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The Impact of Climate Conditions and Traffic Emissions on the Pms Variations in Rhodes City during the Summer of 2021

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Abstract **-** The increased traffic and human activities worsen the ambient air quality by affecting human's health and environment. Additionally, climate conditions are considered as one of the major factors that affect the concentration of the most pollutants. The aim of this study is to investigate the impact of climate conditions and traffic emissions on the concentration of PM2.5 and PM10 (Particulate Matter) variability in the center of Rhodes city during the summer of 2021. For the analysis, a series of recordings from a mobile air quality monitoring system located in the city center as well as climatological parameters from the 5th generation ECMWF reanalysis (ERA5) are analysed. The analysis was performed during the period from July 17 to August 31, 2021. In order to investigate the effect of climate conditions on the concentration of PMs, maps of mean wind speed, relative humidity and temperature at 2m are constructed. To study the impact of the concentration of PMs on air quality, the Common Air Quality Index (CAQI) is calculated. During the summer of 2021, a number of wildfire events over southwest Turkey and Rhodes island affect the air quality in the eastern Mediterranean region. Composite maps of climate conditions between the wildfires season and the fire-free season, as well as the regression maps between a non-linear fire danger index (Fosberg Fire Weather Index; FFWI) and PMs variability are constructed in order to investigate the effect of wildfires on the air quality in the city of Rhodes. Findings show that the climatic conditions and traffic emissions are driving factors for the variation of PMs concentration. Finally, the current study highlights the importance of the development of green and sustainable technologies to improve the air quality of the cities.

Keywords**:** PM2.5, PM10, air quality, wildfires, Fire Weather index, climatic conditions, east Mediterranean, Aegean Sea, Rhodes

1. Introduction

Air pollution is one of the most important challenges in terms of climate change and human health [1]. The air quality constitutes a major global concern and a recognizable threat to environmental sustainability [2]. Increase pollution is associated with high health risks [3]. One of the major pollutants regarding health effects are the particulate matters (PMs). In particular, PMs are small-diameter airborne particles that penetrate the respiratory system via inhalation and they infest in lugs and bloodstream, causing health problems such as cardiovascular diseases, cancer, and central nervous system dysfunctions [1,4]. According to the Global Burden of Disease Study, the premature mortality from the ambient air pollution in 2015 is estimated at 4.2 million deaths [5]. In Europe cities a large number of habitants (about 80-85%) were exposed to PM2.5 which is higher than the limit of the World Health Organization (WHO) guidelines [6].

Climate and meteorological conditions are recognized as important factors that affect the air quality. Generally, wind speed and wind direction are considered as a dominant factor influencing the concentration of pollutants [7]. The orography and the atmospheric circulation patterns are dominant factors that affects the concentration of pollution. The transport and transformation of pollutants from continental Europe and western Asia as well as the transfer of desert dust in southern Europe affects the air quality of Mediterranean basin [7, 8]. Previous studies have already shown that climate conditions significantly affect the variability and concentration levels of pollutants. In particular, Han et al. [9] indicated that meteorological conditions could explain a high percentage of the variance (40-65%) in the concentration of ozone in eastern China. Recent studies have already shown that climatological conditions are related to pollution episodes and explain a significant amount of the variation of PMs [10,11,12,13]. For the eastern Mediterranean region, Logothetis et al. [7] have shown that the Etesian wind system acts as a driver for the variability of the concentration of pollutants in the city of

Heraklion in Crete. Etesian winds are permanent northern sector winds that blow during summer over Aegean Sea affecting low tropospheric circulation of the eastern Mediterranean [14,15] as well as the air quality of this region [7].

The traffic emissions and human activities lead to higher concentrations of pollutants [16] and contribute significantly to the air quality degradation. The vehicular traffic is usually considered an indicator of air pollution due to its impact on ambient air quality and local environments [17,18]. Moreover, the traffic density, the vehicle type and the distance from traffic roads are associated with the increased concentration of pollutants in the urban environments [18]. In this context, local authorities usually have adopted policies to limit the number of vehicles in the urban regions in order to improve air quality and promote health benefits [19,20]. In addition, the rapid growth of tourism industry is a significant factor that affects the air quality in touristic regions [21] and contributes significantly to the economic sector. Furthermore, tourism is a vital component for the sustainable development of the regions [22]. Generally, the touristic activities could be considered as a factor that contributes to climate change and to the increase of the concentration of pollutants [22]. The development of the tourism industry degrades the air quality over the Mediterranean region. In particular, Altinoz and Aslan [23] found a bidirectional causality between tourism and the concentration of PM2.5.

