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Evaluation of the impact of the COVID-19 pandemic on photochemical pollution in urban areas

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Abstract

Background: The effect of confinement due to the coronavirus disease 2019 (COVID-19) pandemic on air pollution has been investigated in several cities. Indeed, the concentration of the main air pollutants have decreased significantly due to the decline in activities consuming fossil fuels. However, it was found that the concentration of ozone (O_3) has increased in Nice, Rome, Valence, Barcelona, Turin, and Wuhan. The main objective of this study was to assess the impact of the COVID-19 pandemic on photochemical pollution in Oran, Algeria.

Methods: In Oran, a port city in the north-west of Algeria, the level of tropospheric ozone pollution was measured automatically every 15 min for 10 days at the same location before and after the confinement period, using an electronic nose, called APOMOS (air pollution monitoring system). This electronic circuit is equipped with an electrochemical sensor (MQ131) as well as a temperature and humidity sensor. Sampling was carried out in the central part of the Oran agglomeration from May to June 2020. The data related to the direction and intensity of the wind were processed to find a correlation between these parameters and the concentration of ozone in the studied area.

Results: The impact of confinement on the increase of the ozone pollution levels in Oran, was estimated to be 52%. On the other hand, the statistical study of the pollution levels, the intensity and direction of the wind indicates that the important part of the downtown is involved in the generation of tropospheric ozone.

Conclusion: The confinement due to the COVID-19 pandemic in Oran led to the reduction of the road traffic and pollutants emissions and the increase of ozone levels in urban area. Thus, ozone was less degraded because there were low levels of nitrogen oxides (NOx) in the atmosphere of this city during the confinement period.

Keywords: Tropospheric ozone, Confinement, COVID-19, Electronic nose

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Introduction

In December 2019, the coronavirus disease 2019 (COVID-19) pandemic appeared in Wuhan, China. Within a few weeks, the disease had spread to countries in all parts of the world (1). Like other countries in the world, Algeria was affected by the COVID-19 pandemic from February 25, 2020 (2). In order to reduce the risk of exposure to the virus, partial confinement measures have been imposed on some cities that had reported the highest number of contaminated cases (3). Confinement is a barrier measure used to break the chain of virus transmission during an epidemic (4). Thus, the epidemiological situation was stabilized by taking a set of measures such as staying off educational establishments and higher, stopping urban-suburban transport and air traffic, closing non-critical businesses, and finally, closing borders (5,6).

Confinement measures have been imposed in several countries in order to control the spread of COVID-19 and to mitigate its impact (7) and to contribute to the flattening of the epidemic curve. At the same time, the confinement of the population, the reduction of public transport and essential economic activities significantly decreased the road traffic, and consequently, reduced the levels of air pollution in Barcelona (8), São Paulo (9), Delhi (10), and

Salé (11).

However, increased ozone (O$_3$) pollution was found in Nice Rome, Turin, Valencia, and Wuhan (12). The same phenomenon was observed in Barcelona (Spain), in which maximum daily 8-hour O$_3$ concentrations increased and it was estimated to be between +33 and + 57%. This phenomenon can be explained by the lower titration of O$_3$ by nitrogen oxide (NO) and a decrease in nitrogen oxides (NOx) in a limited number of volatile organic compounds in the environment (8,13).

However, there is not enough evidences to get a general idea of this phenomenon. In order to have a better understanding, we have carried out a statistical data processing. In this study, the direction and intensity of the wind in relation to the recorded O$_3$ concentrations were also investigated.

Materials and Methods
Study area
Oran is located in a semi-arid region (14), and is made up of several municipalities with a total population of 1 026 900 people in 2015 and a traffic flow greater than 600 PCU/h (passenger car unit) at the evening peak hour in the main roads of the city (15).

In this second largest city in Algeria, the first case of COVID-19 was reported on March 19, 2020. Figure 1 shows the progression of proven cases from COVID-19 with the confinement stages in Oran. As shown in this figure, the highest number of COVID-19 cases was reported between 3 PM to 7 AM.

Ozone measurements were made in Oran, every 15 minutes for 10 days at the same location before and after the confinement period (from May to June 2020). Figure 2 shows the study area and sampling point.

Working day correspond to ordinary economic activities with heavy road traffic and industrial units in production. Saturday is a semi-working day, which corresponds to a drop in economic activities and road traffic. On Friday, which is a public holiday, these two parameters decrease more.

