

# Identifying and recording environmental pollutants in the Attica basin: the archaeological site of Kerameikos

## Identificação e registo de poluentes ambientais na bacia do Ática: o sítio arqueológico de Kerameikos

IOANNIS PRODRAMOS  
KOTSIFAKOS\*  
VASILEIOS  
LAMPROPOULOS

Department of Conservation of  
Antiquities and Works of Art,  
School of Applied Arts and  
Culture, University of west Attica,  
Agiou Spiridonos 28, Egaleo,  
12243, Greece

\*[ikotsifakos@uniwa.gr](mailto:ikotsifakos@uniwa.gr)

### Abstract

This study investigates the identification and effects of atmospheric pollutants in the archaeological sites of the Athens basin, particularly at Kerameikos. The objective was to identify the pollutants surrounding this historically significant area at the center of a large city and assess the damage they inflict on the monuments. By examining the environment and documenting atmospheric parameters, it became evident how significantly geomorphology influences the dispersion of pollutants. The assessment of pollutants was achieved through a combination of marble sampling and air quality sensors. The collection of water washes and the use of diagnostic analysis methods documented the airborne elements deposited in the samples. The results were evaluated based on the climatic factors of deterioration, the sensors data, statistical graphs, and the bibliographic sources. In conclusion, gaseous particles and pollutants from wheeled vehicles are the biggest threat to the environment, and their limitation is also the most difficult.

### Resumo

Este estudo investiga a identificação e os efeitos dos poluentes atmosféricos nos sítios arqueológicos da bacia de Atenas, particularmente em Kerameikos. O objetivo foi identificar os poluentes que rodeiam esta área historicamente significativa no centro da cidade e avaliar os danos que causam aos monumentos. Ao examinar o ambiente e documentar os parâmetros atmosféricos, tornou-se evidente a influência significativa da geomorfologia na dispersão dos poluentes. A avaliação dos poluentes realizou-se através de uma combinação de amostragem de mármore e sensores de qualidade do ar. A recolha de amostras de água e o uso de métodos de diagnóstico documentaram os elementos transportados pelo ar depositados nas amostras. Os resultados foram avaliados com base nos fatores climáticos de deterioração, nos dados dos sensores, nos gráficos estatísticos e nas fontes bibliográficas. Concluindo, as partículas gasosas e os poluentes dos veículos motorizados são a maior ameaça ao meio ambiente, e sua limitação é também a mais difícil.

### KEYWORDS

Air pollutants  
Stone degradation  
Marble monuments  
Urban ambient pollution  
Atmospheric deterioration  
factors  
Contamination

### PALAVRAS-CHAVE

Poluentes atmosféricos  
Degradação da pedra  
Monumentos de mármore  
Poluição ambiental urbana  
Fatores de deterioração  
atmosférica  
Contaminação

## Introduction

Air pollution is a major factor in erasing monuments and works of art. It has been found that monuments that are away from cities and industrial environment are in much better condition than those that are in the polluted atmosphere of an urban one. Degradation from environmental factors is of secondary importance about corrosion due to extreme climatic conditions and high levels of air pollution [1].

Nowadays, where it is evident that the human activities in the last two centuries have destabilized the climatic conditions of the planet, the results of this situation have a direct impact and effects on the current conservation state of most monuments and works of art. The need for scientists to protect exposed archaeological sites has led to modern technological applications of field control in order to predict their rate of deterioration as far as possible. In the present study, the central purpose was to determine the atmospheric pollutants and the mechanisms of creation, deposition and effect in the Kerameikos archeological area, within the field.

Kerameikos uniquely merges an archaeological site with a vibrant urban area in a bustling city like Athens. The ancient river Iridanos, which flows through parts of the site, plays a significant role in this distinction. Various road crossings were introduced, including the Sacred Way, which historically marked the route for the procession to Eleusis during the Eleusinian Mysteries. Kerameikos is a rare combination of archaeological site and inhabited area of a large industrial city like Athens. The historical river Iridanos that crosses the archaeological site in some places contributes particularly to this. Among the small and large road crossings that were opened was the Sacred Way, while Kerameikos in ancient times was the place from where the procession to Eleusis started in the context of the Eleusinian Mysteries [2].

The formation and continuation of air pollution in the environment is significantly enhanced by the surrounding mountains and hills. This research examined the environmental factors that influence the area, the geomorphological features of the basin, and the impact of pollutants on the stone samples that were positioned in their natural setting.

## Methodology and instruments

This research has been conducted by using data from various sources, a set of devices and observations.

Initially, a bibliographic study was carried out in order to outline the effects of atmospheric pollutants on the building materials of the monuments in open archaeological sites and especially in the area of Athens, in the archaeological site of Kerameikos.

The collection of the pollution data was made using an Airsence Standard sensor from A.U.G. Signals placed in the field for one calendar year (2020), to include all seasonal changes, in contrast with the Greek state's specialized monitoring stations that collect information at the perimeter of the area.

The Airsence sensor has been chosen because it is an innovative, compact, reliable, affordable and a real-time device that monitor atmospheric air pollutants. It is also highly time-durable and it provides point-referenced pollution maps while its unique architecture and sensor array circuitry overcome sensor drift and degradation and provide near-reference data at low cost compared to the conventional station [3].

The device used to measure relative humidity (RH %) and temperature is the TROTEC BL30 datalogger, an ultra-compact climate data logger capable of storing up to 32,000 measurements.

Apart from the sensors, in this research, marble samples have been placed in order to observe their degradation, and liquid deposition collectors have been used to record the precipitation concentration (Figure 1).



**Figure 1.** Presentation of the field equipment at the archaeological site of Kerameikos.

The pollutants that were studied are nitrogen oxides (NO, NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), ozone (O<sub>3</sub>), carbon monoxide and dioxide (CO, CO<sub>2</sub>), and particulate matters (PM<sub>2.5</sub>, PM<sub>10</sub>).

In **Figure 1**, the positions of the different devices in the archaeological site of Kerameikos is depicted. Marked as Σ1 are the Marble samples and Σ2 wet deposition collectors while in Σ3, the temperature and relative humidity sensors are placed. In Σ4 the pollution collection device (AirSence Standard) is placed.

Along with these measurements, other climatic parameters directly related to atmospheric deterioration factors, such as RH%, temperature, and wind, were taken into account and recorded. Wind data was collected from the reports of the Greek Ministry of Environment.

Marble fragments from Dionysos, Attica: D1-D3 (**Table 1**), of identical dimensions, were prepared for this experimental study, exposed in the field, labeled for microscopic analysis, and their deterioration carefully documented.

