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Air Quality Index study in the area of Thessaloniki
A valuable public health tool

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Δείκτης ποιότητας του αέρα στην περιοχή της Θεσσαλονίκης: Ένα πολύτιμο εργαλείο στα «χέρια» της δημόσιας υγείας

Περίληψη στο τέλος του άρθρου

OBJECTIVE **To analyze the Air Quality Index (AQI), the most widespread tool for recording air quality, for the region of Thessaloniki.** METHOD **Calculation of the AQI was made from the concentrations of PM10, PM2.5, NO_2, CO and O_3, i.e., the gaseous pollutants the concentrations of which are systematically recorded by the national air pollution recording network. To evaluate the AQI in the area of Thessaloniki, the data for the years 2011–2019 from seven air pollution recording stations, with different urban characteristics, in the region of Central Macedonia were used.** RESULTS **The data processing indicated that PM10 and O_3 are the main pollutants determining AQI. Based on the data form the Aghia Sophia monitoring station in the center of Thessaloniki, the AQI shows a statistically significant difference between the cold (October–March) and the warm (April–September) periods of the year in all stations ($p<0.01$), which is attributed to the seasonal differentiation of anthropogenic sources (e.g., heating systems), high concentrations of O_3 during the summer months (secondary pollutant favored by sunshine) and meteorological factors. Another interesting finding is the statistically significant difference in AQI between weekdays and weekends ($p<0.05$) at the downtown stations, which reflects the effect of human habits on the concentrations of pollutants that make up the index.** CONCLUSIONS **AQI is an easy-to-use tool with the ability to calculate the hazard of gaseous pollution levels and produce information that could be beneficial to public health.**

Key words
Air pollution
Air Quality Index
Particulate matter
Public health

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Air pollution is the presence of pollutants in the atmosphere, i.e., any kind of substances, noise, radiation, or other forms of energy, in quantity, concentration, or duration, which exceed the normal environmental levels, and which can cause short- or long-term adverse health outcomes in living organisms, ecosystems and materials. The term "substance" describes any natural, or anthropogenic chemical compound, or chemical element, that exists in the atmosphere in gaseous, liquid, or solid form. Pollution is the addition of any molecular or particulate material in the atmosphere, which increases the normal levels and can be poisonous for life on the planet.[1,2]

Air pollutants are not necessarily hazardous for living organisms, but augmentations of their concentrations could indirectly affect living organisms. For example, "greenhouse" gases in the atmosphere can intensify the greenhouse effect, which will have long-term detrimental effects on global climate change, with a severe impact on all living organisms.[3]

According to the World Health Organization (WHO), air pollution causes approximately seven million premature deaths worldwide each year, mainly due to increased mortality from stroke, heart disease, obstructive pulmonary disease, pneumonia and cancer. It is estimated that 9 in 10 people breathe air that is characterized by high levels of pollutants exceeding the limits of the WHO guidelines.[4] WHO identifies particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and ozone (O_3), as the most harmful air pollutants to human health. According to the European Environment Agency (EEA), in 2014, PM2.5 caused about 400,000 premature deaths of EU citizens, NO_2 caused 75,000 and O_3 13,600 premature deaths. In Greece, further studies are needed on the matter.[4,5]

The principle on which EU environmental policy is based, is the prevention and remediation of environmental damage, as the "polluter pays" principle is the baseline of EU strategy. Since the mid-1970s, environmental action programs have been in place, setting priorities and frameworks for future action in all areas of environmental policy. Air quality in Europe has greatly improved since then, as the concentrations of certain substances, such as sulfur dioxide (SO_2), carbon monoxide (CO), benzene (C_6H_6) and lead (Pb), have dropped significantly.[6] EU action to address air pollution is implemented through three different legal mechanisms: (a) setting general air quality standards for air pollutant concentrations, (b) setting national limits for total emissions, and (c) issuing legislation for each source of pollution.[1,2] This legislation is complemented by strategies and measures to promote environmental protection and its integration into other areas.[7] In line with the objectives of the Thematic Strategy on Air Pollution 2005, in June 2008 the European Commission (EC) Directive 2008/50/EC on air quality came into force, aimed at reducing air pollution. At the end of 2013, the EC launched the "Clean Air for Europe" program, with two main objectives: to comply with existing legislation by 2020, and to set new air quality targets for 2030. The directive also includes reduction commitments by 2020. Atmospheric quality limits for air pollutants which were set out in Directives 2008/50/EC and 2015/1480/EC, have been incorporated into the Greek legislation.[8]

