Proceeding Paper

The Influence of Meteorological Parameters on PM$_{2.5}$ Concentrations on the Aegean Islands †

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Abstract: A network of low-cost sensors operates at six islands in the Aegean Sea (Lemnos, Lesvos, Chios, Samos, Syros and Rhodes) providing real-time PM$_{2.5}$ concentrations to the public. In the present study, the effect of the prevailing meteorological conditions on the local air quality was examined. For this reason, data about wind direction, dry and wet temperature, wind speed and sunlight were provided by the Hellenic National Meteorological Service for the period from January to September 2022. The analysis of the hourly PM$_{2.5}$ concentrations revealed different air quality patterns on each island, as well as seasonal changes for the same islands (e.g., higher concentrations in Samos during the cold period). Temperature was found to contribute significantly to the PM$_{2.5}$ measurements since it affects the anthropogenic activities related to emissions. For instance, higher temperatures in winter result in limited residential heating needs.

Keywords: air quality; particulate; Aegean; Greece; meteorology

1. Introduction

Air quality remains among the most crucial issues since it affects human health and the environment [1]. Despite the measures taken, exceedances of the EU standards about pollutants’ concentrations are still recorded in many European cities. Air quality is affected by the dispersion of pollutants emitted by local anthropogenic activities (traffic, residential heating, port activities, industry) and natural sources. The prevailing meteorological conditions play an important role in the formation and distribution of the different pollutants [2]. Many cities with similar population densities and emission sources can have totally different environmental problems due to the existence of different meteorological conditions [3,4]. For instance, extreme ozone pollution episodes are usually recorded in the Mediterranean during summer due to sunlight and low wind speeds [5], as well as tropopause folds and stratosphere-to-troposphere transport [6]. However, many areas suffer from particulate pollution in wintertime because of the burning of biomass in combination with a low boundary layer (PBL) that prevents the dispersion of particulates [7,8]. Moreover, under favorable meteorological conditions, air masses can be transported from areas characterized by increased pollutants concentrations to nearby small towns [9]. Thus, the study of the correlation of the prevailing meteorological parameters with the measuring concentrations is of great importance.

Temperature and wind profiles, extreme wind speed, sunlight and humidity are among the meteorological parameters that contribute to formation of the measured pollutants’ concentrations [10]. In the present study, a statistical approach was followed to understand the impact of meteorology on the local air quality. The area of interest comprises six islands...
in the Central (Syros) and East Aegean Sea (Chios, Lemnos, Lesvos, Rhodes and Samos) on which a network of seven PurpleAir sensors has been established.

2. Materials and Methods

In this research, PM$_{2.5}$ hourly concentrations were measured by low-cost PurpleAir sensors located at six islands in the Aegean Sea (Figure 1). On Chios Island, two sensors were established at an urban and a suburban area of Chios City to further study the differences in the air quality at two areas characterized by different population densities and local sources. The Chios_urban sensor is located closer to the port area. Measurements were corrected based on the below equation:

\[
PM_{2.5, \text{corr}} = 11.051 + 0.423 \times \text{PM}_{\text{purpleair}} - 0.117 \times \text{RH},
\]

where PM$_{\text{purpleair}}$ is the average PM$_{2.5}$ concentration measured by the two channels, A and B, of the sensor and RH is the relative humidity.

![Figure 1. The network of air quality monitors in the Aegean Sea.](image)

For the correlation of the meteorological parameters with the particulate measurements, wind speed and direction, dry and wet temperature data were provided upon request by the Hellenic National Meteorological Service (www.emy.gr). Both time series (concentrations and meteorological data) cover the January–14 September 2022 period.