The microscopic observations of the field samples were carried out with the following diagnostic methods:

- Macro observation using Hoya close-up filters (+1, +2, +4, +10 diopters) mounted on a Nikon D90 DSLR camera; 6 images per sample.
- Digital microscopy with Pico Scopeman I-scope Moritex (USB 2.0), connected to an iPad Pro 11-inch; 6 images per marble sample.
- Digital microscopy with Dino-Lite AM4013MT-FVW, connected to a Toshiba Encore 2 Write WT10PE-A tablet; 6 images per sample.
- Stereomicroscope observation using Leica M80 (Leica Microsystems), with image acquisition via dedicated software on an external display; 10-12 images per sample.
- Atomic absorption spectroscopy (AAS); Measurements were performed with a 5 s integration time, averaging three scans per sample after 15 s stabilization.
- SEM coupled with energy-dispersive X-ray spectroscopy (EDX); 3-9 images per marble specimen.

The experimental process used passive wet deposition collectors (Palmex Rain Sampler RS1) to obtain representative samples of pollutants from acid rain.

## Results and discussion

After the contaminants study was deposited on the surface of the marble samples, observation and microphotography in SEM at magnifications ranging from 150× to 7500×, along with elemental analysis in EDX, were performed (Figure 2) and X-ray diffraction (Figure 3) was conducted.

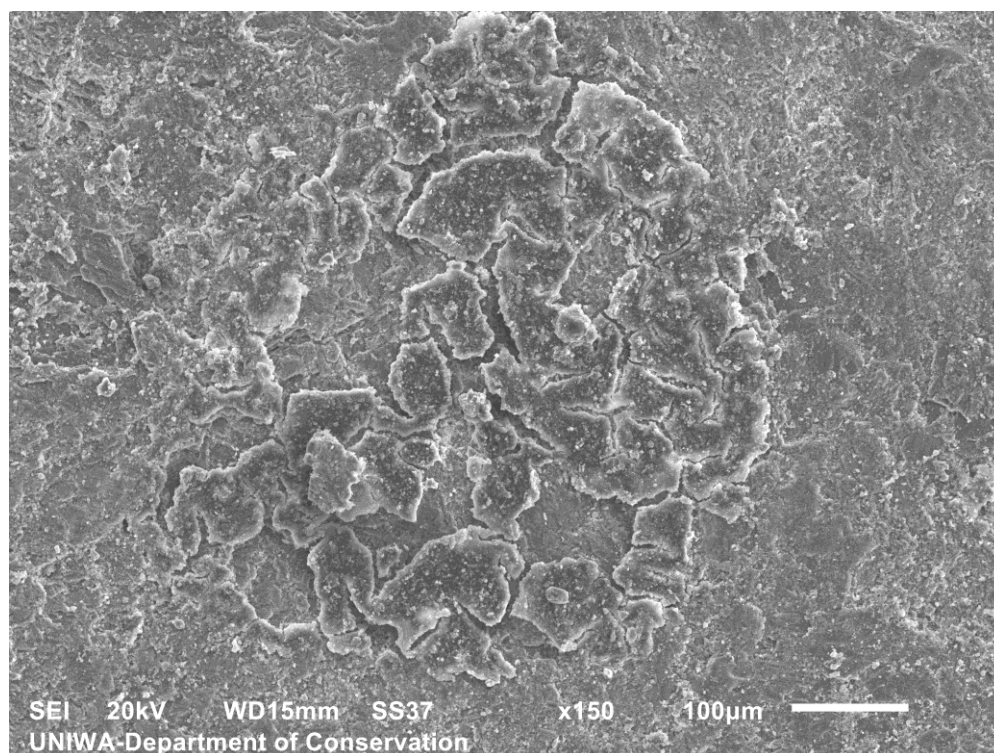


Figure 2. SEM photomicrograph, sample D2 kerameikos. Traces of carbon "stain" ("smoke").

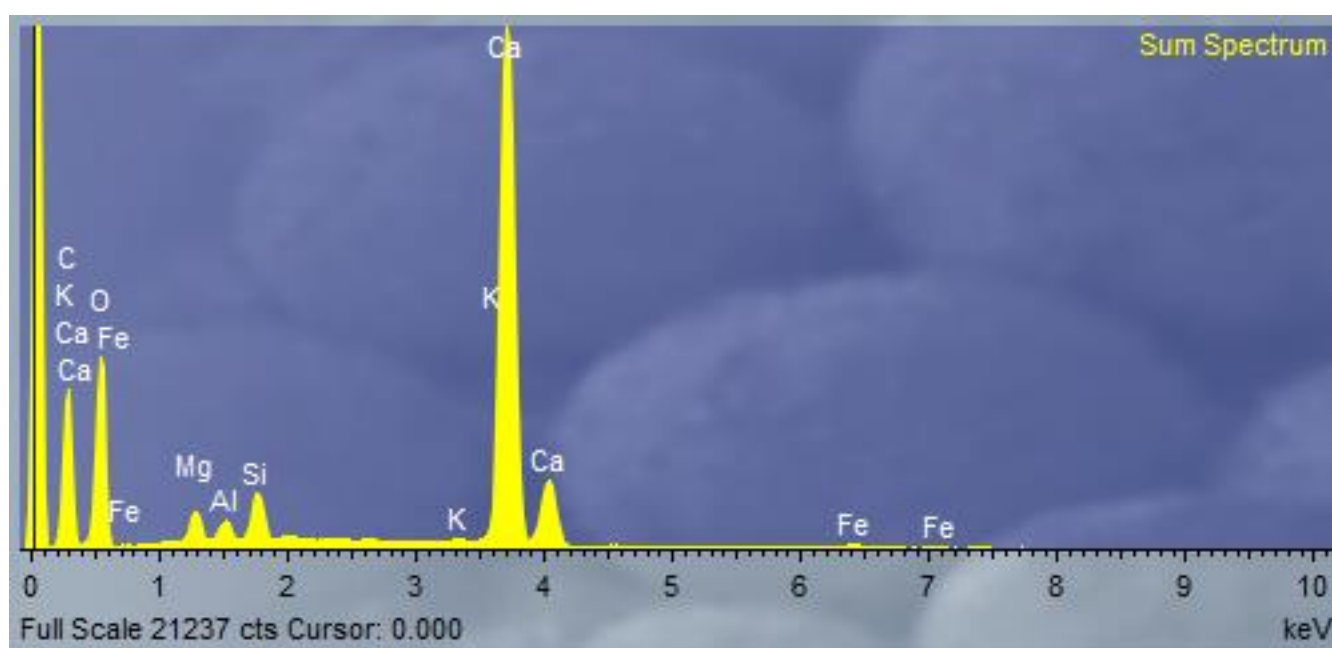


Figure 3. X-ray diffraction, sample D2 Kerameikos, ×150. The EDX spectrum shows a carbon "spot".

