53 µg/m^3. This difference was important and was a very important observation as we refer to the most harmful particles for health. On this day in the Monastiraki point, the value was 36.29 µg/m^3 while only 10.76 µg/m^3 in the forest (Figure 2a). In addition, the biggest differences for the whole study period were noted between Monastiraki and the Mt. Hymettus Aesthetic Forest were noted. However, all points had a much higher average value than the forest for all indicators. It is important to note that the highest mean value of the $PM_{2.5}$ (24.33 µg/m^3) was above the permissible limit of the world-known AQI index, showing "Moderate". All the high values recorded in the points for $PM_{2.5}$ were marked "Unhealthy for Sensitive Groups" and "Moderate", which meant that they were exceeding the allowed limit set by European Commission [17]. On the other hand, the smallest differences were observed between the Mt. Hymettus Aesthetic Forest and the point of the Acropolis (Figure 2b).



(**a**) (**b**)

Figure 2. (**a**) Comparability graph of average each day for $PM_{2.5}$ between the Mt. Hymettus Aesthetic Forest and Monastiraki point, and (**b**) comparability graph of average each day for $PM_{2.5}$ between the Mt. Hymettus Aesthetic Forest and Acropolis point.

A further essential finding is the difference in temperature values between the two areas. When the highest temperature recorded in the center of Athens was 43 °C, at the same time, the temperature in the forest, just 6 km away, was 37 °C (Figure 3). In terms of temperatures, observations revealed differences that reached up to 6 °C in the two areas both within the city of Athens.

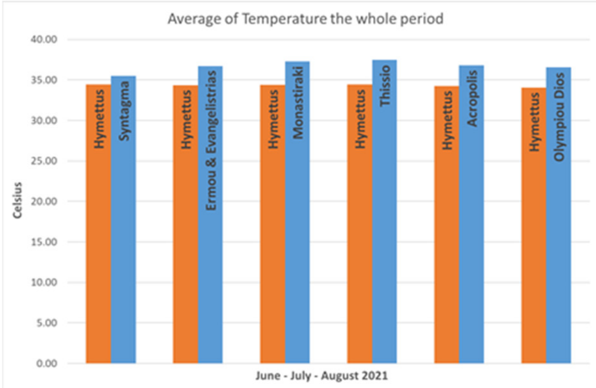


Figure 3. Comparability graph of average of temperature the whole period between the Mt. Hymettus Aesthetic Forest and each point of Athens.

Nevertheless, it is important that such measurements are made at various points and not at a specific one. Consequently, there is a real representative picture for the concentrations of the PM in the center of Athens. The initial prediction of the results concerning the large negative various values of the concentrations between the forest and the center of Athens was ascertained. Eventually, PurpleAir sensors were easy to use and made measurements easy and fast, so multiple point measurements were possible. Furthermore, the sensor that was permanently placed in the peri-urban forest due to its small size was discreet in space without altering the aesthetics of the natural environment. Overall, sensors could also be considered reliable during short measurement periods, as evidenced by post-use comparison.

4. Discussion and Conclusions

In conclusion, this research highlighted that areas with vegetation, even within urban environments, exhibit significantly improved conditions. In contrast to pollution hotspots, peri-urban spaces, especially large public parks, serve as essential air quality oases in densely populated cities. On the other hand, the findings in the center of Athens were that the concentrations were high on average, especially for $PM_{2.5}$. This is a cause for concern, as the measurements were specifically taken during the summer, a period known for increased tourism. However, Athenian residents typically take their summer leave during this time, resulting in significantly reduced traffic in the center of Athens compared to other times of the year. This was confirmed by an updated European Environment Agency analysis of air quality in Europe [18], which showed that the vast majority of Europe's urban population is exposed to levels of air pollutants in excess of the World Health Organization's new guidelines [19].

Low-cost air pollution sensors have emerged as a valuable tool for monitoring air quality in real-time and at a localized level. Traditionally, air quality monitoring has been conducted by government agencies using expensive and complex equipment, with limited availability of data for a few selected locations. However, low-cost sensors that are now available provide affordable and easy-to-use solutions for air quality monitoring, enabling monitoring in more locations and at a lower cost. This provides researchers with the opportunity to conduct studies encompassing a wider range of environments and demographics, thereby enhancing the characterizations of air pollution patterns and exposures. Low-cost sensors serve as valuable tools for advancing our understanding of air pollution sources, distribution, and associated health effects.

As for other research, this study is not free of limitations, and a more detailed statistical analysis is needed to evaluate the sensor data, as suggested by the authors in their previous work [3].

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