Ozone measurement
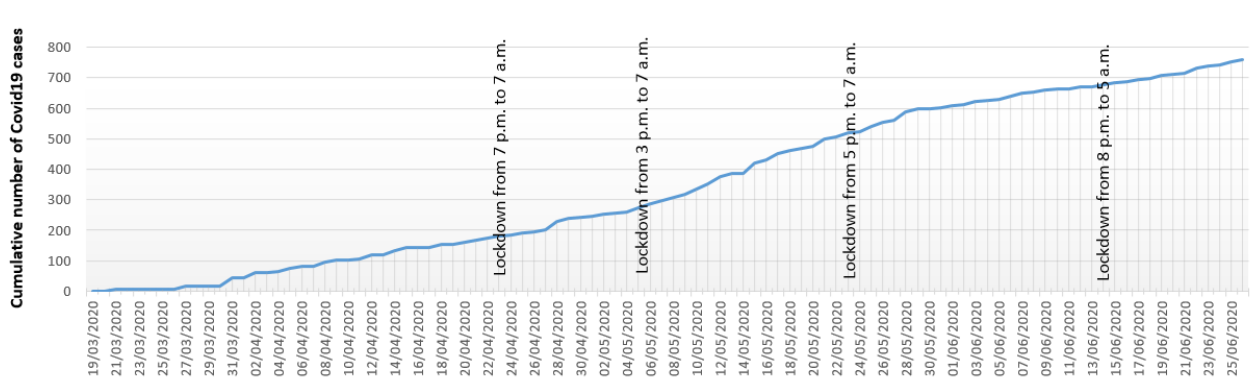The measurements were taken with an electronic assembly, called APOMOS (air pollution monitoring

Figure 1. The number of confirmed cases infected with COVID-19 in Oran since 19/03/2020 with the main stages of confinement (6).

Figure 2. The study area and sampling measurement point.

system) (Figure 3), which was placed at human height. This system is equipped with two electrochemical sensors (MQ131-Winsen Electronics), one for low concentrations and the other for high concentrations. The detection limits of the sensor range from 10 to 1000 ppb. This system is also equipped with a temperature and humidity sensor (DHT22 sensor) for measuring temperature and humidity.

The MQ131 sensor was successfully used in several studies (16,17).

Electrochemical air quality sensors have the potential to fill the gap left by traditional monitoring of air pollution. The cost and size of air pollution sensors is decreasing, which means that it is now possible to use portable and inexpensive air pollution analyzers (18). The APOMOS can manage data acquisition every 15 min.

For a more relevant analysis of the data obtained, it is necessary to process them with statistical tools. Thus, in many applications, the paired data controls other relevant variables through a matching process.

Basic textbooks analyze such data by applying the paired Student's t-test. This test is optimal when the differences are normally distributed (19). However, before using the test, it is necessary to verify that the data follow a normal distribution. Given the size of our data, the Shapiro-Wilk test (20) appears to be the most suitable one for performing a normality test.

Results

Analysis of the raw data showed an increase in ozone concentrations during confinement (Figure 4). This figure shows the average of the measurements collected during and after confinement for the working day, Friday which is a public holiday, and Saturday which is a semi-holiday in Algeria.

The ozone concentrations increased significantly during confinement except for Saturday morning, in which a very modest increase was observed (Table 1). This can be explained by a significant difference in relative humidity between Saturday mornings during and after confinement.

Indeed, the relative humidity of Saturdays after confinement is 12.61% higher than that of the same days during confinement according to the data recorded by the DHT22 sensor of APOMOS. Figure 5 shows the average measurements collected every 15 minutes by the APOMOS regarding temperature and humidity for the working day, Friday, and Saturday.

Usually, in a historical data set, the presence of multiple outliers can easily go unnoticed due to the masking effect (21).

Statistical analysis of the data collected makes it possible to detect any atypical or extreme outliers. Figure 6 shows a

Table 1. Relative increase in ozone concentrations during confinement and standard deviation of data during and after confinement

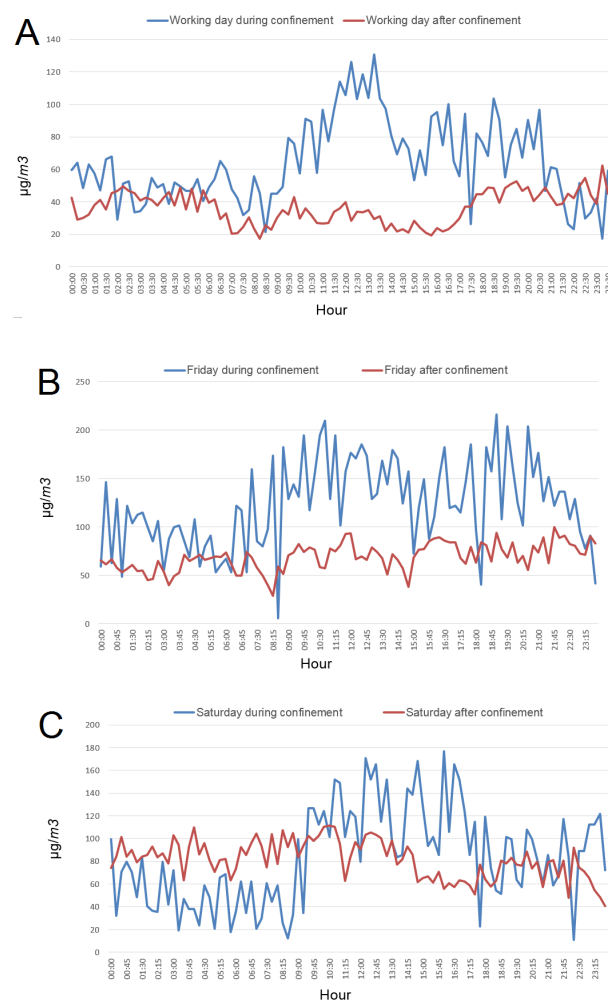| Day	%	SD during confinement
Working Day	76.02	25.08
Friday	78.63	45.22
Saturday	2.13	42.13