3. Results and Discussion

Summary statistics for several meteorological parameters, as well as PM$_{2.5}$ concentrations, are presented in Table 1. The mean dry temperature ranges from 17.1 °C (Samos) to 20.1 °C (Rhodes), while the maximum wind speeds are recorded in Syros. Northern winds prevail in Chios, Lemnos, Samos and Syros, while multiple wind directions are recorded in Lesvos and Rhodes. It is obvious that the lowest concentrations are measured on Syros Island (mean value: 8.5 µg/m$^3$). This is because it is an area of small population density, so the emissions from anthropogenic activities are low. In summer, even though the population increases due to tourism, the prevailing northern strong winds (called Etesians) disperse the pollutants. However, the Etesian winds can also negatively affect the local air quality by transporting polluted air masses from nearby large cities located in Eurasia (Istanbul, Black Sea) [11,12]. Lesvos (the city of Mytilene in particular, where the PurpleAir
sensor is established) appears to be the most polluted area among the six islands (mean annual PM$_{2.5}$ concentration: 14.3 $\mu$g/m$^3$). In general, for all islands, mean annual PM$_{2.5}$ concentrations are below the limit value set by the EU Air Quality Directives (25 $\mu$g/m$^3$) but are higher than the 5 $\mu$g/m$^3$ mean annual value proposed by the WHO Air Quality Guidelines. They are also lower than the ones measured in other urban areas in Greece (Athens [13], Thessaloniki [14], Patras [15]).

Table 1. Mean values of the dry and wet temperature, wind speed, the prevailing wind direction and PM$_{2.5}$ concentration on six islands in the Aegean Sea for the 1 January–15 September 2022 period.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Dry Temperature ($^\circ$C)</th>
<th>Wet Temperature ($^\circ$C)</th>
<th>Wind Speed (knots)</th>
<th>Max Wind Speed (knots)</th>
<th>Wind Direction</th>
<th>Concentration ($\mu$g/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chios</td>
<td>19.7</td>
<td>11.8</td>
<td>7.8</td>
<td>16.3</td>
<td>N (52.8%)</td>
<td>13.5</td>
</tr>
<tr>
<td>Lemnos</td>
<td>17.1</td>
<td>10.3</td>
<td>6.6</td>
<td>14.7</td>
<td>N (41.4%)</td>
<td>11.8</td>
</tr>
<tr>
<td>Lesvos</td>
<td>19.5</td>
<td>15.0</td>
<td>7.2</td>
<td>14.4</td>
<td>E (19.4%)</td>
<td>14.3</td>
</tr>
<tr>
<td>Rhodes</td>
<td>20.1</td>
<td>16.2</td>
<td>8.7</td>
<td>15.0</td>
<td>SW (24.2%)</td>
<td>12.2</td>
</tr>
<tr>
<td>Samos</td>
<td>17.1</td>
<td>14.6</td>
<td>7.0</td>
<td>14.4</td>
<td>N (49.5%)</td>
<td>13.4</td>
</tr>
<tr>
<td>Syros</td>
<td>19.0</td>
<td>11.4</td>
<td>11.5</td>
<td>21.0</td>
<td>N (36.9%)</td>
<td>8.5</td>
</tr>
</tbody>
</table>

3.1. PM$_{2.5}$ Concentrations and Temperature

The relationship between the PM$_{2.5}$ concentrations and dry temperature are presented in Figure 2 (the Chios_urban sensor was used for Chios Island). Most concentrations are below 20 $\mu$g/m$^3$, indicating that this amount of PM$_{2.5}$ is due to background concentrations and local sources that remain rather stable throughout the year (e.g., local traffic). In Samos, Lesvos and Chios, and to a lesser extent in Rhodes, peaks appear when the temperature is less than 12 $^\circ$C (wintertime). A further study of the PM$_{2.5}$ concentrations revealed that the values reach their maximum in the evening during wintertime. Probably, they are related to the fuel used for residential heating. Higher particles concentrations during the cold period compared to the warm period were also found by [16] in Lesvos. It is considered that wood burning contributes significantly to particulate pollution [17], and the maximum concentrations recorded during nighttime have been attributed to wood burning for residential heating by other researchers as well [18]. The estimation of the possible sources in the area of interest and the locals’ perception about air quality was attempted through the conduction of a survey. Responses revealed that in Samos, Lesvos and Chios, people usually use fireplaces and stoves and, consequently, biomass (e.g., wood, pellets) for residential heating. In general, the preference for residential heating means depends on the temperatures, the economic conditions and the availability of fuel. On the northern Aegean islands (with low GDP per capita and lower temperatures), stoves, fireplaces and central heating with oil are used. On the southern Aegean islands (high GDP per capita and higher temperatures), air-conditioning or heat pumps (both for winter and summer) are used. In addition, whereas Lesvos, Chios and Samos are islands with quite high forest cover and/or olive groves, Lemnos is mainly covered by bushes and low vegetation, so people prefer central heating (fuel used: oil), which is mainly associated with NOx emissions [17]. So, despite the low temperatures in winter, no exceedances of PM$_{2.5}$ concentrations are recorded in Lemnos. It should also be mentioned that the island’s capital, Myrina, where the sensor is located, is a small town (approx. 6000 inhabitants). Rhodes (Figure 2b) is characterized by mild winters; thus, the heating period is short, and people prefer to use air-conditioning (or heat pumps) as the main heating source and central heating and stoves secondly. As a result, low PM$_{2.5}$ concentrations are recorded even though the city of Rhodes is the most populated among all (approx. 50,000 inhabitants). No extreme values were measured on Syros during the cold period. Since brushes occupy a large part of the island, people use central heating and air-conditioning. In addition, the high winds on Syros (Table 1) disperse the pollution.
Figure 2. Scatter plots of hourly PM$_{2.5}$ concentrations (in µg/m$^3$) and dry temperature (in °C) for monitoring stations: (a) Samos, (b) Rhodes, (c) Lemnos, (d) Chios_urban, (e) Syros and (f) Lesvos.

