Proceedings of the 10th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2025)
Barcelona, Spain - April, 2025
Paper No. ICEPTP 168
DOI: 10.11159/iceptp25.168

The air quality in a touristic area of southeastern Mediterranean: The case of Chalki Island during a summer and autumn period of 2024

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Abstract – Environmental sustainability is one of the Smart Specialization Strategy (S3) priorities for Greece. The relation between air pollution and human health consists a challenging issue regarding the green transition of Islandic place-based ecosystems of Mediterranean region. In this context, this work is a case study which investigates the air pollution and its impact on human health using recordings from a mobile air quality monitoring system (AQMS) which is located in the port of Chalki Island (in the southeastern Aegean basin), covering the period from 24th July to 25th November 2024. Hourly measurements of concentrations of pollutants (particulate matter with diameter less than equal 2.5 and 10 μm, nitrogen dioxide and ozone) as well as meteorological factors (temperature and relative humidity) are analysed. The Air Quality Health Index (AQHI) and Discomfort Index (DI) are calculated as a measure of the impact of air pollution on human health and discomfort sense of population. The diurnal, daily and monthly mean variation of the concentration of pollutants, AQHI and DI are studied. Additionally, the possible relation between the air pollution and its impact on human health is investigated. Findings show lower concentrations of pollutants than the limits of Directive EU 2024/2881. AQHI mainly ranges between "good" and "moderate" classes. The maximum concentration of pollutants is shown during summer period where the tourist density is increased. Finally, the analysis highlights that the increased discomfort conditions (temperature and DI) and AQHI in summer period (as compared to the autumn) could have a negative synergy on human health and feeling.

***Keywords*:** air quality, health risk, low cost sensors (LCS), southeastern Mediterranean, Aegean Sea

1. Introduction

The air quality is considered as priority from World Health Organization (WHO) regarding its impact on health and quality in humans' life. In particular, WHO emphasizes on health risk that is related to high concentration of basic pollutants such as particulate matters (PM2.5 and PM10), nitrogen oxides (NOx), ozone (O3) etc. [1]. It is known that the synergy between degraded air quality and extreme weather conditions negatively affects human health triggering various health disorders such as cardiovascular, cognitive issues and respiratory diseases [2,3,4]. In literature various indices have been developed to describe the air quality conditions and humans' discomfort sense expressing health risk and feeling sense of mean population. In particular, Air Quality Health Index (AQHI) provides a measure that reflects health risk that is related to air pollution [5,6]. Additionally, Discomfort Index (DI) is a measure that reflects human discomfort feeling that is associated to weather conditions (temperature and relative humidity) providing messages to inform and protect people's health [2].

Generally, the anthropogenic emission sources are an important factor that affect the air pollution and contribute to the degradation of socioeconomic and climate resilience of ecosystems [7,8]. Some of the dominant factors that affect the air quality over Islandic Mediterranean area are traffic (i.e. the vehicles) and other anthropogenic activities such as port and tourist activities [2,9]. In Islandic Greek region, where tourism is one of the fundamental socioeconomic activities, vehicle and shipping traffic (arrivals, departures and manoeuvring) determine the air pollution levels and the pollutants profile [9,10]. In addition, atmospheric and weather conditions influence the level of pollution [11,12]. Wind speed, precipitation and relative humidity are some of the climate factors that affect the concentration of pollutants. Furthermore, the weather conditions influence discomfort conditions affecting the feeling for the mean population [12].

European Union (EU) has as a strategic priority the energy sector, air quality and socioeconomic sustainability for Islandic ecosystems ("Clean energy for EU is-lands" initiative) [13]. In the context of "GR-eco Island" initiative and S3 priorities, the Greek government promotes sustainable and green development, circular economy, energy autonomy and digital innovation over the Greek Islands by 2030 [14]. The socioeconomic challenges in combination with climate danger for the regional-based ecosystems of eastern Mediterranean increase the risk affecting the socioeconomic and climate resilience over this sensitive area [13-15]. The increased penetration of renewables, the waste and water management, promotion of clean energy, zero emissions and measures for pollutants reduction, electro-mobility and green transformation, sustainable tourism, and the development of green ports are some of the actions of national S3 (2021-2027) priorities that promote the sustainability in social, financial and environmental sectors [15]. "NHSOS" project involves actions which promote a holistic model for the sustainable development of selected Islandic vulnerable Greek ecosystems over the Aegean Sea (namely: Chalki, Antikythera and Kastelorizo Islands). The project's actions involve circular economy, decarbonization, waste and water management practices, climate and air quality studies, innovative technologies for green ecosystems, energy autonomy, environmental protection actions etc. Results of project are expected to be a pilot for the sustainable development of other Islandic areas with common features [16].