Another important contributor to the atmospheric aerosol loads for the Mediterranean basin is the fire events [24]. During the summer, warmer and drier climate conditions increase the fire danger occurrence [25]. Forest fires affect atmospheric chemistry and climate change [26]. Global warming may increase the danger of forest fires affecting the air quality. Southern Europe is considered a prone area to wildfire events (high fire risk) mainly during the summer period – from June to October [27,28]. Over the Euro-Mediterranean region large fire events occur. Fires have been estimated to account for a significant amount of annual emissions [27]. Greece is considered as one of the most sensitive regions of Europe regarding the fire events occurrence, especially in the summer months [29]. Aguilera et al. [30] have shown that PM2.5 from fires are more toxic than PM2.5 from other ambient sources.

This analysis examines the impact of climate conditions and traffic emissions in the variability of PMs in downtown Rhodes, located in Dodecanese, in the southeastern Aegean Sea. The urban area of Rhodes city is considered as one of the most important tourist destinations for the Mediterranean region and the medieval center of the city is designated as a UNESCO World Heritage Centre (https://whc.unesco.org/). There is a lack of studies regarding the investigation of the air quality over this region. This study aims to improve the knowledge about the effect of climate conditions and human activities on the variation of the concentration of PMs during the peak tourist period for the city in the context of green and sustainable development.

2. Data and Methods

The city of Rhodes is located in the north of Rhodes Island over the southeastern Aegean Sea (Fig. 1). The analysis employs recordings of particulate matter (PM2.5 and PM10) from a mobile air quality monitoring system (Haz-Scanner™ model HIM-6000; [31]) located in the center of Rhodes city (28°13'34.23" E, 36°26'18.55" N). The measurements include the hourly concentration of PM2.5 (μg/m³) and PM10 (μg/m³). The campaign is conducted during the summer period of 2021 (from July 17 to August 31, 2021). During the common period, hourly data from wind speed (WS; m/s), relative humidity (HR; %) and temperature at 2m (T; ºC), available from the 5th generation of European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis dataset (ERA5, spatial resolution: 0.25ºx0.25º), are also retrieved. At this point it could be noted that the days from August 2 to August 5 are excluded from the analysis because the wildfire events in Rhodes Island affected the electricity supply of the monitoring system and the recorded measurements.

The composite mean maps of the studied climate parameters are constructed in order to examine the mean climate conditions that possibly affect the variability of PMs. To investigate the influence of traffic emissions and wildfire events on air quality, the Common Air Quality Index CAQI was calculated [32]. CAQI was developed under the CITEAIR project and has been in use since 2006. The purpose of the index is to compare air quality among the European cities. According to the index, the air quality is classified into five pollution classes (very low; dark green, low; green, medium; yellow, high; red and very high; dark red). The composite difference maps of WS, HR and T between fire and non-fire

periods were constructed to investigate the impact of climate parameters on fire danger. The statistical significance is studied with a two-tailed t-test at a significant level of 95% [33]. To estimate the fire danger, a non-linear index (Fosberg Fire Weather Index, also known as Fire Weather Index; FFWI) is calculated over geographical window of the southeast Aegean and south coast of Turkey (23º - 35º E, 33º - 39º N). This index is suitable for interpreting the effects of variation of weather conditions (temperature, relative humidity and wind speed; [34]). The FFWI is defined by the following equations:

$$FFWI = \frac{\mathrm{n} * \sqrt{1 + \mathrm{WS}^2}}{0.3002} \tag{1}$$

$$\mathrm{n} = 1 - 2 * \left(\frac{\mathrm{m}}{30}\right) + 1.5 * \left(\frac{\mathrm{m}}{30}\right)^2 - 0.5 * \left(\frac{\mathrm{m}}{30}\right)^3 \tag{2}$$

where n is the moisture damping coefficient, WS is the wind speed (miles/ hour), m is the equilibrium moisture content which is given as a function of Temperature (°F) and humidity (HR; %).

