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# Air Quality and Climate Comfort INDICES over the Eastern Mediterranean: The Case of Rhodes City during the Summer of 2021 †

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**Abstract:** Climate and weather conditions have a profound influence on human comfort and discomfort sense. In addition, the impact of emissions and human activities on air quality seems to be scientifically indisputable. The maintenance of low levels of environmental nuisance in areas of high environmental and cultural interest, such as some Greek islands, is becoming increasingly important. Thus, exploring the combination of the effect of air quality and climate comfort in a high-traffic area falls within the scope of the principles and practices of sustainable development in such areas. The current study aims to shed some light on this field, for the case of Rhodes city which is located in eastern Mediterranean, during the summer of 2021. For the analysis, measurements of the concentration of pollutants ($PM_{2.5}$,$NO_X$ and $O_3$) and meteorological recordings (wind speed, wind direction and temperature) from a mobile air quality system located in the center of Rhodes city were conducted. Furthermore, meteorological data from the ERA5 reanalysis (wind speed, temperature, relative humidity, precipitation, cloud cover and height of boundary layer) over a geographical domain around Rhodes Island are included in the study. Results show that climate conditions and emissions are closely linked to traffic and tourism activities, which in turn affect the variability of pollutant concentrations. The calculation of the discomfort index shows that during the period of higher levels of air pollution, the population of Rhodes city feels partially comfortable, while the holiday climate index values show that the climatic conditions are suitable for tourist activities. In conclusion, this study could enhance our understanding of climate comfort and air quality by providing some evidence of the benefits of implementing a sustainable development policy in such tourist areas.

**Keywords:** air quality; climate comfort; climate conditions; discomfort index; holiday climate index; Rhodes city; eastern Mediterranean; sustainable development

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## 1. Introduction

Tourism is a contributing factor to global economic growth. The World Travel & Tourism Council shown that before the COVID-19 pandemic crisis, the economic footprint was growing due to tourism, providing a huge potential for the economic sector (about 10.5% of GDP) [1,2]. Even though tourism was heavily influenced by COVID-19 restrictions, 2021 showed a slow recovery, still remains lower than the pre-pandemic period [3]. The Mediterranean region is one of the most significant tourist destination due to the temperate climate, the mild weather, the sandy beaches as well as the rich cultural heritage. In particular, the region of the medieval and modern city of Rhodes in the

southeast Aegean Sea over eastern Mediterranean attracts a large number of people every year. The old city of Rhodes has been registered as an UNESCO World Heritage Site [4]. Moreover, the port of the city is an important passenger and trade center for the eastern Mediterranean.

The Mediterranean region is prone region to impending climate change [5]. Global warming over the Mediterranean could negatively influence the economic sector and tourism [6]. Additionally, high level of pollution can affect climate change and vice versa [7]. In general, atmospheric circulation patterns and climate conditions significantly affect the air quality of coastal regions [5]. Previous studies have shown that higher wind speed and precipitation contribute to the reduction of the particulate matter and gaseous pollutants in the troposphere [5,6]. In addition, the boundary layer height (BLH) affects the mixing ratio over the atmosphere. In particular, BLH impacts on the concentration of pollutants because the pollutants are diluted over the near surface layer [10]. Another important factor that influences air quality, especially in the summer months, is the meteorological conditions that affect the likelihood of wildfire events [9,11]. In particular, in the summer of 2021 the wildfires over southeast Mediterranean significantly deteriorate the air quality over the city center of Rhodes. Synchronously, high traffic emissions due to tourism activity seem to be associated with the fluctuations in concentration of particle matter (PM2.5 and PM10) [9].

Environmental conditions (climate and weather) influence the comfort scenes and human health. The bad air quality and adverse comfort conditions negatively affect the urban population and enhance the Urban Heat Island phenomenon [12]. In general, climate indices are a simplified way to quantify the impact of climate conditions on human health and the average person's sense of comfort [2,12]. Discomfort is associated with a high incidence of disease and mortality rate [12,14]. Previous studies have shown that human discomfort can be quantified using climate parameters such as temperature, humidity, wind speed etc. [2,12,13]. In order to study the climate sustainability in tourist regions, the holiday climate index (HCI) is developed as an indicator, especially for the tourism climate comfort [2,16].