**Table 1.** SEM–EDS results of marble samples D1–D3 originating from Dionysos (Attica), used in the Kerameikos archaeological site, showing elemental composition and imaging magnifications.

Sample	Analysis no.	Observations	Magnification
D1	1	Fe, Zn, Mg detected	×650
	2	No significant elements detected	×6500
	3	No significant elements detected	×200
	4	Fe, Si detected; no evidence of gypsum formation (in contrast to FTIR results)	×4000
	5	Fe, Si detected (Si: 29 %)	×4000
	6	P, S, Mg, Fe detected; presence of exogenous elements	×2000
	7	Mn, Fe, Ba, S, Cr, Zn detected (lithopone; possible white pigment, barium chromate)	×2700
	8	Fe, S, P detected	×2700
	9	Mg, Fe, Mn detected	×1200
D2	1	Elemental mapping; carbon-rich area (stain)	×150
	2	Si, Al, Mg, P detected	×1500
	3	C, P, Cl detected	×1500
	4	C detected	×2000
	5	C detected (36.79 %) in area with red inclusions; S, P also present	×430
	6	S, Mg, Al, Si, Fe, C detected (C: 30 %)	×1800
	7	Cr (2.81 %) detected (possible pigment-related oxides); Cu (0.94 %) possibly associated with a composite phase; Mg, Mn, Fe also present	×4500
D3	1	Fe, Si, Mg detected	×2200
	2	Si, Fe, Al, Mg detected	×6500
	3	No significant elements detected	×950

The SEM analysis of the marble samples (Table 1) of the archaeological site of Kerameikos (Figure 1, Σ1) showed metal elements magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn) and trace of chromium (Cr): 2.81 %, copper (Cu) 0.94 %, which reveal anthropogenic activity, emissions of gasoline vehicles and emissions from related industries. Their concentration is significantly influenced by the similar activity in the surrounding area [4].

The detection of carbon (C): 68 % wt, also in a find with rod-shaped morphology possibly originates from products of incomplete combustion of fuels [5-7] while mineral oxides silicon (Si), aluminum (Al), calcium (Ca), Mg, Fe, titanium (Ti), potassium (K) and most of the trace elements were detected at the urban traffic point.

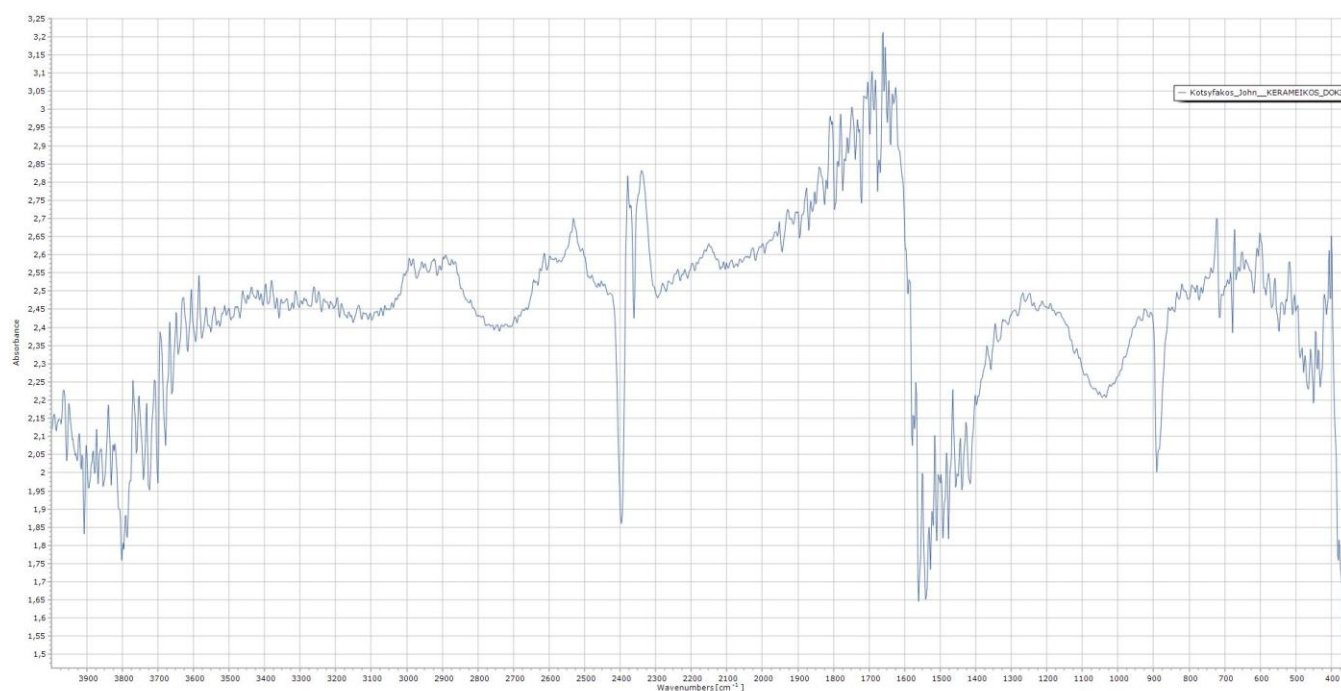
Yet another category of airborne particles was sulfates, which testify to anthropogenic activity [8], and nitrates detected during the dry season in the marble samples. These are photochemical and result in their gradual corrosion to a greater extent than the corresponding oxides after their deposition in the building material [9].

It is worth noticing that an extraneous finding was identified on the surface of the marble sample with the following elements: Mn, Fe, barium (Ba), sulfur (S), Cr, and Zn. It may be a white pigment, lithoponium, combining the barium chromate compound. Their origin is likely to be the industrial activity from the South-Southwest areas of the basin, such as the area of Keratsini and Piraeus.

Summarizing the above analyses of the samples from the archaeological site of Kerameikos in the scanning electron microscope, it follows that the elements identified belonged to earthy, geological particles of aluminosilicate composition, biogenic/organic, and metals or metallic trace elements.

### Infrared spectroscopy (FTIR)

The spectra in Figure 4 is a sample of the images from the archaeological site and belong to the mid-infrared (mid-FTIR) (4000-400  $\text{cm}^{-1}$ ). It is the area with the main vibrational frequencies. The samples had a dimension of 10×10 cm, on a cutting wheel without sanding for a realistic simulation of the sculptural decoration of the marble monuments, but also of their natural aging and deterioration from the urban environment, and the changes this causes.



**Figure 4.** Sample D3, FTIR spectrum from test 1 of the archaeological site of Kerameikos.

Concerning the area's temperature, the maximum values are observed in July (37.7 °C at noon on 24/7/20), while the minimum temperature value – 0.6 °C – is focused on February, 6/2/21 (morning time – 07:28:45). The year's average is 18.33 °C.