- For HR<10%

$$\mathrm{m} = 0.03229 + 0.281073 * \mathrm{HR} - 0.000578 * \mathrm{HR} * \mathrm{T} \tag{3}$$

- For 10%<HR≤50%

$$\mathrm{m} = 2.22749 + 0.160107 * \mathrm{HR} - 0.01478 * \mathrm{T} \tag{4}$$

- For HR>50%

$$\mathrm{m} = 21.0606 + 0.005565 * \mathrm{HR}^2 - 0.00035 * \mathrm{HR} * \mathrm{T} - 0.483199 * \mathrm{HR} \tag{5}$$

Finally, the regression analysis (Theil-Sen estimator; [35,36]) of FFWI fields on the hourly concentration anomalies of PMs normalized to the standard deviation of each pollutant is calculated to study the relation between the fire danger over the southeastern Mediterranean and the variability of PMs in the city of Rhodes.

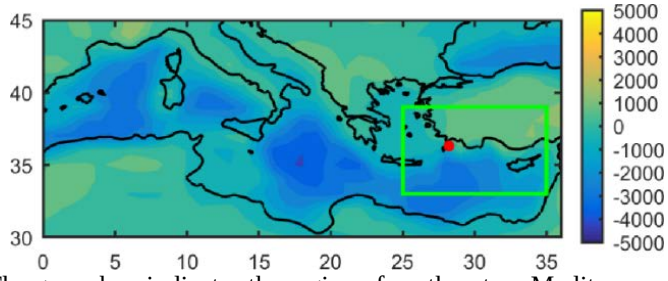

Fig. 1: Mediterranean topography. The green box indicates the region of southeastern Mediterranean and the red point indicates the city of Rhodes.

3. Results

Figure 2 shows the composite mean of wind speed (WS) relative humidity (RH) and temperature (T) at 2m over the southeastern Mediterranean during the studied period. The Etesian regime (northern sector winds) clearly affects the low tropospheric circulation, acting as a ventilating system for the Aegean basin ([14]; Fig. 2a). Previous studies have also shown that Etesian wind system is related with improved air quality regarding their ability to spread the pollutants [37,38]. The significant negative correlation (about -0.4 to -0.6) between the WS and the concentration of PMs in the Rhodes city indicates that the high WS is related with improved air quality. The relative humidity (HR) shows values about 20% to 60% for

southwest coastal Turkey and about 50% to 70% for the Rhodes region (Fig. 2b). The mean temperature at 2m (T) over Rhodes Island and the coasts of southwestern Turkey is higher than 30 ºC (Fig. 3c). These climatic conditions show that during the summer period, the decreased RH and increased T are associated with a high danger for wildfire event

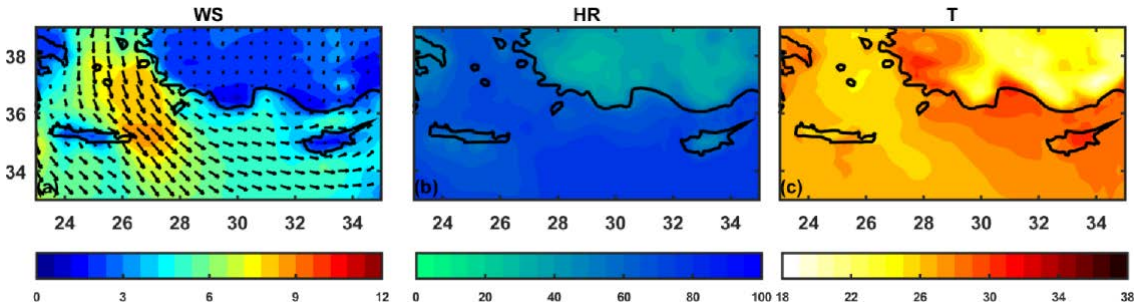

Fig. 2: Composite mean maps of (a) wind speed (m/s), (b) relative humidity (%) and (c) temperature (ºC).