Sadly, the EC has twice referred Greece to the European Court of Justice of the European Union, as Greece exceeded the limit value set by EU air quality legislation (Directive 2008/50/EC). The first was the case of Thessaloniki for the poor air quality due to the high levels of PM10 in December 2020, and the second was the case of Athens for the high levels of NO_2 in July 2021.[9] For these reasons, we analyzed the air quality in the center of Thessaloniki and estimated the Air Quality Index (AQI) based on the data of the Aghia Sophia monitoring station. This station had produced some alarming results over recent years, and, therefore, the study focused on the findings in the city center. We assumed that there would be significant variation in the pollutant concentrations, especially between seasons (winter-summer).

MATERIAL AND METHOD

Various air quality indicators, corresponding to different national air quality standards, have been introduced worldwide. The calculation of the AQI requires the concentrations of several air pollutants for a specified average period, obtained from air quality monitoring stations. Concentration and time represent the dose of each air pollutant. Air pollutants vary in strength, and the methods used to convert atmospheric pollutants to AQI vary with the pollutant and from country to country. AQI values are usually cataloged into classes. Each class corresponds to a brief description of ambient air quality or health effects, with a color identification code.

Structure of air quality indicators – The Air Quality Index

In the mid-1970s, the US Environmental Protection Agency (US EPA) established, for the first time, a single national index, the Pollutant Standards Index (PSI), as part of the establishment of a unified system for monitoring and assessing air quality in large urban centers. The PSI is calculated from the concentrations of NO_2, SO_2, CO, O_3 and PM, converting pollutant concentrations into simple numerical values.[10]

Since then, several other air quality indicators have been developed and established around the world, most of which are based on the PSI index, but using different names. In July 1999, the USA replaced the PSI with the new and improved AQI, to incorporate PM2.5 particles.[11]

The AQI is a daily air quality indicator, showing how clean or polluted the atmosphere is, and whether it is a cause of concern for public health. It is calculated from the concentrations of five air pollutants, O_3, SO_2, CO, NO_2, PM10 and PM2.5, for each of which the USA has established national air quality standards. The AQI is used mainly to provide valid, timely and reliable information to the public about air quality at the local level, and the effects it may have on human health.

The six categories[12,13] into which the indicator is classified, according to the level of public health concern are: 1. 0 to 50 AQI values for good levels, 2. 51 to 100 AQI values for moderate levels, 3. 101 to 150 AQI values for unhealthy for sensitive groups levels, 4. 151 to 200 AQI values for unhealthy levels, 5. 201 to 300 AQI values for very unhealthy levels, 6. 301 to 500 AQI values for dangerous levels.

The calculation of the Air Quality Index

The AQI (I), which is a linear function of the pollutant concentration, is calculated from equation 1, where the conversion of the pollutant concentrations into numbers is achieved.

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} (C_{high} - C_{low}) + I_{low} \qquad \text{(equation 1)}$$

"I" is the AQI air quality index, "C" is the measured pollutant concentration, "C_{low}" is the minimum concentration limit of the category to which "C" belongs, "C_{high}" is the maximum concentration limit of the category to which "C" belongs, "I_{low}" is the minimum value of the quality index corresponding to "C_{low}", and "I_{high}" is the maximum value of the quality index corresponding to "C_{high}".