As for the relative humidity (RH%) in the Kerameikos area, based on the recorder's in-situ measurements, rates ranged from a minimum of 8.9 % (on 4/7/2020) to a maximum of 100 % (on 27 /1/2021), with an average of 62.87 % for the year 2020-2021. A large range of values is observed from the minimum to the maximum. On 27/1/21, the highest moisture value recorded occurred due to the rainfall that took place, collecting an amount of water of 46.2 mm.

### **Airsence standard device measurements**

In this section a presentation of the measurements of the pollutants that have been collected from the Airsence standard device.

#### ***Sulfur dioxide (SO<sub>2</sub>)***

##### *Intertemporal variation of pollutant concentrations*

The geomorphology and meteorology of the Attica region significantly influence sulfur dioxide levels. Based on the diagram, sulfur dioxide concentrations tend to decline over time, attributed to the overall improvement and reduction of this pollutant in diesel and heating oil, as well as in unleaded gasoline.

However, during the winter months, pollutant levels are relatively higher due to increased fuel consumption for heating. A noticeable rise occurs in the months of January, March, April, and October (based on average monthly values) (Figure 5).

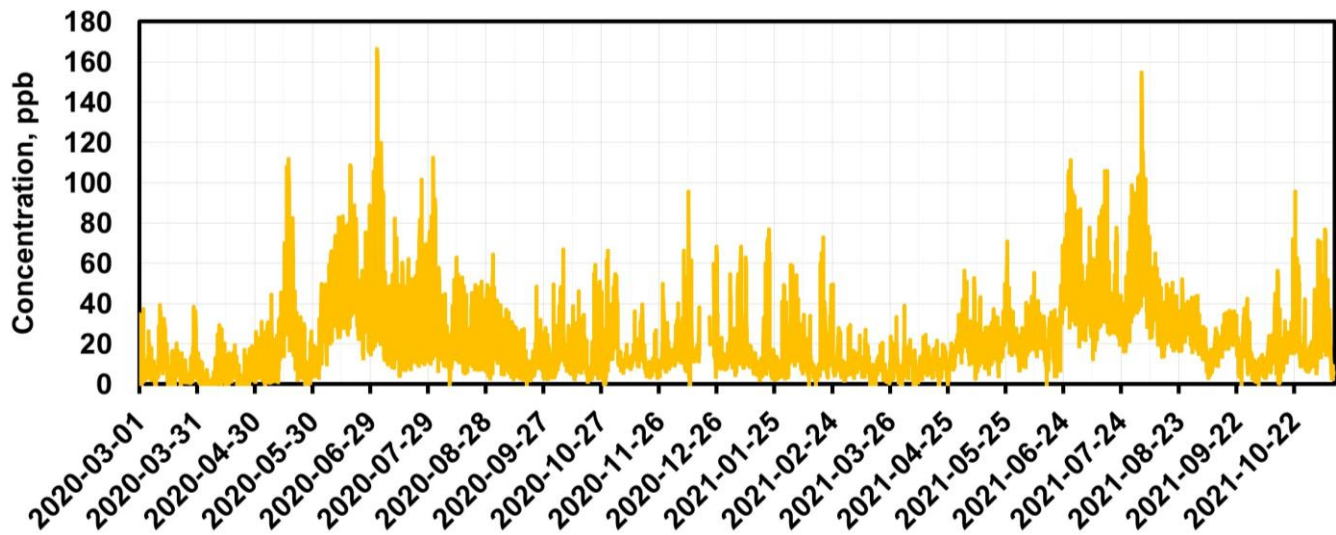


Figure 5. Intertemporal variation of pollutant  $\text{SO}_2$ .

#### *Intraday variation*

This pollutant does not exhibit high fluctuations throughout the day, as its concentration values are relatively low. The increased and maximum trend shown by Kerameikos in the morning hours is due to favorable environmental conditions, including temperature inversion, which strengthens its presence.

During the winter months, as noted above, these maximum values correspond to the operating hours of the central heating in the houses, additionally, even during peak traffic hours, the values are justified to be slightly increased.

#### **Nitrogen dioxide ( $\text{NO}_2$ )**

##### *Intertemporal variation*

A stabilization trend is observed, with the highest values occurring from November to February. When nitrogen dioxide is combined with consistently high relative humidity throughout the year, it causes acid attacks on the monuments at the archaeological sites [10-11].

##### *Intraday variation of pollutant concentrations*

For nitrogen dioxide, as illustrated in the diagram, the highest values are recorded in the morning from 10:00 to 11:00, slightly delayed compared to the pollutant  $\text{NO}$ , since the latter is a necessary component for its formation. Throughout the day, levels fluctuate significantly, ultimately showing a weaker secondary value at 21:00, which is also confirmed by the relevant report from the Ministry of Environment and Energy.

#### **Nitrogen monoxide ( $\text{NO}$ )**

##### *Intertemporal variation of pollutant concentrations*

Overall, there is a slight tendency to reduce the concentrations of Nitrogen Monoxide ( $\text{NO}$ ).

The values of  $\text{NO}$  are certainly observed during the winter months and are directly related to vehicle traffic, where pollutant emissions are higher as engines work harder to perform immediately when cold. Corresponding observations exist for the  $\text{CO}$  pollutant below.

More specifically, it is observed that the archaeological sites of Kerameikos studied in the Attica basin exhibit higher values of nitrogen oxides, particularly from January to March and from September to December. However, during the summer months, there is a downward value trend (Figure 6).