In order to study the impact of PM2.5 and PM10 concentration on the air quality degradation in the city center of Rhodes, the Common Air Quality Index (CAQI; [32]) is calculated. The analysis shows that during fire periods (from July 27 to August 12, 2021) the CAQI for PM2.5 is mainly classified in the medium air quality class (Fig. 3a). During the pre-fire period (from July17 to July 26) the air quality is fairly good (classified as very low and low according to CAQI; Fig. 3a). Additionally, the CAQI for PM2.5 indicates that air quality during the period from July 27 to August 1 and from August 5 to August 11 (period with fire events) is mainly classified as medium (Fig. 3a). These findings show that the wildfire events are associated with the degradation of air quality over the city center of Rhodes affecting the concentration of PMs. During 20th, 24th, and 25th August (days without wildfire events) the air quality is classified as moderate (Fig. 3a). This result indicates that the effect of human activities and traffic emissions affect the air quality in the city center of Rhodes. Previous studies have already shown that traffic emissions have a significant footprint on the concentration of the majority of pollutants leading to air quality degradation [16,18]. The CAQI for PM10 shows that the classes of air quality are very low, low and limited medium, corresponding to a very good, good and moderate air quality (Fig. 3b). The CAQI for PM2.5 is classified as medium (9 out of 12 days) during the fire studied periods. Additionally, the CAQI for PM2.5 come under the medium class during 20th, 24th, and 25th August due to traffic emissions, touristic and human activities. Green technologies such as electric and hybrid vehicles can lead to an improvement of the air quality with a substantial contribution to health benefits [39]. For the concentration of PM10, only one insignificant exceedance of the daily limit is recorded by the mobile monitoring system (on August 7th the recorded concentration of daily PM10 was about 50.24 μg/m^3). To sum up, the analysis shows that the fire events over the eastern Mediterranean, the traffic emissions and human activities have a significant impact on the pollution levels of Rhodes city, affecting the variability of the concentration of PM2.5 and PM10.

Generally, the hot weather and the hydrological (dry) conditions increase the fire danger during the summer months. Additionally, climate change may increase wildfire events [25] in the future. In order to study the climate conditions regarding the fire danger over a geographical window (please see green box in Fig. 1) around Rhodes Island, the composite difference maps of wind speed, relative humidity and temperature at 2m between period with fire events and period without fire events are constructed (Fig. 4). The analysis shows that the WS is increased about 0.8 m/s to 1.5 m/s around Rhodes Island (Fig. 4a). The RH decreases (about 10% to 30%; Fig. 4b) and the T increases (about 1ºC to 5ºC; Fig. 4c), respectively. These statistically significant changes increase the danger for wildfire occurrence over the southeast Mediterranean and Aegean basin. The fire events in southwest Turkey in combination with the pattern of wind speed and direction (Etesian winds; Fig. 2a) promote the transfer of PMs from the burning regions of southwest Turkey to Rhodes Island. The analysis shows that the wildfire events as well as the low tropospheric circulation and the climatic conditions over eastern Mediterranean contribute to the concentration of PMs in the city of Rhodes.

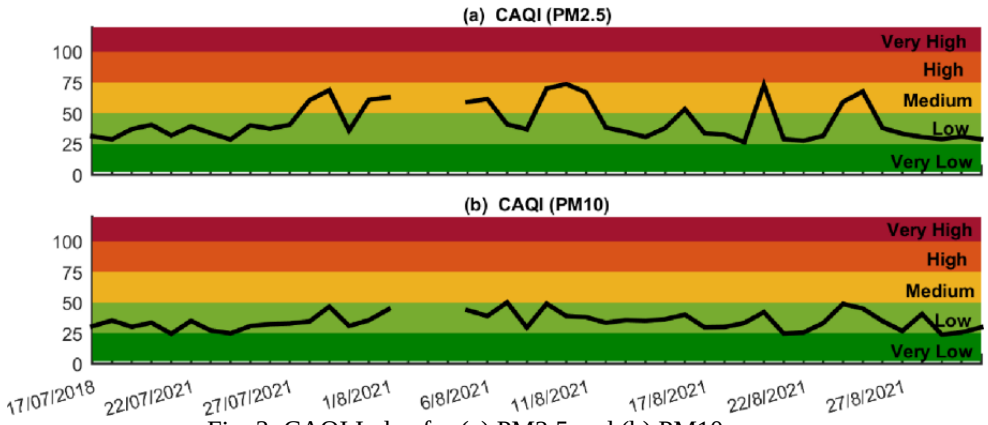

Fig. 3: CAQI Index for (a) PM2.5 and (b) PM10.