This study investigates the air quality, the impact of air pollution on human health and the discomfort conditions in the port region of the city of Chalki. Chalki is a small Island with ~ 500 citizens which is located in the southeastern Aegean Basin, in eastern Mediterranean. For the analysis, recordings of a calibrated AQMS are analysed. Generally, these systems are equipped with various sensors to measure air quality and meteorological parameters. Despite the uncertainties to capture the absolute values of concentrations of pollutants, these types of systems are a vital solution regarding the investigation of the concentration of pollutants over the areas where no previous systematic measurements have done before. In addition, the affordability, mobility and high spatiotemporal coverage of these systems provide the ability for air quality investigation in cases that show special features (i.e. difficulties in energy supply) [9,17,18]. The analysis was conducted during a period that covers the summer and autumn seasons of 2024 (from 24th July to 25th November) where the traffic and touristic activities are increased (during the first period, July and August months) and reduced during the second period (autumn), respectively. The analysis is focused on the investigation of pollutants variability and their impact on human health using the AQHI and DI indices [2,6,9]. Results aim to provide elements, following up the analyses of previous studies that are focused on the investigation of air pollution and the impact of atmospheric circulation features as well as traffic activity on the air quality of southeastern Aegean (Rhodes Island) [3,6,9]).

This work is organized as follows: In section 2 ("Materials and Method") the data and methods that were used in this work are presented. The main findings are shown in section 3 ("Results"). Finally, the main points of this study are concluded in "Conclusion" section.

2. Material and Methods

In this work, hourly measurements of particulate matters (PMs) with diameter less/equal than 2.5 and 10 μm (PM2.5 and PM10), nitrogen dioxide (NO2), and Ozone (O3) as well as the meteorological factors of temperature and relative humidity (Temp. and HR) from a mobile air quality monitoring system (AQ-Mesh AQMS; [9,19]) are analyzed. During the measurement campaign the AQMS was calibrated and follows all the standards that are provided by the constructor. The system was located in the area of Port of Chalki Island (**Fig. 1**). The location was selected in order to provide elements regarding the air quality over the port area. This region is a high traffic area for the city of Chalki with increased activities such as vehicle and shipping traffic mainly during summer period (high touristic season).

The air quality measurements were conducted during the period from 24th July to 25th November 2024 covering a summer and an autumn period (two periods with different traffic profile). During summer months the tourist activities are increased and during autumn period traffic density and population are significantly reduced compared to summer season. This traffic variation possibly affects the air pollution levels over the region. In this study, hourly mean values of concentration of pollutants (namely, O3, NO2 and PM2.5) and meteorological factors (temperature and relative humidity) are employed in order to calculate the AQHI and DI [2,5,9]. AQHI is a measure regarding the air quality that provides the population with a health message which is related to the level of pollution. For the calculation of AQHI the

Eq.1 is followed [5]. Table 1 shows the classes of AQHI and the related health suggestions for the population. DI provides messages for discomfort feeling of population regarding the temperature and relative humidity conditions [2]. For the calculation of DI the Eq. 2 is used. The classes and the related messages to DI are presented in Table 2.

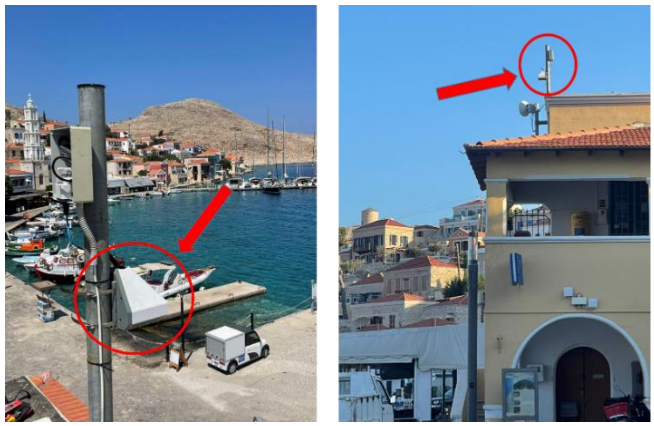

Fig. 1: The location of the mobile air quality system (AQMS) in the Port of Chalki Island in souteastern Aegean Sea in two different visions

