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Changes in Air Quality Health Index in a Coastal City of the Southeastern Aegean Sea between a Summer and Winter Period of 2022 †

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Abstract: The increased concentration of pollutants is a challenge to the health of the population. This work aims to investigate the health risk that is related to the pollutants' level in the center of Rhodes city. Rhodes Island is a desirable tourist destination with important economic activity over the southeastern Aegean Sea. This analysis covers the (summer) July–August months and the (winter) December month of 2022. Hourly recordings of the concentrations of $PM_{2.5}$, NO_2 and O_3 from a mobile air quality monitoring system (AQMS) are analyzed. In order to investigate the effects of pollution level on people's health, the Air Quality Health Index (AQHI) is calculated. Results show that summer shows an increased health danger compared to winter period, possibly due to increased traffic emissions, tourist density and the different meteorological conditions. In the summer period, the AQHI is classified between the middle and upper-medium health risk class. During the winter month, AQHI is mainly classified in the low-medium health risk class. The summer shows increased health risk despite the AQHI diurnal variability being lower when compared to December. Additionally, the diurnal differences between the two periods show an increased health risk in the summer period for the majority of the hours. Finally, this analysis shows that traffic activities possibly affect the health risk and also highlights that the authorities should adopt green policies to protect human health and the environment.

Keywords: Air Quality Health Index (AQHI); air quality; pollution; Rhodes Island; southeastern Mediterranean; Aegean Sea; $PM_{2.5}$; NO_2; O_3

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1. Introduction

The World Health Organization (WHO) highlights that increased pollution is related to various health issues such as respiratory disorders, cancers, cardiovascular disorders, etc. [1]. Air quality degradation is a health challenge for contemporary societies [2]. In this context, the scientific community is highly interested in further investigating air quality and its related impact on human health [3,4].

Rhodes Island is located in the southeastern Aegean Sea in the southeastern Mediterranean. Rhodes city is the capital of the Dodecanese municipality, and it is located on the north edge of the Island. The temperate climate conditions, the mild winter and hot (sunny) summer [5], in combination to the unique landscapes, gastronomy and cultural heritage, are some of the factors that make this place a desirable destination for thousands of tourists each year. The increased anthropogenic activities, which include human activities, traffic and vehicle emissions, are some of the fundamental factors that affect the

local air quality [5,6]. The high traffic emissions in the city center of Rhodes affect the pollution levels degrading the air quality in this region [5]. Additionally, the synergy between the poor air quality and conditions of discomfort increases the health risk for the local population [7]. Previous studies have already shown that anthropogenic activities, meteorological conditions and atmospheric circulations determine the level of pollution in the region of the Aegean, affecting air quality in the city [5,6,8].

Investigating of air quality and its related impact on human health is a dominant concern for the public and authorities throughout the southeastern Aegean [9]. This region is an important socioeconomic entity with respect to the sustainability of the southeastern Aegean Sea. The Air Quality Health Index (AQHI) is a measure that provides a message (and suggestions) to the public regarding the impact of the pollution level on human health. The AQHI is calculated using the concentration of $PM_{2.5}$, NO_2 and O_3 in order to provide health suggestions for population [10].

This study is conducted in the context of the "ELEKTRON" project (https://elektron-project.gr/index.php; accessed on 10 September 2023), which aims to promote green technologies in the coastal regions of southeastern Aegean. In this work, a mobile air quality monitoring system (AQMS) with sensors that measure the concentrations of $PM_{2.5}$, NO_2 and O_3 is used during the summer and winter period of 2022. Generally, the AQMS does not provide a desirable accuracy regarding the absolute values of the concentration of pollutants [11,12]. However, the AQMS provides a means of investigating air quality in regions where monitoring stations are missing [13]. In this context, this analysis aims to highlight factors regarding the impact of pollutants on human health risk in the center of Rhodes city.

2. Materials and Methods

An AQMS (HazScanner™ model HIM-6000 (Rhodes, Greece); [14,15]), equipped with a calibrated sensor to measure the concentration of pollutants, is located in the center of Rhodes city. The location of the AQMS is selected because this area shows high vehicle density, increased commercial activities and also neighbors the (high-traffic) touristic area of the medieval city (Figure 1). The AQMS provides high-frequency recordings (sampling rate: 5 min) of the pollutants' concentration. In particular, recordings of the concentration of $PM_{2.5}$ ($\mu m/m^3$), NO_2 (ppb) and O_3 (ppb) are used to calculate hourly and daily mean concentrations in order to investigate the effects of air quality on human health risk. The analysis covers two summer (July–August, JA) months and a winter (December) month in 2022. For the analysis, the Air Quality Health Index (AQHI) is calculated following the analysis of Yao et al. [10] (Equation (1)). Generally, the AQHI provides the population with a health message that is related to the level of pollution. The classes of AQHI and the related health suggestions for the population are presented in Table 1.