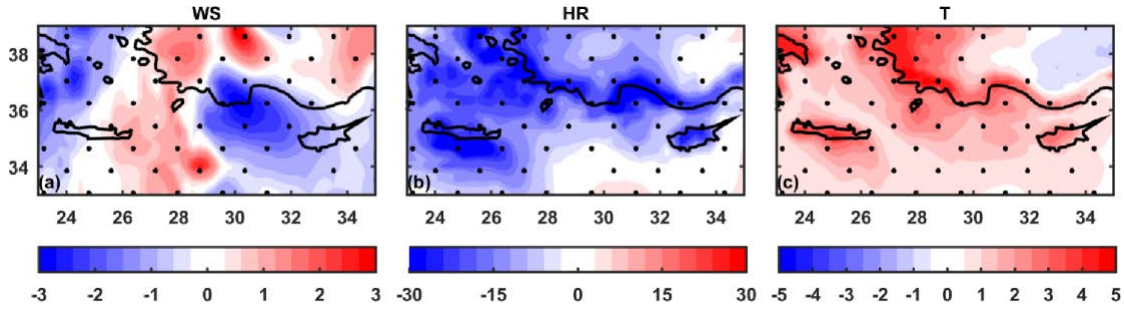

Fig. 4: Composite difference maps between fire and non-fire period for (a) wind speed (m/s) (b) relative humidity (%) and (c) temperature (ºC). Stippling denotes the statistically significant areas at the 95% level.

In order to further investigate the association of wildfire events on the air quality of Rhodes city, the Theil-Sen regression of the FFWI hourly anomalies (calculated from ERA5 data) on the hourly concentration anomalies, normalized with a standard deviation of each PMs (PM2.5 and PM10 - recordings from monitoring station), are calculated (Fig. 5). The analysis shows positive regression values over the southwest Turkey and Rhodes Island. This result indicates that the FFWI is associated with the increase of the concentration of PMs. Moreover, the analysis shows that the wildfire events (combined with appropriate climate conditions – in terms of WS, HR and T) act as a driver for the hourly variability of the concentration of PM2.5 and PM10 in the city center of Rhodes.

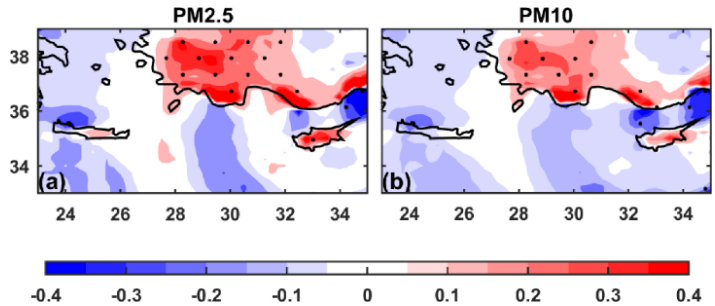

Fig. 5: FFWI fields regressed on the hourly concentration anomalies of (a) PM2.5 and (b) PM10 normalized with the standard deviation of each pollutant. Stippling denotes the statistically significant areas at the 95% level.

4. Conclusion

This study investigates the impact of climate conditions, human activities and traffic emissions on the variation of concentration of PM2.5 and PM10. For the analysis, recordings from a mobile monitoring system located in the centre of Rhodes city combined with data from ERA5 reanalysis are studied at the peak of the tourist period. Results indicate that the climate conditions the concentration of pollutants over Rhodes city, resulting in the improvement of air quality. In particular, the wind speed show significant negative correlation (about -0,4 to -0,5) with PMs. Moreover, the air quality in the city center is influenced by the traffic density and touristic activity in the region. The calculation of CAQI for PM2.5 and PM10 shows that the air quality ranges from very good to moderate classes. This analysis indicates that the human activities and the wildfire events that occur in southwestern Turkey and Rhodes Island are associated with the degradation (higher CAQI values) of the air quality in Rhodes city. Additionally, the low tropospheric circulation pattern, in terms of wind speed and direction, contributes to the transfer of PMs from wildfire regions, in southwestern Turkey, in the city of Rhodes. Finally, the analysis emphasizes the illustration of the air quality conditions in the city of Rhodes and highlights the need for the development of a green and sustainable management for this socio-economic center of southeastern Greece.

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