$$AQHI = \frac{10}{10.4} * \left(100 * (e^{0.000871*NO_2} - 1 + e^{0.000537*O_3} - 1 + e^{0.000487*PM_{2.5}} - 1)\right) \quad (1)$$

$$\mathrm{DI}(°\mathrm{C}) = \mathrm{T_h} - 0.55 \cdot (1 - 0.01 \cdot \mathrm{RH_h}) \cdot (\mathrm{T_h} - 14.5) \quad (2)$$

Table 1: The classes of AQHI

Health Risk	**Air Quality Health Index (AQHI)**	**Health Suggestions**	
		Sensitive population	**General Population**
Low	1 - 3	Enjoy your usual outdoor activities.	Ideal air quality for outdoor activities.
Moderate	4 - 6	Consider reducing or rescheduling strenuous activities outdoors if you are experiencing symptoms.	No need to modify your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	7 - 10	Reduce or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	Consider reducing or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very High	>10	Avoid strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	Reduce or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

Table 2: The classes of DI.

Class number	DI (°C)	Discomfort Conditions
1	DI < 21	No discomfort
2	21 ≤ DI < 24	Less than half of population feels discomfort
3	24 ≤ DI< 27	More than half of population feels discomfort
4	27 ≤ DI < 29	Most of population suffers discomfort
5	29 ≤ DI < 32	Everyone feels severe stress
6	DI ≥ 32	State of medical emergency

To investigate the relation among air quality factors and meteorological conditions [20] for the port area of Chalki Island, Pearson correlation coefficients among the PMs (PM2.5 and PM10), AQHI, DI are calculated. This analysis could provide elements regarding the relationship among air pollution parameters, meteorological conditions and impacts on human health [9]. In order to further investigate the degraded conditions (in terms of high temperature and increased AQHI as well as increased values of DI and AHQI) the Risk Ratios (RR) for the days with high temperature/DI and high AQHI are calculated. Here, RR is considered as a measure of the risk of a high temperature/ DI happening during the days with high AQHI compared to the risk of the same event happening during the days with low AQHI. As days with high/low temperature, AQHI and DI are considered the days that temperature, AQHI and DI are higher/ lower than the value of the third/ first quartile (Q3/ Q1) of the distribution of each one of these parameters (temperature, AQHI and DI), respectively [21,22]. For the calculation of RR the following equation (Eq. 3) is used:

$$\mathrm{RR} = \frac{Propability\ of\ getting\ high\ AQHI\ (AQHI > Q3)\ if\ Temperature\ is\ high\ (T > Q3)}{Propability\ of\ getting\ high\ AQHI\ (AQHI > Q3)\ if\ Temperature\ is\ low\ (T < Q1)} \tag{3}$$

3. Results

The daily mean concentrations of PM2.5 and PM10 are lower from the daily limits (25 and 45μg/m³, respectively) according to the European Directive for the air quality [23] (**Fig. 2a**). The monthly mean concentrations of PM2.5 and PM10 are increased during the warm period (days from 24^{th} July to 31^{st} August, summer period) as compared to the autumn months (from 1^{st} September to 25^{th} November 2024). In particular, the mean concentration of PM2.5 is about 4.2 μg/m³ during summer period and it is reduced to 2.5 to 2 μg/m³ during the autumn period (a reduction about 1.5 to 2.0 μg/m³), respectively (**Fig 1b**). For the monthly mean concentrations of PM10, the summer period shows mean values about 8.0 μg/m³ dropping to 6.5 and 5.6 μg/m³ for September and October, respectively. The daily mean variation of AQHI and DI shows negative trend during the studied period. AQHI is about 5.5 at July-August period and it reduces to 4.2, 3.0 and 2.8 over September, October and November (**Fig. 2e**), respectively. The common variation is also shown for the DI where July-August DI is about 27 and it reduces to 25, 22 and 19 over September, October and November (**Fig. 2g**), respectively. This analysis indicates that the air quality during summer period is more degraded (higher concentrations of pollutants) as compared to the autumn period. This result in combination with the increase of DI values during the warm period (as compared to autumn period) shows that the measurements of air quality parameters in real time could provide important information regarding the protection of the population mainly during the high tourist season.

