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Seasonal fluctuations of $PM_{2.5}$ concentrations at six Greek islands

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Abstract $PM_{2.5}$ concentrations in urban areas vary significantly spatially and seasonally. Measurements can be affected by multiply parameters such as anthropogenic activities, meteorological conditions as well as land use. In the present study one-year $PM_{2.5}$ measurements from the network of low-cost sensors deployed at six Aegean Sea islands (Lemnos, Lesvos, Chios, Samos, Rhodes, and Syros) were used to study the seasonal changes and the possible impacts from the local sources (e.g., road transport, residential heating) on the air quality. It is the first time that such a long timeseries of $PM_{2.5}$ concentrations was collected simultaneously at islands with different socioeconomic characteristics (e.g., Syros and Rhodes are among the most popular touristic destinations in Greece) and meteorological conditions (longer warm period in Rhodes in comparison to Lemnos, Lesvos, and Chios). Moreover, citizens' insight on local air quality and emission sources was collected through the conduction of semi-structured interviews. Results revealed that lower $PM_{2.5}$ concentrations were recorded during the warm period and the range of minimum – maximum concentrations was smaller. In the cold period peak values were measured at Lesvos, Samos, and Chios mainly in the evening hours. Comparing the mean seasonal concentrations, it was found that the lowest values were measured at Syros for both warm and cold periods.

Keywords: $PM_{2.5}$, low-cost sensors, air quality, Greece, Aegean

1. Introduction

The local air quality is very important for people's health and wellbeing, and it is affected by anthropogenic activities as well as biogenic sources (EEA, 2022; Harrison, 2020). Although it is believed that in rural areas and small cities the pollutants concentrations are much lower than in metropolitan cities, this is not always true. The transportation of polluted air masses from nearby large urban areas (Triantafylllou et al., 2016), the seasonal increase of the population (e.g., touristic period, Zhang and Lu 2022) and thus the emissions from traffic and shipping, physical phenomena (e.g., Sahara dust events) and the types of fuel used for residential heating are among the parameters that can negatively affect the local air quality. The existence of a low-cost network of air quality sensors that operate on a daily basis can provide an insight of the conditions that influence the recorded concentrations (Kosmopoulos et al., 2022).

At the Aegean Sea (Eastern Mediterranean) a network of seven PurpleAir sensors has been established at six islands with different climatic conditions and emissions sources. The aim of this study is to present the seasonal changes in $PM_{2.5}$ concentrations at the area and identify the parameters that influence the recorded values.

2. Methodology

2.1. Study sites

The area of interest includes six different port-cities located at the Aegean Sea: Myrina (Lemnos Island), Mytilene (Lesvos Island), Chios (Chios Island), Karlovasi (Samos Island), Rhodes (Rhodes Island), and Ermoupoli (Syros Island) (Fig.1). They are small urban areas. The largest city is Rhodes (approx. 50,000 inhabitants) followed by Mytilini (28,000 inhabitants) and Chios (27,000 inhabitants). Ermoupoli has 11,500 inhabitants while Karlovasi (7,000 inhabitants) and Myrina (6,000 inhabitants) are classified as towns. It should be noted that in Rhodes (and less in Ermoupoli) the population increases dramatically in summer due to tourism, which is the main economic activity. According to the Eurostat Database the number of establishments and bed-places on islands at the South Aegean is six times higher than on islands at the North Aegean Sea. So, on the rest of the islands the economy is based mainly on the primary sector (farming, shipping, livestock) and secondarily on services (with public administration to be important in Lesvos). Apart from the anthropogenic activities, meteorology defines the local air quality. During summer, strong northern winds, called Etesian winds, blow over the Aegean Sea, contribute to the transportation of air masses from nearby large cities

and thus affect the local air quality (Dafka et al., 2021; Prezerakos 2021; Tombrou et al., 2015).