The AQI is publicly available to the citizens in real time, for their rapid information, but also provides the ability to predict air quality for the planning of daily activities and the protection of health. The AQI has met with international scientific acceptance, and as a result, has been adopted by many countries around the world.

Data collection

The data in this study were provided by the National Air Pollution Monitoring Network of the Ministry of Environment and

Energy. These were the data sets of five gaseous pollutants, for the city of Thessaloniki from 2011 to 2019.[14]

In the region of Central Macedonia, the stations for measuring air pollution are located in the following areas: (a) Aghia Sophia, Thessaloniki (AGS), (b) Aristotle University of Thessaloniki (APT), (c) Panorama (PAO), (d) Kalamaria (KAL), (e) Kordelio (KOD), (f) Sindos (SIN), and (g) Neochorouda (NEO).

In order to assess the air quality in the center of Thessaloniki, the AQI was calculated, based on the concentrations of PM10, PM2.5, CO, NO_2 and O_3, at the Aghia Sophia monitoring station (AGS).

Analysis

The calculation of AQI was performed based on equation 1, above, after the appropriate transformation of the NO_2 and O_3 units, from μg/m^3 to ppb, and of CO units from mg/m^3 into ppm, according to the (2) and (3).

$$\text{(ppb)} = \frac{22.4 \times \text{concentration } (\mu g/m^3)}{\text{molecular weight}} \qquad \text{(equation 2)}$$

$$\text{(ppm)} = \frac{22.4 \times \text{concentration } (\mu g/m^3)}{\text{molecular weight}} \qquad \text{(equation 3)}$$

In addition, the variation in AQI between the different periods of the year was studied, with separation of "hot" (April–September) and "cold" (October–March), and between the weekdays and the weekends. The t-test was used for the statistical comparison of the mean values, with the Kolmogorov-Smirnov regularity test, with statistical significance at $p<0.01$.

RESULTS

The statistical processing, according to equation 1, of the air pollution data from the Aghia Sophia monitoring station for the period 2011–2019, revealed interesting findings on the AQI annual fluctuation, as shown in figure 1. It should be noted that the daily value of AQI was considered to be the maximum daily value of the respective interval that was studied. The year 2014 presented the lowest levels of air pollution, with an average AQI of 24.4. From 2016 onwards, an upward trend of AQI was recorded, with levels exceeding 100 (the international air quality limit). The air quality of such a level is considered unhealthy for vulnerable groups of the population, with possible consequences for wider population groups.[13]

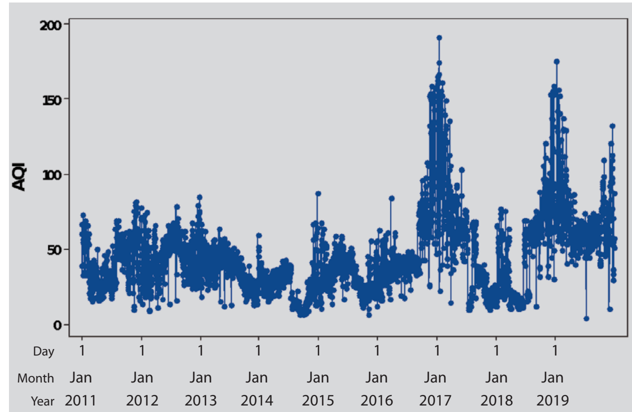

Figure 1. Intra-year course of the Air Quality Index (AQI) at the Aghia Sophia Station (AGS) during the period 2011–2019.

A mild fluctuation in AQI was observed from April to October (4th to 10th months), with a wider variation during the winter months, when an upward trend was recorded (fig. 2). Various factors could explain this finding, including the use of home heating systems and meteorological conditions that do not favor the dispersion of pollutants. The mean AQI was lower than 50 in several months, where the index turns green and air quality is considered satisfactory.