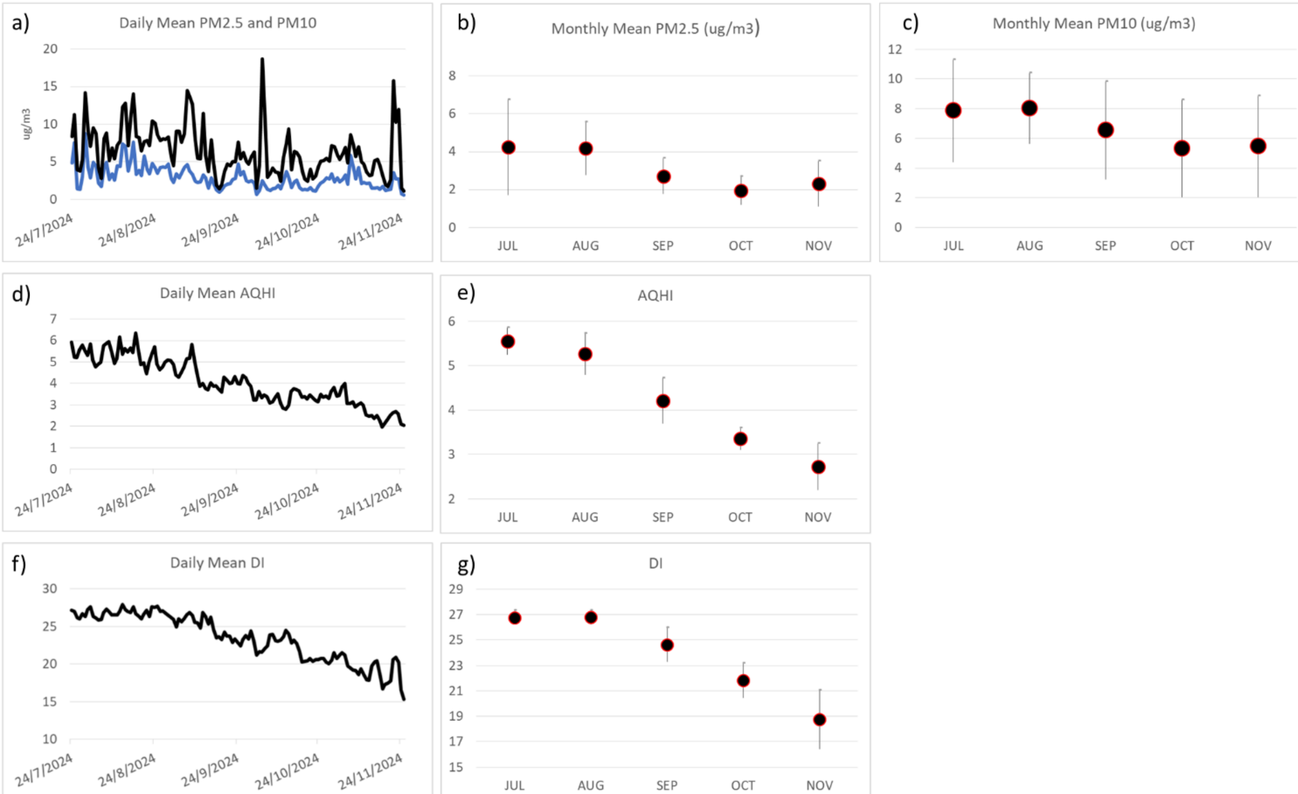

Fig. 2: Daily mean evolution (a,d,f) and Monthly mean values (b,c,e,f) of the concentration of PM2.5 and PM10 as well as AQHI and DI. The whiskers indicate mean value plus/minus one standard deviation.