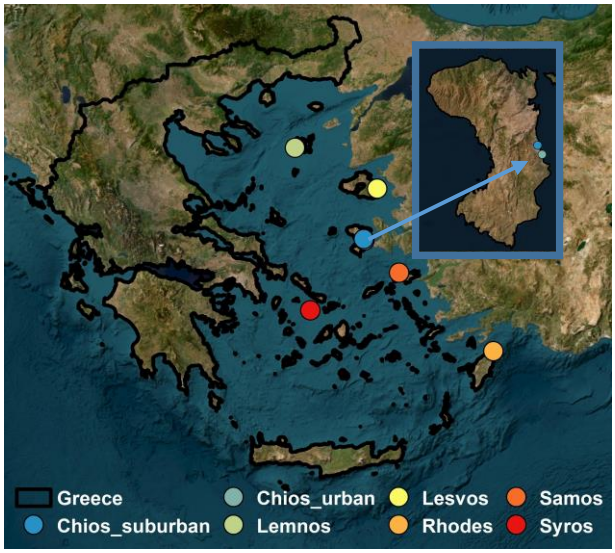

Figure 1. The network of air quality monitors at the Aegean Sea.

Table 1. Characteristics of the stations at the Aegean Sea.

#	Coordinates (lat/lon), altitude (a.s.l.)	Type	Station name
1	38.365/26.137, 19.2 m	Urban	Chios_urban
2	38.388/26.131, 42.8 m	Suburban	Chios_suburban
3	39.093/26.558, 16.0 m	Urban	Lesvos
4	37.445/24.942, 26.1 m	Urban	Syros
5	37.790/26.705, 37.3 m	Urban	Samos
6	36.427/28.222, 33.4m	Urban	Rhodes
7	39.879/25.064, 7.9 m	Urban	Lemnos

1.2. Instrumentation

$PM_{2.5}$ concentrations are reported continuously using Purpleair – PA II monitors. Each device has two sensors (channel A and B) the operation of which is based on laser particle counters and conversion of the signal to mass concentration values. For the needs of the present study, mean hourly values were used which were corrected based on the below equation:

$PM_{2.5,\ corr} = 11.051+0.423*PM_{purpleair}-0.117*RH$,

where $PM_{purpleair}$ is the average $PM_{2.5}$ concentration measured by the two channels and RH is the relative humidity. The PurpleAir monitors are located at the first floor of private or public buildings in the urban area of each island (except for station #2) as presented in table 1. Since the purpose was to study the representative levels of the exposure of the general population the sites were carefully selected in order not to be dominated by a single source (e.g., a manufacturing unit, a smokestack etc).

2. Results

The data completeness was above 95%, except for the sensor in Syros (80.8%). As presented in table 2 the average annual $PM_{2.5}$ concentration for each monitoring site is above the value of 5 μg/m^3 recommended by the World Health Organisation (WHO, 2021) for long-term exposure but below the limit value of 25 μg/m^3 proposed by the European Union Air Quality Directives (2008/50/EC, 2004/107/EC). Generally, the average annual concentrations for the year 2022 ranged from 7.40 μg/m^3 (in Syros) to 14.7 μg/m^3 (in Lesvos).