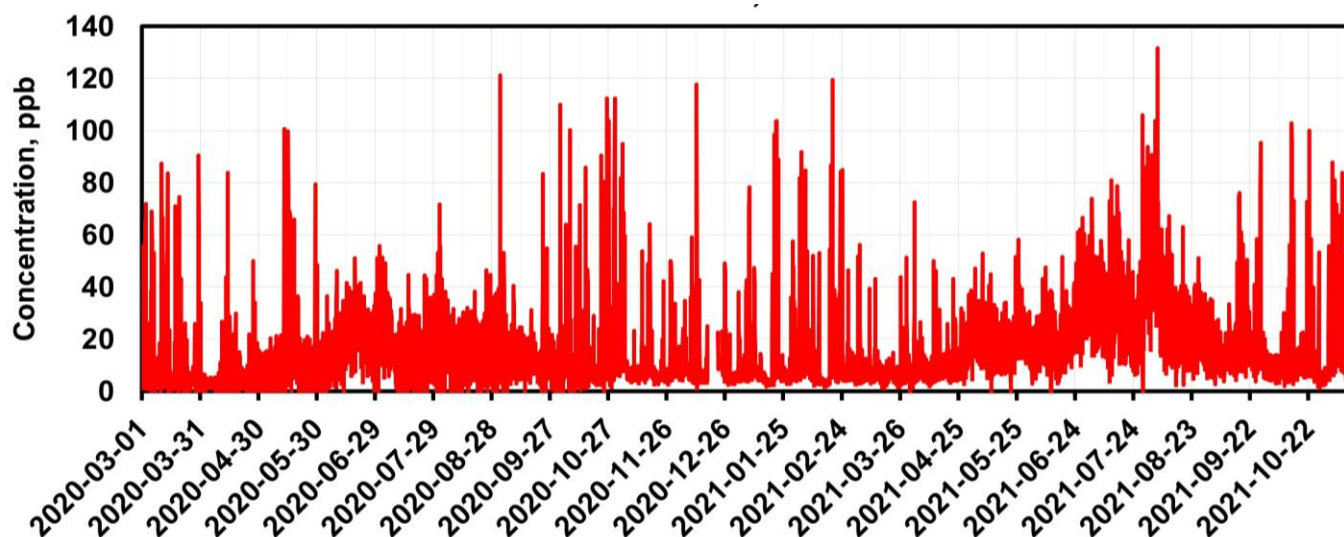


Figure 6. Intertemporal variation of pollutant NO.

These pollutants, along with carbon monoxide, show a slight decrease in the diagram, particularly on Sunday. Nitrate is sensitive to temperature, peaking when the temperature is at its lowest, just before sunrise. However, they are highly soluble and less resistant, leading to their easier removal from stone monuments through rain washing [1]. As for the NO, the values are high.

#### *Intraday variation*

Pollutants primarily associated with traffic, such as nitrogen oxides, carbon monoxide, and benzene, exhibit either a significant or minor decrease on Sunday.

#### **Carbon monoxide (CO)**

##### *Intertemporal variation*

No tendency to increase carbon monoxide is observed (Figure 7). The emission source of this pollutant includes evaporation from fuel storage areas at gas stations and the use of solvents due to their high volatility. Additionally, an important observation is that in cold months the organic carbon is lower as mentioned by Valavanidis [12].

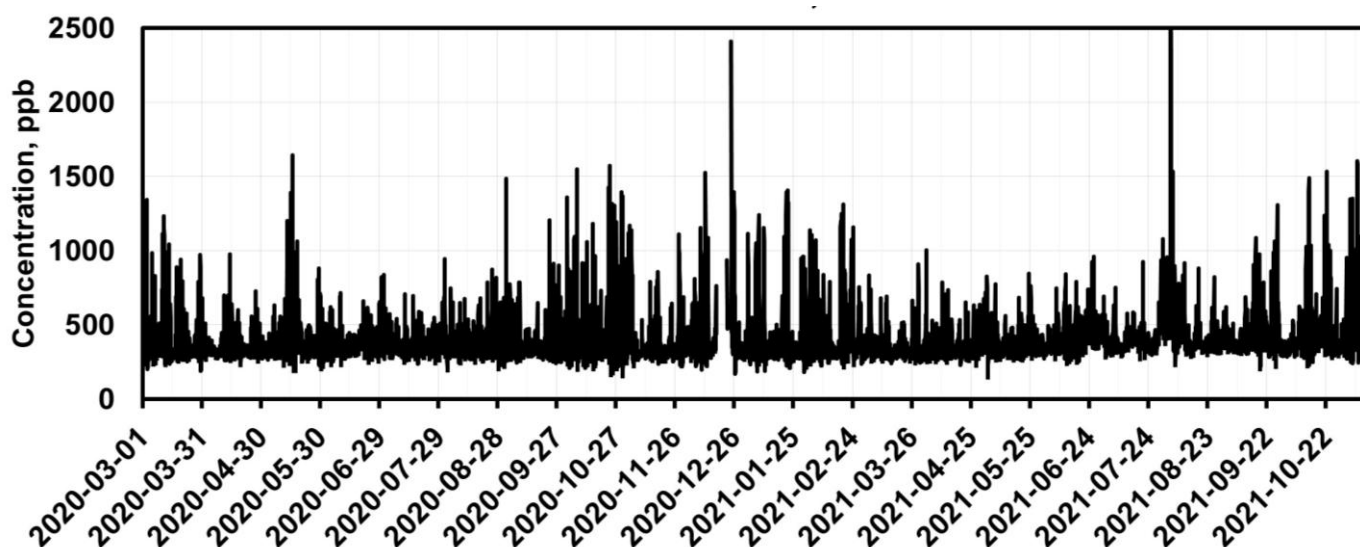


Figure 7. Intertemporal variation of pollutant CO.

### *Intraday variation*

Regarding CO, the values decrease in the afternoon and increase in the evening, only to fall again after around 3 am (Figure 8) This primary pollutant, similar to NO, typically shows a rise during the early morning hours, specifically between 8 and 10 p.m., and from 9:00 to 11:00 p.m. (secondary maximum).

### **Carbon dioxide (CO<sub>2</sub>)**

#### *Intertemporal variation of pollutant concentrations*

Pollution levels tend to decline over the years.

### *Intraday variation*

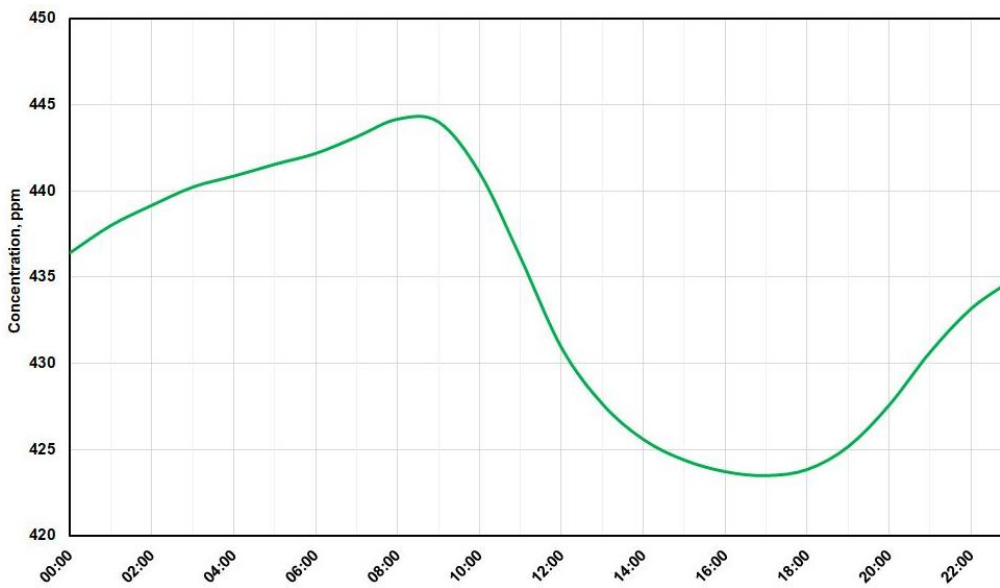


Figure 8. Intraday variation of pollutant CO<sub>2</sub>.