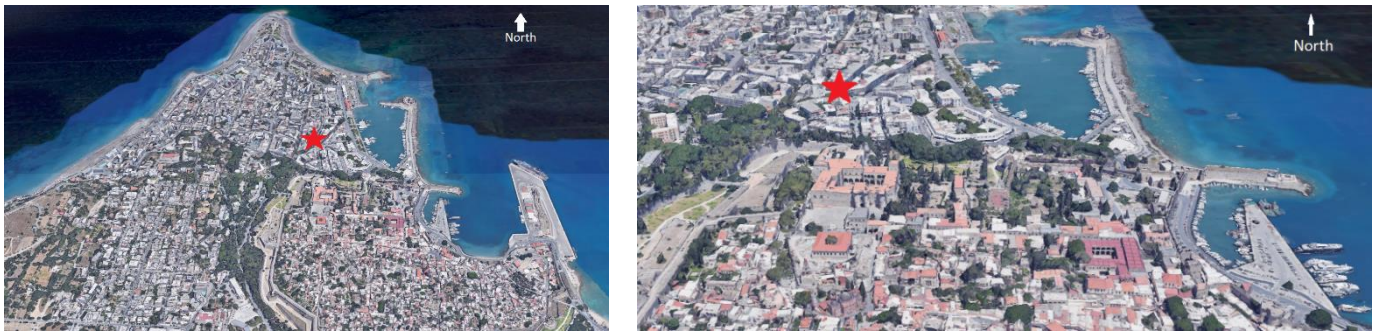
This work follows up the analysis of Logothetis et al. [9] by providing elements on air quality and climate comfort indices for the case of Rhodes Island during the summer of 2021. The study goes beyond emphasizing the impact of emissions and climate features on the air quality and human comfort in the city of Rhodes.

## 2. Data and Methods

For the analysis, hourly recordings of the concentration of $PM_{2.5}$, $NO_X$ $(NO + NO_2)$ and $O_3$ from a mobile air quality monitoring system (AQMS; Haz-Scanner™ model HIM-6000 [9] as well as climate factors (boundary layer height; BHL, precipitation; pr, wind speed; WS, wind direction; WDir, cloud cover; cv, temperature at 2 m; T and relative humidity; HR) derived from ERA5 reanalysis are used. The AQMS is located in the center of the Rhodes city [9] (Figure 1). In order to study the impact of climate conditions on the variation of the concentration of pollutants, composite difference maps between high touristic (from 13 July to 31 August, 2021; HP) and low touristic activity period (from 22 September to 3 October, 2021; LP) is implemented. HP and LP are considered representative to investigate the impact of anthropogenic emissions (traffic emissions and tourist activities) on air quality of Rhodes city. The odd ratio (OR) shows the strength of the relation between two events indicating the odds for when an event occurs, given a particular influence (outcome) compared to the odds of the outcome occurring in the absence of the outcome [17]. Hours with low BLH/(*concentration of pollutants*) are those with BLH/(*concentration of pollutants*) less than or equal to the first quartile of its distribution. Therefore, low BLH/(*concentration of pollutants*) is defined as "exposure"/("*outcome*"). The OR of the low height of BLH and the concentration of pollutants are calculated. The OR equal to 1.0 means that there is no association between "exposure" and "outcome". OR less/(*higher*) than 1.0 (the null value) indicates

increased/(*decreased*) likelihood to occur an hour with low concentration of pollutants during an hour with low BLH. The statistical significance is assessed by the confidence intervals (CI) at 95%.

The impact of climate conditions on human health and senses quantified by the Discomfort Index (DI) and Humidex (HI) [2,12,13]. Holiday Climate Index (HCI), the impact of climate conditions on the tourism, is also calculated during the period from 17/7 to 5/9, 2021. For the calculation of climate indices the methodology of Poupkou et al. [12] and of Demiroglu et al. [2] are followed using climate parameters from ERA5. The calculation of HCI takes under consideration the thermal comfort (which indicates how the average human feels the humidity and temperature), the aesthetic, the precipitation and wind speed [2,16]. Note that for the analysis the ranking of aesthetic is calculated using cloud cover and the ranking of thermal comfort using the HI [2]. Finally, the regression coefficient between DI and pollutant concentration was calculated in order to investigate the combined effect of air quality and comfort conditions on the population. For the statistical test, a two-tailed t-test at a significant level of 95% is used to study the statistical significance [18].




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

**Figure 1.** The position of mobile monitoring station (red star): (**a**) in the city of Rhodes and (**b**) focusing in the area near the mobile monitoring station. (source: Rhodes city. Google Earth v9.159.0.0. 36°26′49″ N and 28°13′15″. (**a**) ~1700 m (**b**) ~800 m, assessed: 17 May 2022).