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

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

Figure 1. (**a**) The location of the air quality monitoring system (AQMS) in the city center of Rhodes. (**b**) The location of the AQMS near the medieval city in the center of Rhodes city.

Table 1. The classes of the Air Quality Health Index.

Health Risk	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.

In order to investigate the variation of air quality health conditions (in terms of the impact of the concentration of $PM_{2.5}$, NO_2 and O_3 on human health), the daily mean values of the AQHI are calculated for the July–August (JA) and December periods. Additionally, the diurnal variation of the AQHI, as well as the anomalies of the JA diurnal variations of the AQHI (with reference to December), are calculated to study the hours with the most degraded health conditions. The statistical significance of the anomalies is calculated using the two-tailed t-test at a significance level of 95% [16]. Finally, the box-plot of the daily mean AQHI is constructed in order to study the monthly variation of the AQHI between the summer (high-traffic-activity) and winter (low-traffic-activity) period.

3. Results and Discussion

The daily mean values of the AQHI during the JA and December months of 2022 are presented in Figure 2. The calculation of the AQHI shows that the summer months (JA) present degraded air quality health conditions compared to the winter period (December). The mean pollutants' health conditions, which are related to the concentration of $PM_{2.5}$, NO_2, and O_3, are classified mainly in the middle- and upper-moderate class (between 4 and 6 AQHI values). The reduced tourist activities, traffic emissions and vehicle density in the city center of Rhodes during December are the main reasons for the improved health risk as compared to JA of 2022. Robaina et al. [17], studying the air quality in five European countries, have found that the increased tourism is related to the degradation of air quality (in terms of particulate matter). Our findings possibly show that the improved AQHI during December (except the 7th and 28th of December, which, according to the AQHI, were classified in upper-moderate class) are related to reduced anthropogenic activities such as vehicle traffic emissions and tourist density. Additionally, it is important to highlight that possible differences in the height of the boundary layer between the summer and winter periods affect the concentration of pollutants in the low troposphere [18].

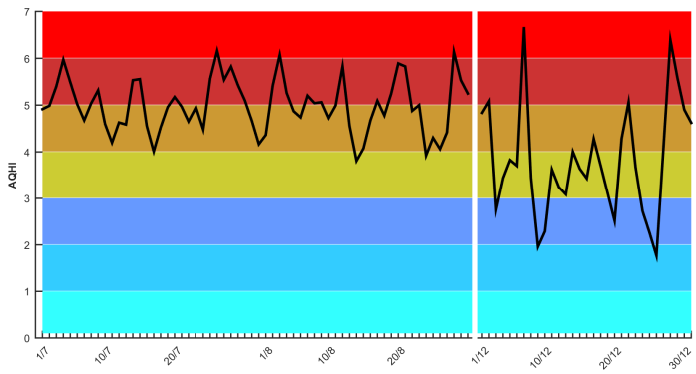


Figure 2. Daily mean evolution in the AQHI during the July–August (JA) and December months of 2022. Cold/warm colors indicate the low/moderate limit of the high AQHI class.

In order to investigate the hourly variation in air quality health risk, the diurnal variation of AQHI is calculated (Figure 3a). This analysis shows that the hours between 7:00 to 18:00 showed improved AQHI for people during the mean day in the summer (JA) months. Generally, December shows lower health risk compared to the JA period due to the decreased concentrations of $PM_{2.5}$, NO_2, and O_3. The improved health conditions during the daytime hours in the summer months are possibly explained by the impact of traffic emissions [19], meteorological conditions, such as wind speed, and the diurnal development of the boundary layer [18]. Kim et al. [20] have shown that the wind speed shows a negative association with the pollution level near road arteries. Additionally, Murthy et al. [21] have shown that the height of the mixing layer is negatively correlated with NOx and $PM_{2.5}$. The diurnal anomalies of the JA AQHI show that for both July and August, the AQHI increases for the majority of diurnal hours compared to the December mean AQHI diurnal cycle (Figure 3b,c). An exception to this result is the difference in the AQHI between August and December at 9:00–10:00 (Figure 3c,d). To sum up, the results show that the summer months, compared to December, present increased AQHI during the hours between mid-day and early evening and between midnight and early morning (Figure 3b,c).