### **Ozone (O<sub>3</sub>)**

#### *Intertemporal variation of pollutant concentrations*

Ozone levels tend to stabilize over time; however, there are occasional fluctuations, which are due to the nature of this pollutant. Specifically, it is a secondary pollutant that has a long residence time in the troposphere and is transported from the stratosphere (Figure 9).

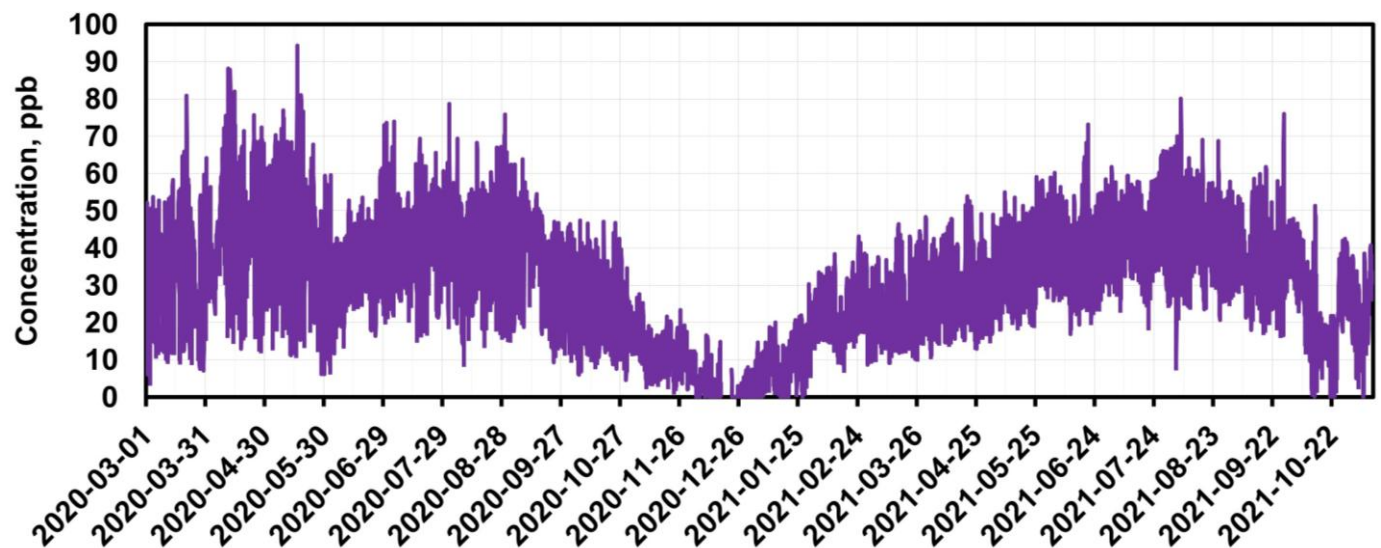


Figure 9. Intertemporal variation of pollutant O<sub>3</sub>.

#### *Intraweekly variation*

This pollutant shows an increasing trend, particularly on weekends and especially Sundays, in the Athens basin, due to the reduction of vehicle traffic, as it is a photochemically produced pollutant.

#### *Intraday variation*

According to the diagrams, during nighttime hours, the production of ozone does not increase. The highest O<sub>3</sub> levels recorded in central Athens on weekends result from the reduction in heavy-duty diesel vehicle traffic.

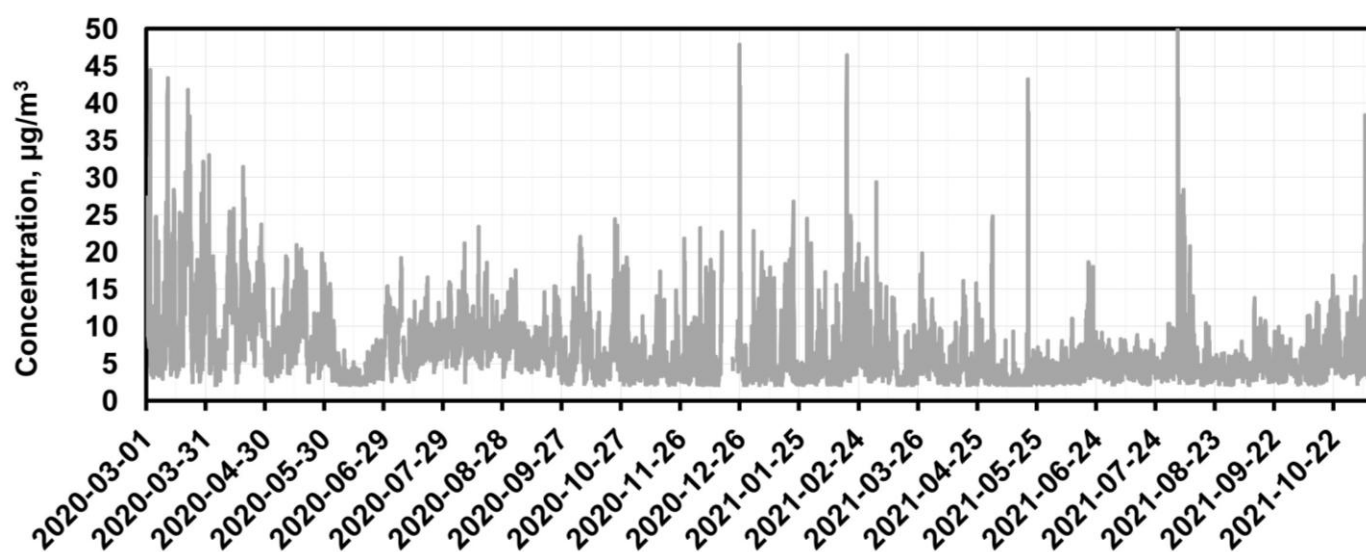
Regarding the level of diurnal variation, the maximum O<sub>3</sub> concentration occurs in the early afternoon when solar radiation on Earth's surface is at its peak during the meridian hours (it is a dynamic situation that requires some time for the accumulation of meridional activity) [13].

The minimum concentration is observed early in the morning, after nightfall, when solar activity is negligible and transport from higher altitudes is disrupted by the nighttime temperature inversion. Ozone is promoted by the sea breeze, which begins at 10 in the morning and blows from South to North, gradually transporting both gaseous and particulate pollutants toward the interior of Athens, particularly when the winds are generally weak [14].

#### **Particulate matter PM<sub>2.5</sub>**

##### *Intertemporal variation of pollutant concentrations*

According to the diagram, the values of airborne particles show a downward trend or even stability (Figure 10). However, during winter, high concentrations of soot are observed due to the operation of central heating and the use of biomass for heating.