Fig. 3 shows the diurnal variability of PMs, AQHI and DI for each month as well as the anomalies of diurnal variability of PMs, AQHI and DI for each month with reference to the diurnal mean cycle of August (August diurnal cycle minus the other month diurnal cycle). In general, the concentrations of PMs are increased during the non-daytime hours. Possibly, the impact of wind speed and the diurnal cycle of the height of the boundary layer (PBL) in combination with the traffic profile of the port area determine the mean PMs diurnal profile. Previous studies over the region of southeastren Aegean have already shown that the variation of PBL and wind speed significantly affect the concentration and variability of air pollutants. In particular, the wind speed and PBL are increased during daytime hours contributing to the reduction of the concentration of pollutants [9,24]. The AQHI are maximized during the hours between 16:00 and 20:00 (**Fig 3c**) and the DI between 11:00 and 16:00, respectively (**Fig 3d**). The analysis indicates that August shows the maximum concentration of PM2.5 and PM10 (**Fig. 3a'&b'**). Additionally, the summer period shows degraded conditions regrading AQHI and DI as compared to the autumn months (September - November, 2024). In order to study the relationship among PMs and bioclimatic indices (AQHI and DI), the Pearson correlation coefficients among the concentration of pollutants and Indices are calculated. The correlation values show that the PMs are "moderate" correlated to AQHI. In particular, the correlation coefficient between daily mean concentration of PM2.5 and AQHI is about 0.61 and between PM10 and AQHI about 0.45, respectively. In addition, the correlation coefficients between DI and PM2.5 is about 0.55 and between DI and PM10 about 0.47, respectively. Finally, the daily mean AQHI and Temperature are "high" correlated (about 0.91) indicating a possible synergy of these features on human health.

In order to investigate the relation between daily mean temperature and AQHI as well as the daily mean DI and AQHI, the related scatter plots are constructed **(Fig.4)**. The analysis shows that the days with higher temperature tend to present higher AQHI (positive trend, R^2=0.82) **(Fig. 4a).** In addition, the days with higher DI tend to present higher AQHI (positive trend, R^2= 77) **(Fig. 4b)**. The calculation of RR shows that the probability of higher temperature and higher AQHI is increased compared to the opposite event (RR= 29.33/ CI (95%): 4.2 to 204.9/p-value <0.05). In addition, the RR between higher temperature and high AQHI shows that the probability of higher DI and higher AQHI is increased compared to the opposite event (RR= 26.03/ CI (95%): 3.7 to 186.5/p-value <0.05). These results emphasize the possibly negative impact of the synergy between degraded air quality (in terms of AQHI) and discomfort conditions (in terms of DI and temperature) on human health.

