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The Air Quality and the Influence of Etesians on Pollution Levels in the Rhodes City, the Case of July 2022 †

Ioannis Logothetis *, Christina Antonopoulou, Georgios Zisopoulos, Adamantios Mitsotakis and Panagiotis Grammelis

Centre for Research and Technology Hellas, Chemical Process and Energy Resources Institute, GR 57001 Thermi, Thessaloniki, Greece; antonopoulou@certh.gr (C.A.); zisopoulos@certh.gr (G.Z.); adamis@certh.gr (A.M.); grammelis@certh.gr (P.G.)

* Correspondence: logothetis@certh.gr

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Abstract: In July 2022 strong and high-frequency northern sector winds blew over the Aegean Sea. The low tropospheric circulation in combination with the air quality and human comfort are of great importance for the climate and human health. This study investigates the variation of pollutants concentrations (PM_{10},NO_2,O_3 and SO_2), meteorological factors (temperature, relative humidity, wind speed and direction) and discomfort index in Rhodes city during July, 2022. Additionally, the impact of Etesians on pollution levels is studied. The strength of the Etesian flow is quantified by calculating a statistical index that takes under consideration the July pressure gradient (ΔP) over Aegean Sea. For the analysis, pollutants concentration recordings from a mobile air quality monitoring system during July 2022 and, mean sea level pressure (MSLP) data from ERA5 reanalysis during July for the period from 1980 to 2022 are analyzed. Results indicate that traffic affects the pollution level although the pollution limits, according to the European directive for air quality (2008/50/EC), are not exceeded. Findings also reveal an increase in ΔP, about 1.8 hPa, during 2022 compared to the period from 1980 to 2022 and the dipole of high (over Balkans) and low (over eastern Mediterranean) pressure centers also strengthens, leading to stronger winds over Aegean Sea. The ΔP is strongly correlated (0.8) to the first principal component of MSLP over the eastern Mediterranean. Finally, study shows that the Etesian flow tends to reduce the concentration of PM_{10},NO_2 and O_3 improving the air quality in Rhodes city.

Keywords: air quality; pollutants; discomfort index; Etesian flow; low tropospheric circulation; eastern Mediterranean; Aegean Sea; pressure gradient (ΔP); PC analysis; EOF analysis

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1. Introduction

In July 2022 strong northern sector winds blew over the Aegean Sea affecting tourism activities and sailing over the Aegean basin. Generally, the northern sector wind speed system during summer period is the dominant atmospheric circulation over the southeastern Mediterranean [1–4]. This annual permanent wind system has been known since ancient times. Aristotle gives these winds the name "Etesians" because they blow every year in the summer period and peak in July and August. The cause of this wind system is a pressure gradient that is created over the Aegean Sea [2,4]. In particular, a dipole of a high pressure center located in the Balkans-central Europe and a low pressure center located over southeast Mediterranean (as part of thermal low extending from the Indian

Monsoon through the Middle East to southeastern Mediterranean [2,5]) leads to the formation of a pressure gradient over Aegean Sea during the summer months [2,4,6]. The pressure gradient in combination with the topography of eastern Mediterranean, establishes the Etesian regime that transfers cool air masses from Caspian Sea and Russia to southeastern Europe acting as a "ventilation" system for the southeastern Mediterranean [7,8].

Poor air quality is a factor that increases the environmental danger and negatively affects human health [9]. Rhodes Island, located in the southeastern Mediterranean, is a desirable tourist destination. The increasing tourism industry (the high rate of tourist arrivals, the increased marine traffic, and cruise shipping) leads to the deterioration of air quality in this climate-prone region affecting the sustainable development [9–11]. Air quality over coastal regions is affected by traffic emissions, human activities and meteorological factors [10,12]. Logothetis et al. [10] have already shown that the urban region of Rhodes is affected by traffic emissions and pollution episodes that are related to the transfer of particle matter and gaseous pollutants from wildfire regions to the southeast Aegean Sea. The Etesian wind system is related to the improvement of the air quality over the Aegean Sea by dispersing the concentration of pollutants over the south east Mediterranean [5,8] whereas Etesians are associated with high wildfire risk during the summer season [13].

The current work studies the variability of pollutants concentrations (PM_{10},NO_2,O_3 and SO_2) and the impact of low tropospheric circulation on the pollution level of Rhodes city during the heart of the summer of 2022. It is important to highlight that the variation of the concentration of pollutants is sensitive to the impact of street planning due to its influence on local air mass circulation. In this context, the present study aims to investigate the impact of the tropospheric circulation of Etesians, which is the dominant summer circulation in the area, on the pollution level and variation of the pollutant concentration. Finally, this study could form the basis for the development of an air quality management plan that would provide data regarding summer atmospheric circulation indices and pollution levels associated with environmental and health risk.