Table 1 shows the AQI values in the cold and hot periods for the entire duration of the study, as they emerged from the statistical processing of the air pollution data at the Aghia Sophia monitoring station. The comparison between the cold and warm periods of the years was made in an attempt to distinguish possible seasonal motifs in AQI. A statistically significant difference was demonstrated in

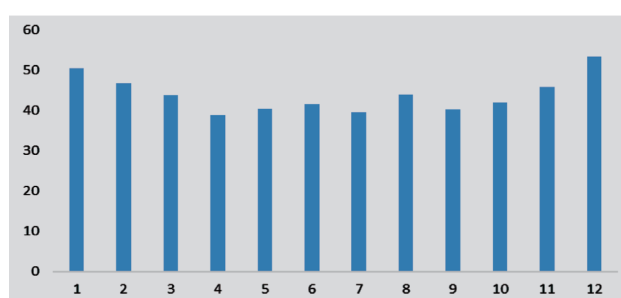

Figure 2. Monthly fluctuation of the Air Quality Index (AQI) at the Aghia Sophia Station (AGS) for the period 2011–2019.

Table 1. Air quality index (AQI) values at the Aghia Sophia Station (AGS) in the "cold" and "hot" seasons in 2011–2019.

	Total days	Mean	Standard deviation	Minimum	Median	Maximum
"Cold" season	1,361	48.0	32.0	5.6	38.0	189.9
"Hot" season	1,926	40.9	18.4	3.2	39.7	108.9

the mean AQI between "cold" and "hot" periods of the year ($p<0.01$).The AQI does not present significant changes during the working week. The slight fluctuations shown in the AQI at the Aghia Sophia monitoring station is thought to be due to its location in the city center, but even there, the mean value is lower than 50 for most of the days of the week (index: green).

Table 2 shows the AQI for the weekdays and the weekends. The comparison of AQI between these two periods of the week was made in an attempt to distinguish the level of pollution between working days (weekdays), when there is more vehicular traffic, and the weekend, when there is clearly less traffic, but possibly higher fuel consumption for home heating. Lower levels of AQI were recorded on weekdays ($p<0.01$).

The contribution of the individual pollutants to the AQI, as derived from the statistical processing of the air pollution data at the Aghia Sophia monitoring station for the period 2011–2019 is presented in table 3. Figure 3 shows the percentage (%) of each pollutant, forming the final value of the AQI. It appears that the air quality in the Aghia Sophia area during the study period was determined mainly by the levels of suspended particles in the atmosphere. Specifically, 43.1% of the AQI is determined by PM2.5, while O_3, with 28.4%, and PM10, with 23.3%, also play an important role. The participation of CO (0.9%) and NO_2 (4.3%) in the formation of the AQI at this site is much smaller.

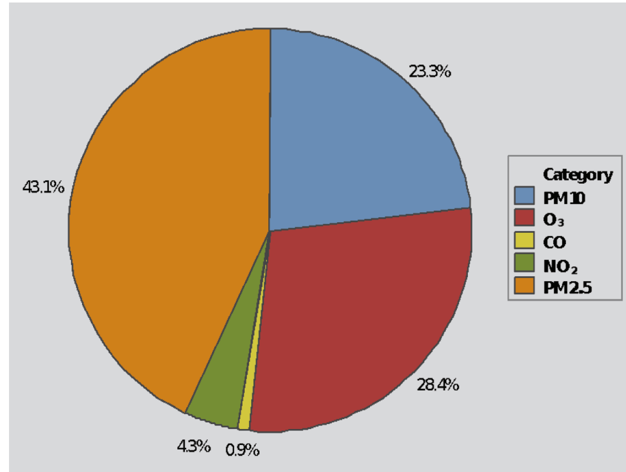

Figure 3. Percentage (%) of participation of each pollutant in the final value of the Air Quality Index (AQI) at the Aghia Sophia Station (AGS) for the period 2011–2019.