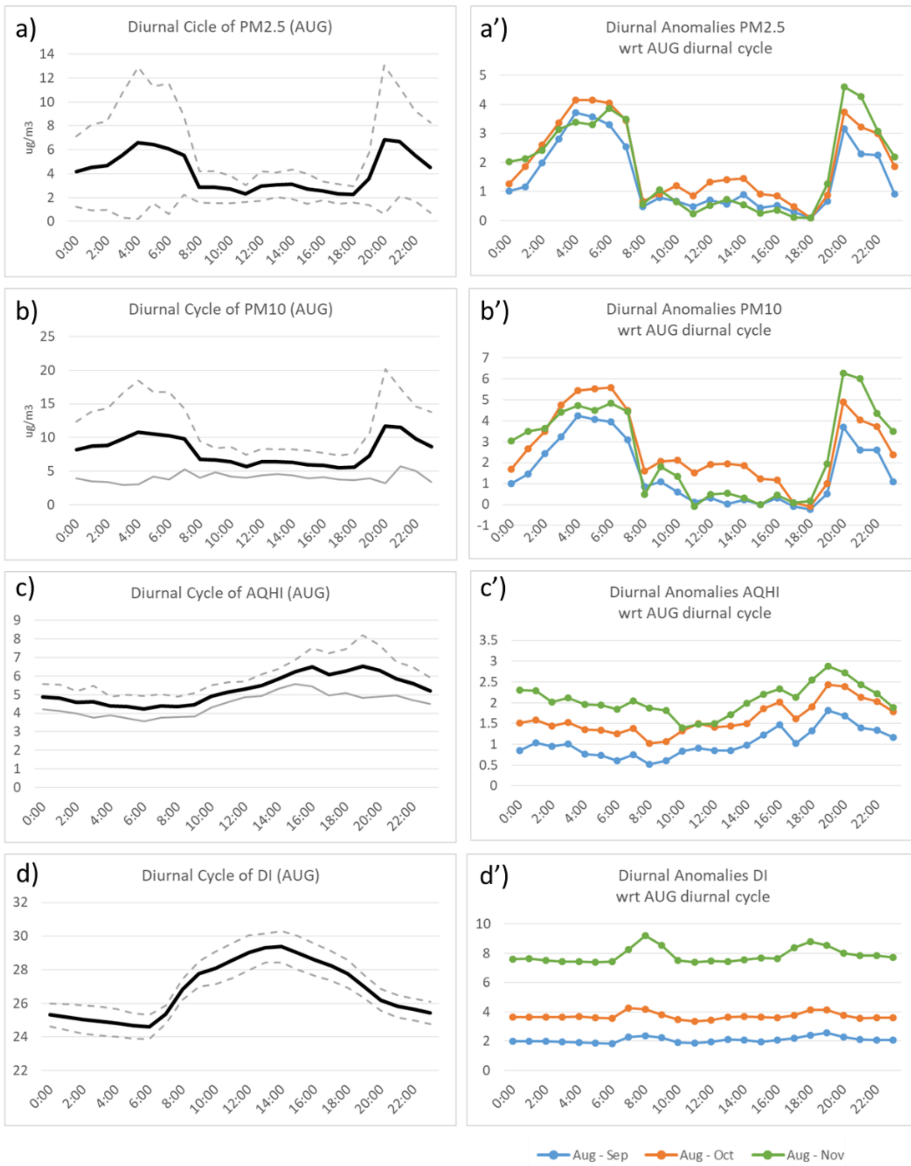

Fig. 3: Diurnal cycle of PM2.5, PM10, AQHI and DI (first column) and the diurnal mean anomalies of PM2.5, PM10, AQHI and DI with reference to August mean diurnal cycle (second column). The blue/orange/ green colour indicates the diurnal anomalies of August minus September/October/November, respectively.

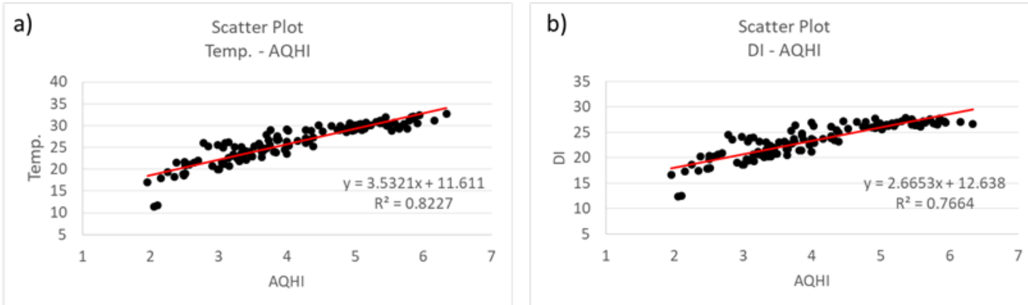

Fig. 4: Scatter plot of daily mean Temperature and AQHI as well as DI and AQHI.

4. Conclusion

Hourly recordings of the concentration of PM2.5, PM10, NO2 and O3 as well as temperature and relative humidity from a mobile air quality system are analysed for the port area of Chalki Island in southeastern Aegean Sea. Additionally, the AQHI and DI are calculated in order to investigate the influence of pollutants and meteorological conditions on human health. The analysis is a case study that investigates diurnal, daily and monthly mean variation covering a summer and an autumn period of 2024 (from 24th July to 25th November). Results show that concentration of PMs are lower than the limits that are set by the European Directive for air pollution. The most degraded air quality conditions are presented during early morning (from 2:00 to 6:00) and night hours (from 19:00 to 21:00). August is the month with maximum concentration of pollutants. Summer is a period of high interest to study because the tourist and traffic density are maximized. Generally, AQHI ranges between "good" and "moderate" classes. The analysis shows that there is high positive risk ratio regarding the probability a day with high AQHI has high temperature/ DI comparing the common event but for low temperature/DI (RR= 29.33/ CI (95%): 4.2 to 204.9/p-value <0.05). These results indicate that possibly there is a synergy between air quality and discomfort conditions which negatively affect human health.

Acknowledgements

The authors would like to acknowledge the Rhodes city local authorities and the members of HIT CERTH Branch of South Aegean Region (Rhodes), namely Mary Papandreou and Stavros Kizalas for the technical support and fruitful discussions.

Funding

NHSOS Project (TAEDR-0537029) is implemented in the frame of National Recovery and Resilience Plan "Greece 2.0" and funded by the European Union – NextGenerationEU.

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