## 3. Results

Figure 2 shows the daily evolution of the concentration of $PM_{2.5}$, $NO_X$ and $O_3$ as well as meteorological parameters (T, WDir and O3) during the examined period from 17/7 to 3/10, 2021. During LP, where the traffic rates and tourist activities are lower compared to HP, the concentration of pollutants decreases. In particular, between LP and HP, the concentration of $PM_{2.5}$ reduces ~9 μg/m$^3$ and NOx ~10 ppm whereas the concentration of $O_3$ does not change significantly, possible due to the variation of seasonal solar activity and photochemical activity [5,9]. Furthermore, the temperature decreases from July to October (Figure 2d Wind speed and direction changes, between LP and HP, are not statistically significant due to the high variation of WS and WDir (Figure 2e,f). According to Logothetis et al. [9] the Etesian regime is the dominant climatic pattern over the low troposphere for the studied region explaining the WS and WDir pattern. Additionally, they showed that the wildfires and traffic emissions determine the variation of particle matter in Rhodes city during the summer of 2021.

In order to investigate the impact of climate factors (BLH, pr, and WS) on the air quality of Rhodes, data from ERA5 and recordings from the AQMS are combined to calculate the maps of composite difference between HP and LP. The analysis shows that BLH presents a lower height during HP compared to LP, increasing the probability of higher concentration of near-surface pollutants (Figure 3a). The differentiation of pr between HP and LP is insignificant around Rhodes Island (Figure 3b).

During HP the WS decreases over the central Aegean and over the region eastern of Crete Island whereas the WS does not change significantly around Rhodes Island. To

further investigate the relation between low height of BLH and high concentration of pollutants the odd ratio (OR) is estimated. The analysis shows that the probability of the increased concentration of pollutants is higher in the presence of a low BLH, compared to the hours with high BLH. In particular, the analysis shows for the $PM_{2.5}$ -OR = 11/ $CI_{95\%}$: 7.6–15.9, for the $NO_X$ -OR = 17.8/ $CI_{95\%}$: 11.7–27.1, and for the $O_3$ -OR = 20.8/$CI_{95\%}$: 13.6–31.7. The $CI_{95\%}$ does not include the null value (OR = 1.0) and the results are statistically significant ($p$-value < 0.05). This analysis provides evidence for the association between low BHL and increased concentration of pollutants over the Rhodes city. Please note that the analysis is mainly focused on the period after wildfire events (from 27-7 to 15/8, 2021) because the impact of fires on the air quality of Rhodes city has already studied in our previous work [9].

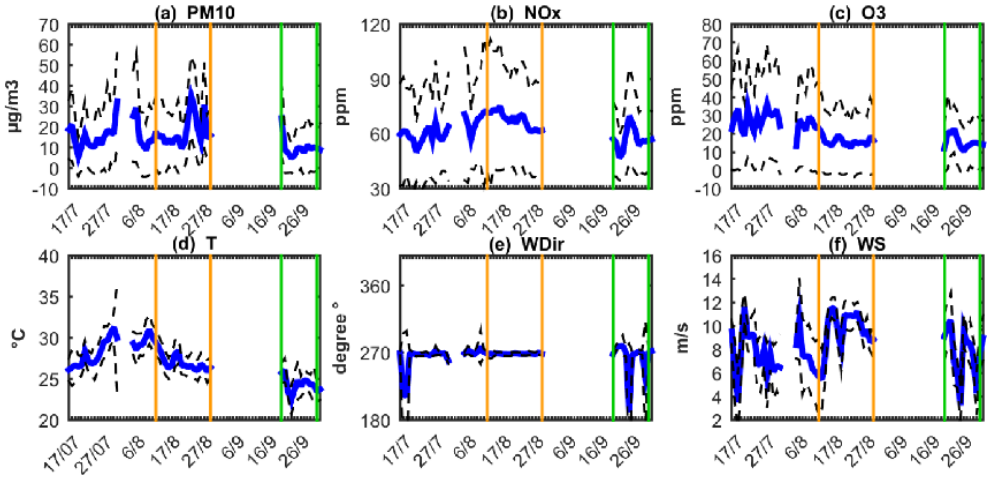



**Figure 2.** Timeseries of (**a**–**c**) the concentration of pollutants $PM_{2.5}$, $NO_X$ and $O_3$3 and (**d**–**f**) the metrological factors T, WDir and WS. The orange/(green) lines denote the high/(low) emissions period.