2. Materials and Methods

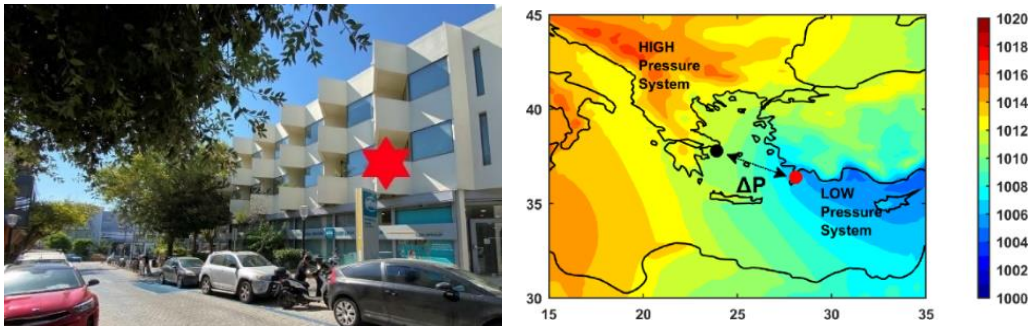
In this work, recordings from the Haz-Scanner™ HIM-6000 model, air quality monitoring station (AQMS) are used to analyze pollutant concentration variation. Recordings include: (a) the concentrations of particulate matter with a diameter less/equal to 10 μm (PM_{10}), nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2) as well as (b) the meteorological factors of temperature (T), relative humidity (RH), wind speed (WS) and direction (WDir). The air quality monitoring station is located on a high traffic road in the center of Rhodes city (Figure 1a). To investigate the impact of Etesian wind system on the pollutants concentrations, MSLP data available from the ERA5 reanalysis, in the frame of European Centre for Medium-Range Weather Forecasts (ECMWF), are analyzed in a spatial window over the eastern Mediterranean (15°–35° E, 30°–45° N).

In order to investigate the comfort sense of population during July 2022 in the city center of Rhodes the Thoms's discomfort index (DI) [14,15] is calculated. DI is considered as the most common bioclimatic index to express human experience under modified meteorological conditions following the equation:

$$DI(°C) = T - 0.55 \times (1 - 0.01 \times RH) \times (T - 14.5) \quad (1)$$

To study the frequency and quantify the strength of the Etesian flow over the Aegean the methodology of Dafka et al. [2] is followed, where the pressure gradient over the Aegean Sea is used to classify a day as an Etesian day. In our analysis, the July pressure gradient (ΔP) is defined by the difference between the pressure in the region of Elliniko (Attica) and Rhodes Island using MSLP data from ERA5 (Figure 1b). ERA 5 is a reanalysis dataset available in the frame of ECMWF that provides hourly estimates of a large number of climate parameters (atmospheric, land and oceanic variables). ERA5 combines

historical observations into global estimates using modelling and data assimilation techniques. Its spatial resolution is 31 km (grid) and the atmosphere is resolved by 137 levels (from surface up to 80 km) [16]. Regarding the analysis, a day is classified as an Etesian day when ΔP is greater than/equal to the median of the positive values of the ΔP distribution. Note that in this work the analysis is focused on July 2022 because this period presents a climatic interest (high-frequency of Etesians and high diurnal wind speed compared to the period from 1980 to 2022). To investigate the concentration of pollutants, during the studied period, the diurnal variation and the evolution of the daily mean concentration of pollutants for July 2022 are calculated. Additionally, the Spearman correlation coefficients among pollutants concentration, meteorological factors, and DI are calculated to investigate the possible association among these variables. Also, in order to identify the impact of Etesian flow on the pollution level in Rhodes city, the composite difference map of MSLP over the spatial window 15°–35° E, 30°–45° N is constructed. This analysis shows the changes in the high and low pressure system over the Balkans and the eastern Mediterranean, respectively. This dipole leads to the establishment of the pressure gradient over the Aegean Sea during summer months causing the Etesian flow. Furthermore, the difference of diurnal variation of (July) ΔP between 2022 and the period from 1980 to 2022 is calculated to investigate the diurnal changes of ΔP between two periods.



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

Figure 1. (**a**) Red star shows the location of the air quality monitoring system in the center of the Rhodes city (**b**) Map of the composite mean July MSLP (hPa) for the period from 1980 to 2022. The black/red points show the location of Elliniko (Attica)/Rhodes. The location of High and Low pressure system is also shown.

In climate studies the empirical orthogonal function analysis (EOF) is commonly used to investigate the spatiotemporal variability of climate variables and to identify patterns [17]. In this study the three dominant modes of EOFs and PCs that explain the 79.1%, 14.1% and 6.1% of MSLP over the eastern Mediterranean are estimated, respectively. Also, the EOF maps with the corresponding PCs (normalized) are constructed. Finally, the two-tailed t-test with 95% significance levels is used for statistical significance [18].