3.2. PM$_{2.5}$ Concentrations and Wind Direction

Box plots of PM$_{2.5}$ concentrations in relation to wind direction are presented in Figure 3 for two selected islands, Samos and Rhodes, since they are characterized by different climatological conditions (warmer winters in Rhodes, sunny and hot summers), landscapes (the city of Karlovasi in Samos, where the sensor is located, is surrounded by a woody area, while there is low vegetation in the city of Rhodes) and population (Rhodes has approx. 50,000 inhabitants, Karlovasi has 7000 inhabitants). Increased concentrations on Samos are connected to low wind speeds (0–1 knots) from the northern direction (the fourth box plot in Figure 3a) and secondly from the NNW direction. On the other hand, on Rhodes, the outliers shown in Figure 3b (30 µg/m$^3$ < values < 40 µg/m$^3$) were recorded in February under the prevalence of strong southern and northwestern winds (>10 knots). However, values above 40 µg/m$^3$ are related to low eastern and southern winds (<4 knots). So, it is more likely, for both islands (Samos and Rhodes), that local sources contribute to the formation of the highest concentrations since the prevalence of low wind speeds prevents the dispersion of pollutants.
while the existence of strong northern winds (Etesians) helps the transportation of the pollutants far from the source. A further investigation of the particles’ chemical characteristics should provide evidence of the sources that determine the concentrations measured.

4. Conclusions

A network of low-cost sensors has been developed on six islands in the Aegean Sea (Lemnos, Lesvos, Samos, Chios, Syros and Rhodes) to examine the local air quality. In the present study, hourly PM$_{2.5}$ concentrations, as well as meteorological parameters, were collected for the period from 1 January to 14 September 2022. The correlation between PM$_{2.5}$ values and temperature indicated that the higher measurements are related to low temperature profiles and the use of biomass burning as fuel for residential heating. In areas where different appliances are preferred for heating (e.g., air-conditioning), there are no extreme PM$_{2.5}$ concentrations. Consequently, anthropogenic activities can highly affect the kind of pollutants emitted and thus the local air quality. Moreover, the prevalence of low wind speeds leads to increased concentrations due to the prevention of particle dispersion, while the existence of strong northern winds (Etesians) helps the transportation of the pollutants far from the source. A further investigation of the particles’ chemical characteristics should provide evidence of the sources that determine the concentrations measured.

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Figure 3. Box plots of hourly PM$_{2.5}$ concentrations (in µg/m$^3$) as distributed at different wind directions for (a) Samos and (b) Rhodes stations for the 1 January 2022–14 September 2022 period (wind direction: E stands for east, S for south, N for north, and W for west).
References


17. Fameli, K.M.; Papagiannaki, K.; Kotroni, V. Optimizing the knowledge on residential heating characteristics in Greece via crowd-sourcing approach. *Atmosphere* 2021, 12, 1178. [CrossRef]


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