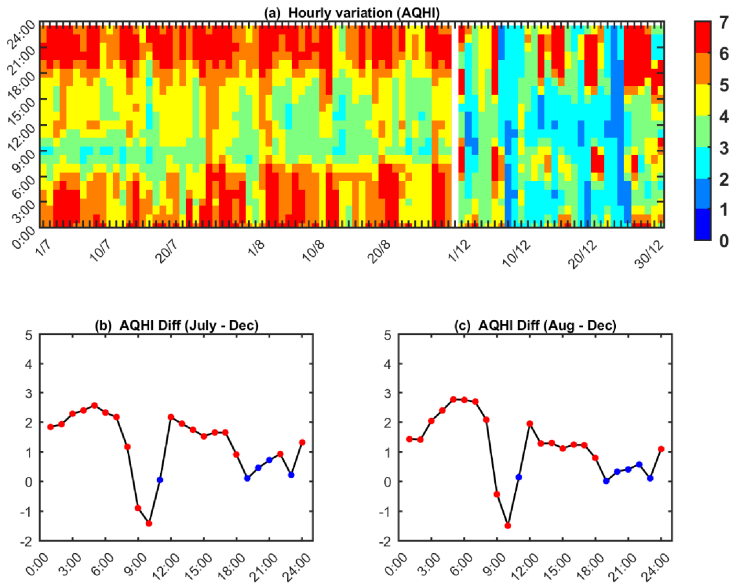
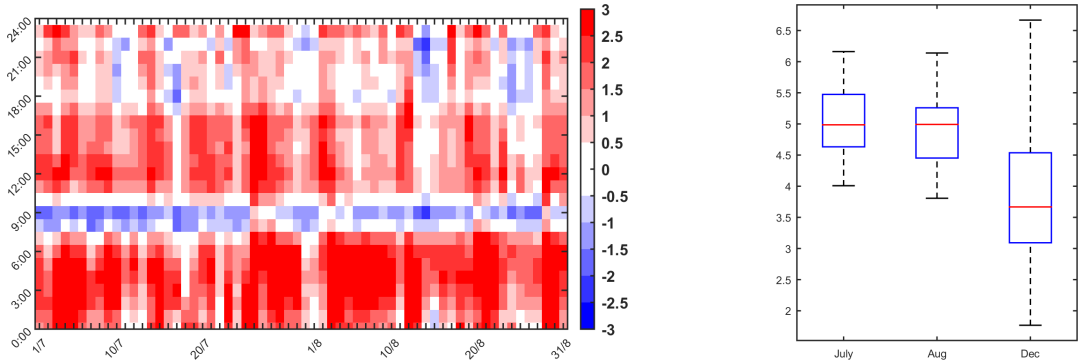


Figure 3. (**a**) Hourly variation in the AQHI for the July–August (JA) and December months of 2022; (**b**) hourly differences in the AQHI between July and December; and (**c**) hourly differences in the AQHI between August and December. The red/blue points denote the statistically significant/insignificant differences at 95%.

To further investigate the diurnal changes of AQHI between the summer (July–August, JA) and winter (December) periods, the diurnal anomalies of the JA AQHI with reference to the diurnal variation of the December AQHI are calculated (Figure 4a). The analysis indicates that the maximum AQHI changes (stat. sign. at 95%) are mainly presented during the midnight-to-early-morning hours (Figures 3b,c and 4a). Song et al. [19] have shown that diurnal traffic emissions, which are related to vehicle traffic, increase the level of pollution during these hours, affecting people's health risk. These elements provide evidence for the impact of vehicle traffic and anthropogenic activities on human health risk.

The median of daily mean AQHI distribution of JA is classified in the moderate class (medium-moderate AQHI; Figure 4b). December shows that the median of daily mean AQHI distribution is about 3.5. In comparison to December, July and August show an increase in AQHI values of about 1.2. This point shows that during December, the air quality health conditions were classified in the lower limit of the moderate AQHI class (about 3.5), indicating a reduced health risk compared to the summer period. Logothetis

et al. [5] have shown that meteorology and traffic activity affect the air quality of Rhodes city (summer 2021). Further investigation of the air quality and the AQHI in different areas of Rhodes city over the seasons could improve our knowledge regarding the impact of traffic density, tourist activity and building planning on the air quality of coastal areas.



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

Figure 4. (**a**) Hourly anomalies in the AQHI between JA and the diurnal mean AQHI of December 2022. (**b**) Box-plot of the daily mean AQHI for July, August and December. The red line indicates the median of the AQHI distribution. The blue box shows the limits of the 25th and 75th percentile. The whiskers show the maximum and minimum values.

4. Conclusions

This study investigates the impact of air pollution on people's health risk in the city center of Rhodes using recordings from an air quality monitoring system (AQMS). In order to investigate the impact of pollution levels on the health risk in the population, the Air Quality Health Index (AQHI) is calculated. The analysis is focused on a summer (JA) (high-traffic) period and a winter (December) (low-traffic) period in 2022. The daily variation of the AQHI shows that JA is categorized mainly in the moderate health risk class. During December, the health risk seems to be improved compared to summer period. The analysis of diurnal variation shows that the summer period shows increased AQHI during the hours between midnight and early morning and the midday hours, possibly due to the impact of high traffic emissions and anthropogenic activities. Additionally, the hourly AQHI variation during the summer months is about 3 to 6 and higher than December, which is about 1.2. The results emphasize the importance of adopting sustainable green measures with respect to the action of various authorities. Finally, our findings can provide the basis for the development of a real-time message system that could inform people of the health risk in Rhodes city as well as other coastal areas across the southeastern Aegean Sea.

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