3. Results

Figure 2 shows the diurnal variation of the pollutants concentration, meteorological factors and discomfort index. This analysis shows that the concentration of pollutants is maximized during the hours with high traffic activity. The maximum concentration of NO_2 and O_3 occurs during the afternoon and midnight hours (Figure 2b,c). This change is probably explained by the combined effect of traffic emissions, photochemical and photolysis reactions as well as the diurnal wind speed variation (Etesian regime) [2,10]. Recordings show that the wind speed is presented to be increased about 30% at hours from 11:00 to 18:00 as compared to the other hours of a mean day of July 2022. The concentration of PM10 presents the maximum hourly values (about 30 to 40 μg/m³) during afternoon and early morning hours. A peak concentration (about 46 μg/m³) is presented about 12:00–13:00 (EEST) possibly due to the maximization of human activities and traffic emissions

during this time (Figure 2a). Additionally, during daytime hours the shipping and port activities are maximized. The activity of passenger and cruise ships in combination with traffic emissions in the center of Rhodes city possibly explains the variability of the concentration of PM10. The common diurnal variation of SO2 and PM10 possibly indicates the common origin of these pollutants (possibly the shipping). DI values vary between 22 and 25 which means that a significant percentage of population feels discomfort (Figure 2g). Generally, increased concentration of pollutants and high DI increase the risk to human health [5,10].

The daily mean evolution of the pollutants concentration during July 2022 does not present any daily mean exceedance of the threshold limit according to the European Air Quality Directive (2008/50/EC; Figure 3). Rizos et al. [8] and Logothetis et al. [10] have shown that strong wind speed is related to the reduction of pollutants concentration. It is likely that the strong winds that blow during July 2022 affect significantly the level of pollution in the center of Rhodes city.

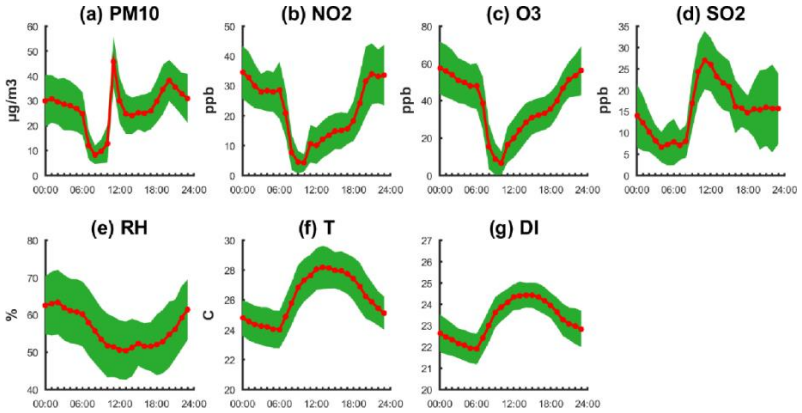


Figure 2. Diurnal variation for (**a**–**d**) the concentration of PM_{10},NO_2,O_3 and SO_2, (**e**,**f**) meteorological factors (RH,T) and (**g**) discomfort index (DI) for the center of Rhodes city during July 2022. The red line shows the daily mean value and the green area denotes the mean value plus/minus one standard deviation.

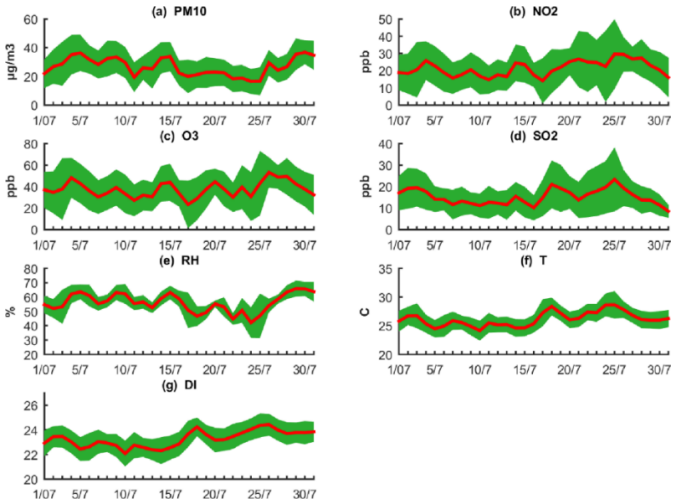
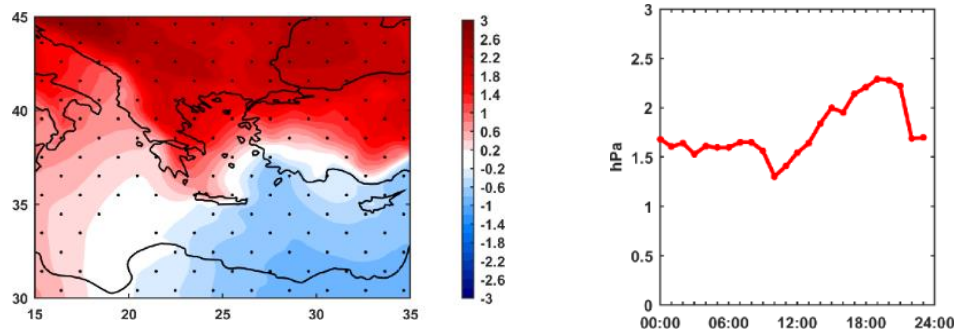