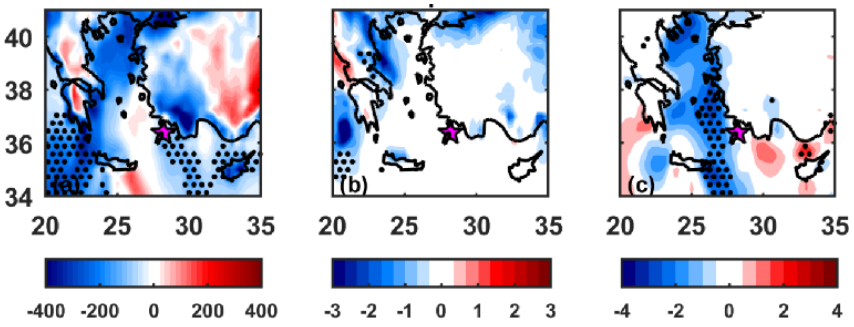
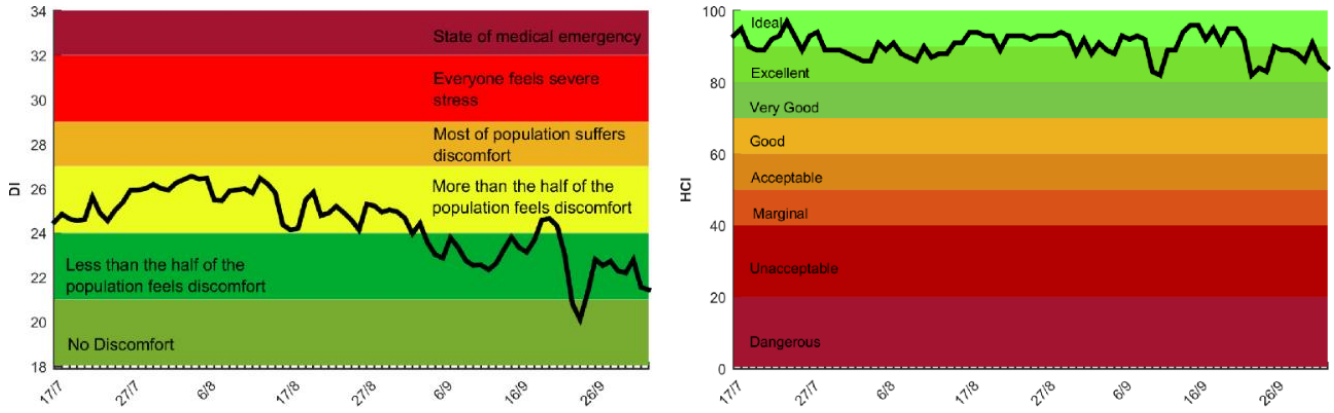



**Figure 3.** Composite difference between HP and LP for the (**a**) boundary layer height, (**b**) precipitation, (**c**) wind speed. The dotted region represents the statistically significant difference at 95%, as estimated using a Student's $t$ test.

To investigate the influence of climate conditions on human health and tourism sustainability, DI as well as HCI are estimated for the summer of 2021. For the calculation of climate indices data from ERA5 were retrieved. During the period from 17/7 to 5/9 the calculated values of DI indicate that more than half of the population feels discomfort (Figure 4). During this period the concentration of pollutants is increased as compared to the last period from 5/9 to 3/10. In particular, the concentration of PM2.5 presents some daily exceedances of the threshold (25 µg/m$^3$) due to traffic emissions and wildfire events (Figure 1a). Logothetis et al. [9] have already shown that during the period from 17/7 to 5/9 the CAQI is classified as moderate for the ~33% of the days. The combination of high DI with the increased concentration of pollutants (PM2.5) increases the risk to human health. Poupkou et al. [12] have shown that there is a strong correlation between air

quality degradation and DI (DI greater than or equal to 24ºC is associated with high CAQI). The current analysis shows that the regression coefficient of DI with the concentration of PM2.5, NOx and O3 is significantly positive (equal to 0.11, 0.12 and 0.1, respectively with $p$-value < 0.05). This relation indicates that during the days with high concentration of pollutants the discomfort index is also high. This result is an evidence for the combined effect of climate conditions (in terms of DI comfort index) and the air quality on the human sense and health in Rhodes city.

Figure 4b shows the HCI which is indicative for the sustaining of tourism destinations [2]. Results of the calculation of HCI show that the climate conditions are classified as excellent and ideal over the region of the Rhodes city.




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

**Figure 4.** (**a**) Discomfort Index and (**b**) Holiday Climate Index for the city of Rhodes during the summer period of 2021.

## 4. Conclusions

This work shows the combine effect of climate conditions and traffic emissions on the human comfort sense and air quality of Rhodes city during the summer of 2021. Findings show that the high tourist activity is related to poor air quality due to high traffic emissions and human activities. At the same time the air quality degrades and the discomfort feeling is enhanced. This combined effect could have an impact on the comfort sense and health risk of the population. The calculation of Holiday Climate Index (HCI) shows that Rhodes is classified as a sustainable tourist destination in terms of climate conditions. Finally, further investigation of air quality and climatic indices in touristic regions in combination with the promotion of green vehicle technologies could provide a resilience context for the sustainable development over the region of southeast Aegean.

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