**Figure 10.** Intertemporal variation of pollutant PM<sub>2.5</sub>.

## Commentary

Despite reduced pollutants in Athens, the areas with the highest pollution concentrations appear to remain unchanged. Pollution levels in the region peak in late autumn and winter, as pollutants become trapped beneath inversion layers and fuel burning for home heating and lighting reaches its maximum [15].

In the case of Attica, the area of interest for this dissertation, where road traffic exceeds 2 million vehicles per day,  $PM_{2.5}$  particles and sulfur dioxide are among the most concerning factors, emitting sulfur oxides from diesel engines [16]. A problem is the presence of Attica KTEL buses in Thisio, the electric railway station, the heavy traffic of vehicles, and the presence of traffic lights on the sloping roads (intense starts & braking) [17]. The transport sector is primarily responsible for fluctuations and changes in the quantification of air pollutants. This is likely due to the heavy traffic load of vehicles on the main Piraeus Street, which is located next to the archaeological site. However, factors such as vehicle speed and type, traffic volume, traffic composition, the geometry of the road surface (whether it's a turn section or a straight road), the terrain of the environment, and local meteorology should be taken into consideration [18].

Furthermore, road traffic has a significant impact on the levels of lead and zinc found along the roadside, within a radius of up to 50 m. Additionally, carbon monoxide, nitrogen oxides, and hydrocarbons are among the primary pollutants emitted by vehicles, as identified through SEM in the present study. However, the new vehicle technologies and the increased use of electric cars have clearly reduced carbon monoxide emissions, as shown in the diagrams, while nitrogen oxides remain higher in the main streets and avenues of Athens, especially during peak hours.

Trees also generally mitigate the greenhouse effect, as they filter atmospheric pollutants and prevent soil erosion. As emphasized by Akbari et al [19], the effectiveness of vegetation in reducing air temperatures within the city depends on its intensity, shape, dimensions, and location. Some of the species found at the archaeological site of Kerameikos and used as a fence include pines, cypresses, plane trees, olives, laurels, washingtonias, maidenhair trees, angelicas, myrtles, oleanders, and rosemary [12].

### Covid 19 effect

At this point, it is important to comment on the effect of the restrictive measures on traffic and human activities in light of the Covid-19 pandemic.

The comparison of air pollutants associated with the above means before and after the coronavirus showed that the atmosphere improved significantly, encouraging scientists to seek better ways to manage the harmful substances caused by humans in the urban environment.

It is characteristic that nitrogen dioxide, a pollutant resulting from vehicle traffic, fell during the first quarter of Covid compared to the pre-coronavirus months and years. This reduction, which occurred on the busiest streets in the center of Athens, by approximately 35 % [17] (Aristotelous and Patision, where over time they also show the most excesses of the limit values), was striking and simultaneously highlighted the need for stricter methods to alleviate traffic congestion on the central roads of the basin. After the measures were lifted, the 52 % increase in pollutant concentrations, mainly nitrogen dioxide, was notable.

As for  $PM_{10}$  microparticles, a reduction was recorded during the pandemic, and for  $PM_{2.5}$  microparticles, the reduction was around 13.3 % [20]. However, after the lifting of the imposed measures, the  $PM_{10}$  microparticles changed little, while the  $PM_{2.5}$  showed an increase. This increase is due to the wind direction during the same period, which generally blew from the South Southwest at a speed of 3.1 m/sec, thereby hindering the diffusion of pollutants.

## Conclusions

The rapid urban development has created serious problems not only for humans but also for works of art and monuments in primarily urban environments. Among the pollutants, dry and wet deposits play a significant role in this deterioration, as limiting them is challenging. However, several factors have gradually contributed to the reduction of air pollution in Athens in recent years, primarily due to the crisis that has led to a decrease in vehicle use.

Gradually replacing older electric cars with newer models has significantly reduced SO<sub>2</sub>, NO<sub>2</sub>, and CO pollutants. Additionally, although the coronavirus has led to less movement among citizens, the phenomenon of weekend pollution remains present.

In the archaeological site of Kerameikos, there is a significant chance of pollution being transported from Eleusis (due to the cement factories and refineries) to Athens. The primary issue is the national highway's road network, as it also facilitates the movement of particles. Measurements have been taken on Attiki odos, and indeed, despite the expressway, particle pollution was detected [16]. The pollutants at night are generally transported to the northern suburbs and trapped there due to the mountains.

Collectively, based on the observations of this study, it appears that the primary source of pollutants is vehicles, which account for 60 %, followed by heating in urban areas. Diesel vehicles contribute to air pollution to a greater extent than gasoline vehicles [21].

The pollutant concentrations studied in this research, based on the results recorded so far, show fluctuations in their average annual values from year to year. However, as a general result a trend of reduction or better stabilization (mainly of primary pollutants) is identified. This is due to various factors, including the recent trend across all European countries to improve conditions in urban centers. In the area of interest, Athens has achieved a reduction in smog through legislative regulations aimed at decreasing the use of sulfur-containing fuels, the adoption of catalytic vehicles with new technologies, and their evolution into hybrids and electric vehicles.

Additionally, the checks on vehicle conditions conducted through the Vehicle Technical Control Centers, the implementation of the exhaust gas card, the use of fuel with enhanced technical specifications, the completion of major road networks that relieved central Athens, and the observance of the ring road have all contributed to improving atmospheric conditions within the city [22].

Furthermore, natural gas for energy and heating was included, and new regulations against industrial pollutants and smoke, as well as measures for energy efficiency, were developed. Therefore, it is important to conduct continuous routine checks on pollution levels in the atmosphere to determine when pollution has exceeded permissible limits and to seek appropriate environmental solutions without hesitation. This concerns the country's cultural heritage, making the long-term preservation and protection for future generations imperative.

## Future work

The purpose of this study is not to create a mathematical prediction model of atmospheric pollution in Kerameikos. However, the data can be future material for new field research where artificial intelligence models can with a more accurate approach give statistical analyzes for the course of pollutants in a site or in a combination of various archaeological sites.

An important development of the present work would be the statistical processing of the measurements in order to extract more information and possible future results. Furthermore, the development of systemic, long-term policy frameworks, at local and national levels, is recommended. The monitoring of air quality and main air pollutants in urban areas, but also the study of other parameters, and the technological development "Smart archaeological sites" is proposed.

Regarding future efforts, a modern network of multiple Airsences devices, equipped with high spatiotemporal resolution databases [18], should be established in the historical center of Athens to ensure continuous monitoring and vigilance of the environmental air situation in the area. Climate change poses a threat not only to humanity but also to our precious archaeological heritage.