Figure 3. Daily mean variation for (**a**–**d**) the concentration of PM_{10},NO_2,O_3 and SO_2, (**e**,**f**) meteorological factors (RH,T) and (**g**) discomfort index (DI) for the center of Rhodes city during July 2022. The red line shows the daily mean value and the green area denotes the mean value plus/minus one standard deviation.

The July mean pressure gradient (July ΔP) over the Aegean Sea during 2022 was stronger about 1.8 hPa compared to the July mean ΔP from 1980 to 2022 period (recent past July period). This indicates the intensification of the Etesian regime in July 2022. The

difference between the composite mean (July) MSLP for 2022 and period from 1980 to 2022 shows that the high pressure center over the Balkan Peninsula increased and the low pressure center over the southeastern Mediterranean deepened (Figure 4a). The change of this dipole (defined by the two pressure centers) leads to the strengthening of ΔP and the wind speed over Aegean Sea. In addition, the diurnal variation of the difference of ΔP over the Aegean Sea between 2022 and the period from 1980 to 2022 shows that the ΔP is stronger in the afternoon and early evening (Figure 4b). This finding emphasizes that during July 2022 the diurnal variation of the Etesian winds shows high wind speed during the afternoon and night hours as well. According to the recordings, during the summer 2021, there are days with moderate air quality above the city center of Rhodes (in terms of CAQI index, [10]). The improved air quality during the summer of 2022 is likely influenced by the intensifying Etesian regime. The analysis shows that the frequency of Etesian days for July for the period from 1980 to 2022 is about 48% and for 2022 is about 81%, respectively (a relative increase of about 68%).

In order to further investigate whether changes in MSLP contribute to the increase in Etesians during July 2022, the three dominant modes of empirical orthogonal function (EOFs) and the corresponding principal component timeseries (PCs) of MSLP variability are calculated (Figure 5). The variation of the EOF1 shows an increase in MSLP over the east Mediterranean (Figure 5a). EOF2 and EOF3 show a north–south dipole that intensifies the pressure gradient over Aegean basin (Figure 5b,c). The analysis shows that ΔP is strongly associated with the PC1 (correlation coefficient ~0.8). Furthermore, ΔP is (significantly) negatively related to the concentration of PM_{10}, NO_2 and O_3 with correlation coefficient −0.45, −0.25 and −0.4. This result indicates that when the Etesian flow increases, in terms of ΔP, the pollutants concentration shows a decrease. In line with previous works [8,19], findings of this study possibly indicate the influence of Etesian winds variability on pollution level.



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

Figure 4. (**a**) Map of the difference between composite mean (July) MSLP (hPa) of 2022 and the period from 1980 to 2022 (**b**) Diurnal variation of the difference of (July) pressure gradient over Aegean between 2022 and (July) 1980–2022 period.

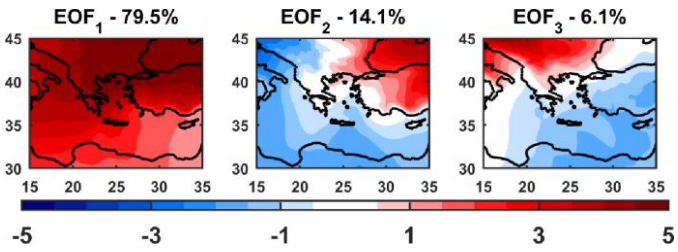


Figure 5. The three dominant EOF modes of MSLP between 15°–35° E and 30°–45° N for July 2022. The percentage of total variance explaining the pattern appears in the title of each subplot.

4. Conclusions

The investigation of the air quality and the influence of Etesians on pollutants concentration in the Rhodes city in July 2022 results in the following points:

- Traffic and human activity affect air quality although the pollution limits do not exceed the thresholds according to 2008/50/EC.
- The discomfort inex indicates that in some cases half of the population feels discomfort in the city center of Rhodes. The combination of high DI values and increased pollutants concentration negatively affects human health.
- ΔP is negatively associated with the concentration of PM_{10}, NO_2 and O_3 providing an evidence that the strong and high-frequency Etesians of July 2022 are related to improved air quality over southeastern Aegean Sea.

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