DISCUSSION

The objective of this study was to contribute to the understanding of the problem of urban air pollution in Thessaloniki. This demands continuous monitoring in order to make timely and reliable assessment of air quality and take appropriate measures, in the context of environmental policy, and to protect vulnerable groups from exposure to pollutants. AQI is a daily air quality indicator, which indirectly provides information about the degree of atmospheric pollution, and whether there is cause for concern for human health.

The calculation of the AQI depends on the appropriate evaluation process (monitoring) of the concentrations of pollutants PM10, PM2.5, NO_2, CO and O_3. In central Thessaloniki, the AQI shows a statistically significant difference between the "cold" (October–March) and the "hot" (April–September) periods of the year, which is attributed to the seasonal differentiation of anthropogenic sources (heating systems), high concentrations of O_3 during the

Table 2. Air quality index (AQI) values at the Aghia Sophia Station (AGS) on weekdays and weekends for the period 2011–2019.

	Total days	Mean	Standard deviation	Minimum	Median	Maximum
Weekends	940	45.3	26.4	5.1	40.7	189.9
Weekdays	2,347	43.3	24.7	3.2	38.0	174.5

Table 3. Air quality index (AQI) values at the Aghia Sophia Station (AGS) per pollutant for the period 2011–2019.

AQI pollutant	Total days	Mean	Standard deviation	Minimum	Median	Maximum
CO	77	17.6	12.6	3.2	10.9	46.9
NO_2	380	16.4	4.5	6.3	16.0	28.0
O_3	1,110	36.9	11.0	5.6	36.3	69.9
PM10	875	38.3	14.9	10.2	36.1	86.6
PM2.5	845	73.5	26.2	28.8	65.6	189.9

summer months (secondary pollution favored by sunshine), and meteorological factors. In addition, in the city center, there is intense human activity, with increased traffic, home heating, poor ventilation, and poor city planning. The high values of the AQI are mainly determined by the levels of PM in the atmosphere. In the suburbs, less vehicular traffic, better ventilation conditions and fewer emission sources create better conditions, contributing to improved air quality where the AQI is determined mainly by the ozone concentration, which is a secondary pollutant, favored by the sunshine.

A statistically significant difference was demonstrated in the mean AQI between weekdays and weekends, which may be due to anthropogenic activity.

Air pollution has been correlated with preterm birth, which needs to be studied further in Greece, especially in the light of the evidence of the hazardous involvement of the ambient PM.[5] PM2.5 has been associated with the prevalence of neurodegenerative diseases (e.g., Alzheimer's disease), and PM10 also appears to be associated with Alzheimer's disease and vascular dementia.[15] Air pollution affects all systems of the human body. It can cause inflammatory and allergic respiratory diseases, asthma and allergic rhinitis and predispose to respiratory infections. These diseases can decrease the quality of life, especially of patients vulnerable to respiratory problems. Cardiovascular diseases are also correlated with the ambient air pollution, and kidney disease and metabolic disorders could also be affected. Finally, deterioration of mental health is a common finding regarding air pollution.[3] In addition, cities with serious air pollution showed the highest numbers of SARS-CoV-2 cases and deaths.[16] This evidence highlights the importance of the reduction of pollution and effective monitoring, in order to protect public health.

In general, according to the above findings, air pollution in the greater Thessaloniki area poses a serious problem with implications for public health. To address this problem, measures must be taken to improve air quality, both in terms of control measures and in terms of effective and sustainable solutions to reduction of emissions, primarily from anthropogenic sources, and then from all sources of gaseous pollutants. Climate change, increased humidity and the constant rise of the temperature are threats to public health and the quality of life. These rapid climate changes affect the well-being of citizens in numerous ways. For example, the local rise of temperature and humidity due to air pollution could cause an alarming rise in the numbers of cockroaches, especially in large cities.[17] It is clear from the above that public health could be undermined not only directly but also indirectly from ambient air pollution.