A seasonal pattern appears for Chios_urban, Lesvos and Samos sites with highest values to be recorded during wintertime (table 2), in accordance with the findings of Triantafyllou et al. (2020). These three islands are located at the Northern Aegean Sea and are characterized by lower temperatures during the cold period in comparison to areas in the Southern and Central Aegean Sea (Syros and Rhodes). The mean monthly temperature for January at Mytilini, Samos and Rhodes is 9.6ºC, 10.5ºC and 12.2ºC respectively (source: Hellenic National Meteorological Service). The examination of the diurnal variation of the mean hourly concentrations revealed a peak in $PM_{2.5}$ concentrations in the evening (26.1 μg/m^3 at 20:00 LT in Chios_urban, 25.9 μg/m^3 in Lesvos and 26.9 μg/m^3 at 18:00 in Samos) which is attributed to the residential heating. Semi-structured interviews conducted to the local citizens in terms of the heating appliance as well as fuel type revealed a preference for biomass burning in Samos. It is found that the use of biomass at fireplaces and stoves is related to increased particulate emissions (Fameli et al, 2022). Quite low values were recorded throughout the year in Lemnos since it is a region of low population. The monitoring site "Chios_suburban" is located at a suburban area close to pastures and brushlands, thus the increased $PM_{2.5}$ concentrations during spring can probably be attributed to biogenic emissions. Milder winter period at the Southern Aegean Sea leads to limited energy needs for residential heating and a shorter heating period. Consequently, the mean winter concentration is low at Rhodes even though 6700 people/km^2 live in the urban area (Batista et al, 2021), more than in the rest islands. Similarly, in Syros the mean $PM_{2.5}$ concentration in winter is below the mean annual value (7.4 μg/m^3). As shown in figure 2, the diurnal variation of $PM_{2.5}$ concentrations is flat for all the seasons in Syros while a rather small increase (about 4 μg/m^3) from the mean daily value appears in the evening (from 18:00 LT till 01:00 LT) during winter in Rhodes.

The lowest mean seasonal concentrations were found in autumn for all sites except for Samos where the values during autumn and summer were almost equal. The difference between the lowest and highest seasonal concentrations was larger for Samos (6.5 μg/m^3), Chios_urban (4.9 μg/m^3) and Lesvos (4.9 μg/m^3) sites due to increased winter values.

Table 2. Average seasonal and annual $PM_{2.5}$ concentrations (in μg/m^3) at each monitoring site for the year 2022.

	Chios_urban	Chios_suburban	Lemnos	Lesvos	Rhodes	Samos	Syros
autumn	10.49	9.56	8.80	12.3	10.7	11.3	5.50
spring	14.2	13.7	12.7	16.6	11.9	12.9	8.99
summer	12.0	11.0	9.96	12.4	12.4	11.3	8.25
winter	15.4	13.1	11.9	17.2	13.1	17.7	7.35
annual	13.0	11.8	10.9	14.7	11.9	13.3	7.40