#### Acknowledgements

The author would like to thank Professor and supervisor Mr. Lampropoulos for his valuable guidance and supervision, the three members of the advisory committee, Theoulakis and Lazaridis, the scientific operator of the analysis equipment at the University of Athens, Karabotsos, the head of the Department of Conservation of Antiquities and Works of Art Boyatzis, and my family for supporting my dissertation.

#### REFERENCES

- Lampropoulos, V. N., *Environment of monuments, museums and archaeological sites*, Athens 2017, Athens (2003).
- Iliopoulos, T., *The archaeological museum of ceramics*, Fund for Archaeological Resources and Expropriations, Athens (2009).
- Crilly, L. R.; Shaw, M.; Pound, R.; Kramer, L. J.; Price, R.; Young, S.; Lewis, A.C.; Pope, F.D.; 'Evaluation of low-cost optical particle counter (Alphasense OPC-N2) for ambient air monitoring', *Atmospheric Measurement Techniques* **11**(2) (2018) 709-720, <https://doi.org/10.5194/amt-11-709-2018>.
- Moropoulou, A.; Bisbikou, K.; Torfs, K.; Van Grieken, R.; Zezza, F.; Macri, F., 'Origin and growth of weathering crusts on ancient marbles in industrial atmosphere', *Atmospheric Environment* **32**(6) (1998) 967-982, [https://doi.org/10.1016/S1352-2310\(97\)00129-5](https://doi.org/10.1016/S1352-2310(97)00129-5).
- Giere, R.; Querol, X., 'Solid particulate matter in the atmosphere', *Elements* **6**(4) (2010) 215-222, <https://doi.org/10.2113/gselements.6.4.215>.
- Lazaridis, M., *Air pollution, with meteorological data*, 2nd edition, Tziolas, Athens (2010).
- Satsangi, P.G.; Yadav, S., 'Characterization of PM 2,5 by X-ray diffraction and scanning electron microscopy – energy dispersive spectrometer: its relation with different pollution sources', *International Journal of Environmental. Science and Technology* **11** (2014) 217-232, <https://doi.org/10.1007/s13762-012-0173-0>.
- Stefanis, A.; Theoulakis, P.; Pilinis, C., 'Dry deposition effect of marine aerosol to the building stone of the medieval city of Rhodes', *Building and Environment* **44**(2) (2009) 260-270, <https://doi.org/10.1016/j.buildenv.2008.03.001>.
- Skoulikidis, T.; Vassiliou, P., 'Corrosion and conservation of building materials of monuments; the Acropolis case', *Corrosion Reviews* **17**(5-6) (1999) 295-332, <https://doi.org/10.1515/CR.1999.17.5-6.295>.
- Kirkitsos, P.; Sikiotis, D., 'Deterioration of pentelic marble, Portland limestone and baumberger sandstone in laboratory exposures to gaseous nitric acid', *Atmospheric Environment* **29**(1) (1995) 77-86, [https://doi.org/10.1016/1352-2310\(94\)00230-1](https://doi.org/10.1016/1352-2310(94)00230-1).
- Lampropoulos, V. N., 'Conservation and restoration works of the monument and sculptures of the Academy of Athens' (5 November 2010), in *Blog Round-About Art*, <http://roundaboutart.blogspot.com/2010/11/blog-post.html> (accessed 2022-07-12).
- Valavanidis, A.; Vlachogianni, T.; Loidas, S.; Fiotakis, C., 'Atmospheric pollution in urban areas of Greece and economic crisis. Trends in air quality and atmospheric pollution data, research and adverse health effects', in *Research Gate* (2015), <https://www.researchgate.net/publication/284415702> (accessed 2021-06-18).
- Proias, G. T.; Larissi, I. K.; Moustris, K. P.; Nastos, P. T.; Paliatsos, A. G., 'Assessment of surface ozone variability in an urban coastal area at the Eastern Mediterranean', *Global Nest Journal* **15**(2) (2013) 163-168, <https://doi.org/10.30955/gnj.001034>.
- Kadja, M.; Anagnostopoulos, J. S.; Bergeles, G. C., 'Study of wind flow and pollutant dispersion by newly developed precision-improving methods', *International Communications in Heat and Mass Transfer*, **23**(8) (1996) 1065-1076, [https://doi.org/10.1016/S0735-1933\(96\)00088-7](https://doi.org/10.1016/S0735-1933(96)00088-7).
- Yentekakis, I., *Atmospheric pollution, effects, control and alternative technologies*, Ed. Keydarithmos, Athens (2010).
- Grivas, G.; Chaloulakou, A.; Kassomenos, P., 'An overview of the PM10 pollution problem, in the Metropolitan Area of Athens, Greece. Assessment of controlling factors and potential impact of long range transport', *Science of the Total Environment* **389**(1) (2008) 165-177, <https://doi.org/10.1016/j.scitotenv.2007.08.048>.
- Basoulou, M.; Spyropoulos, G., 'Comparative measurements of air pollution using low-cost sensors in the center of Athens and the Mt. Hymettus aesthetic forest', *Environmental Science Proceedings* **26**(1) (2023) 79, <https://doi.org/10.3390/enviroscienv.2023026079>.
- Spyropoulos, G.; Nastos, P. T.; Moustris, K. P.; Katopodis, T., 'The use of low-cost sensing for air pollution measurements in urban outdoor environments', conference paper, in *14th international conference on meteorology, climatology and atmospheric Physics (COMECAP)*, Alexandroupolis (2018).
- Akbari, H.; Davis, S.; Dorsano, S.; Huang, J.; Winett, S., *Cooling our Communities – A guidebook on tree planting and light coloured surfacing*, Electric Power Research Institute, Palo Alto (1992).
- Triantafyllou, E.; Diapouli, E.; Tsilibari, E. M.; Adamopoulos, A. D.; Biskos, G.; Eleftheriadis, K., 'Assessment of factors influencing PM mass concentration measured by gravimetric & beta attenuation techniques at a suburban site', *Atmospheric Environment* **131** (2016) 409-417, <https://doi.org/10.1016/j.atmosenv.2016.02.010>.
- Moussiopoulos, N., 'Photochemical air pollution in Athens', *WIT Transactions on Ecology and the Environment* **1** (1993) 19-26, <https://doi.org/10.2495/AIR930191>.

22. Spyropoulos, C.; Nastos, P.; Moustris, K.; Chalvatzis, K., 'Transportation and air quality perspectives and projections in a Mediterranean country, the case of Greece laboratory of climatology and atmospheric environment', *Land* **11**(2) (2022) 152, <https://doi.org/10.3390/land11020152>.

RECEIVED: 2024.11.30

REVISED: 2025.5.8

ACCEPTED: 2025.10.10

ONLINE: 2026.6.2



This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/deed.en>.