In conclusion, the AQI is an easy-to-use tool, with its direct calculation of the risk from air pollution levels, as it provides the final result in a visual form, easily perceived by the end-user. The overall air quality in the area studied is estimated to be satisfactory to acceptable, but in recent years there is evidence of an increasing trend in the levels of air pollution, indicating unhealthy air quality for vulnerable populations, who could manifest health problems, in comparison to the general healthy population. The AQI should be widely used for assessing, interpreting and understanding air quality, which would be beneficial to public health, in terms of prevention.

ΠΕΡΙΛΗΨΗ

Δείκτης ποιότητας του αέρα στην περιοχή της Θεσσαλονίκης: Ένα πολύτιμο εργαλείο στα «χέρια» της δημόσιας υγείας

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Αρχεία Ελληνικής Ιατρικής 2022, 39(6):838–843

ΣΚΟΠΟΣ Η ανάλυση του πλέον διαδεδομένου εργαλείου για την καταγραφή της ποιότητας του αέρα, του δείκτη ποιότητας αέρα (Air Quality Index, AQI), για την περιοχή της Θεσσαλονίκης. **ΥΛΙΚΟ-ΜΕΘΟΔΟΣ** Επιλέχθηκε η υιοθέτηση και η εφαρμογή του πλέον διαδεδομένου δείκτη ποιότητας αέρα για την περιοχή της Θεσσαλονίκης. Ο υπολογισμός του AQI προκύπτει από την κατάλληλη επεξεργασία των συγκεντρώσεων των ρύπων, PM_{10}, $PM_{2,5}$, NO_2, CO και O_3. Για τον υπολογισμό του AQI στην περιοχή της Θεσσαλονίκης χρησιμοποιήθηκαν τα διαθέσιμα πρωτότυπα δεδομένα από επτά σταθμούς καταγραφής ατμοσφαιρικής ρύπανσης, διαφορετικών αστικών χαρακτηριστικών, της Περιφέρειας Κεντρικής Μακεδονίας, για τα έτη 2011–2019. **ΑΠΟΤΕΛΕΣΜΑΤΑ** Τα αποτελέσματα της επεξεργασίας των δεδομένων ανέδειξαν τους ρύπους PM_{10} και O_3 ως τους βασικούς ρύπους που καθορίζουν τις τιμές του AQI. Ο AQI παρουσιάζει στατιστικά σημαντική διαφοροποίηση μεταξύ της ψυχρής (Οκτώβριος–Μάρτιος) και της θερμής (Απρίλιος–Σεπτέμβριος) περιόδου του έτους σε όλους τους σταθμούς και κυρίως στον σταθμό της Αγίας Σοφίας Θεσσαλονίκης. Ένα ακόμη ενδιαφέρον εύρημα είναι η στατιστικά σημαντική διαφοροποίηση του AQI μεταξύ καθημερινών και Σαββατοκύριακων σε σταθμούς τοποθετημένους στο κέντρο της πόλης, που αντανακλά την επίδραση των ανθρώπινων συνηθειών στις συγκεντρώσεις των ρύπων οι οποίοι διαμορφώνουν τον δείκτη. **ΣΥΜΠΕΡΑΣΜΑΤΑ** Ένας μεγάλος αριθμός επιδημιολογικών ερευνών συσχετίζουν τα επίπεδα των ατμοσφαιρικών ρύπων με επικίνδυνες επιπτώσεις στην ανθρώπινη υγεία. Ο AQI αποτελεί ένα εύχρηστο εργαλείο με δυνατότητα άμεσου υπολογισμού της επικινδυνότητας των επιπέδων της αέριας ρύπανσης, ο οποίος οπτικοποιεί το τελικό αποτέλεσμα, ώστε να είναι εύκολα αντιληπτό από τον τελικό χρήστη. Συνιστά με αυτόν τον τρόπο ένα χρήσιμο εργαλείο για την πρόληψη και την ενίσχυση της δημόσιας υγείας.

Λέξεις ευρετηρίου: Δείκτης ποιότητας αέρα, Δημόσια υγεία, Μόλυνση, Σωματίδια

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