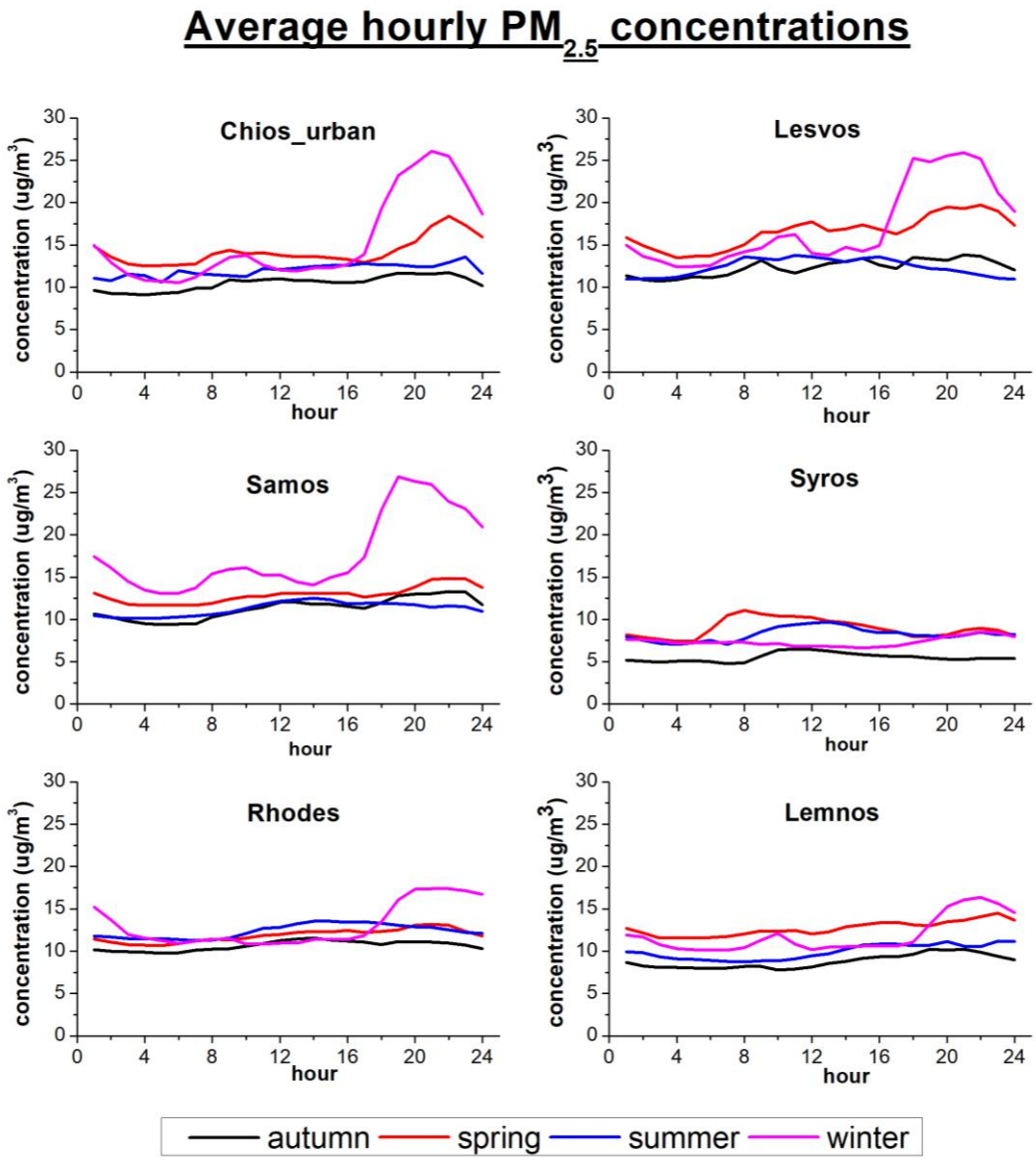

Figure 2. The diurnal variaton of $PM_{2.5}$ average concentrations at six measuring sites in the Aegean Sea.

The impact of tourism at the local air quality is obvious at the diurnal variation of the hourly concentrations (Fig. 2). During winter there is a morning peak which is attributed to the local traffic due to the beginning of working hours. The maximum values appear in the evening and are related to traffic and residential heating. However, for Rhodes and Syros the summer $PM_{2.5}$ concentration is the second higher, 4.6% and 11.6% above the mean annual value, 11.9 μg/m^3 and 7.4 μg/m^3 respectively (table 2). The diurnal profile of the mean hourly values for Rhodes and Syros reveals an increase of about 1.3 μg/m^3 and 1.3 μg/m^3 in summer from 09:00

LT till 16:00 LT, when compared to the mean hourly values. As mentioned above the local economy of these two islands is based mainly on tourism while at the islands located at the North Aegean Sea different economic activities prevail. Thus, the summertime diurnal profile of $PM_{2.5}$ concentrations remains below the winter values even though a small increase appears at the aforementioned period.

3. Conclusions

The main conclusions from the present study can be summarised as:

- The average annual $PM_{2.5}$ concentration is below the limit value (25 μg/m^3) proposed by the European Union Air Quality Directives for all the islands.
- A seasonal pattern was found at the monitoring sites located at the North Aegean Sea with higher values to be recorded during winter and especially in the evening.
- Climatic conditions affect $PM_{2.5}$ concentrations. Lower values are recorded during the wintertime in Rhodes city, despite the fact that it is the most populated area, due to the milder cold period and consequently limited needs for residential heating.
- The impact of tourism at the local air quality is obvious at the diurnal variation of the hourly concentrations for Rhodes and Syros islands since an increase is recorded during the period 09:00 – 16:00 LT which can be attributed to the traffic due to touristic activities.

Further steps will include the examination of the relationship between the recorded concentrations and the prevailed meteorological conditions as well as the further study of the daily variation in order to reveal qualitatively and quantitatively the sources that define the $PM_{2.5}$ concentrations at the six Aegean islands.

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