Figure 4. The average of the measurements collected during and after confinement for the working day (A), Friday (B), and Saturday (C).

Figure 3. The APOMOS equipped with MQ131 detectors for low and high concentrations, and the DHT22 sensor for measuring temperature and humidity.
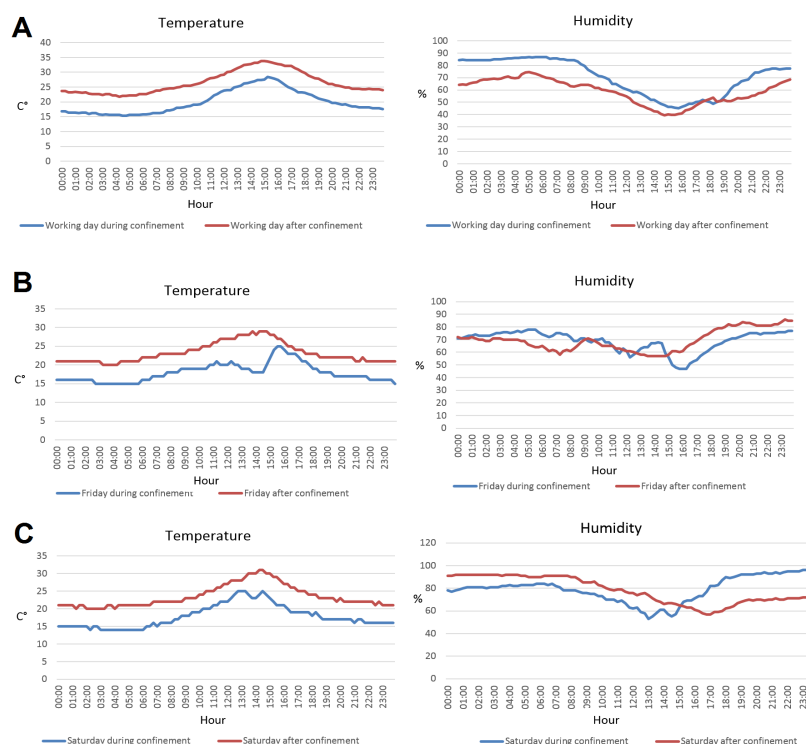
Figure 5. Average measurements collected by the APOMOS regarding temperature and humidity every 15 min during and after confinement for the working day (A), Friday (B), and Saturday (C).

box-and-whisker plot box or box plot of the data recorded during confinement, which indicates the extreme values of the ozone concentrations.

Thus, data processing makes it possible to perform a statistical analysis with the paired student's t test in order to verify the increase of ozone concentrations during and after confinement. The value of pairing is that each individual is their own witness. With this method, we can eliminate the inter-individual variability that risks masking the phenomenon studied (22).

However, the paired student's t test can only be used if the differences between the ozone concentrations during the two periods studied follow a normal distribution.

This condition can be evaluated using the Shapiro-Wilk test, the null hypothesis of which is that the differences follow a normal distribution if P-value is greater than 0. Table 2 shows the results of the Shapiro-Wilk test applied to the working day, Friday, and Saturday.

According to the results, the paired student's t test can be applied during and after confinement. The results presented in Table 3 clearly indicate that there was a significant increase in the ozone concentrations during the confinement period in Oran.

Several studies have shown the effect of meteorological factors on photochemical pollution (23-25). Thus, to assess the role of meteorology on the concentrations of tropospheric ozone measured in this study, meteorological data were obtained from the meteorological station at Es-Senia airport (Longitude: -0.6°, Latitude: 35.63°), which is

about 10 km from the sampling site.

Ground-level ozone concentrations are closely related to wind speed (26) and wind direction (27). Figure 7 produced by the openair package in R language from Carslaw and Ropkins (28) shows the level of ozone pollution in Oran according to the direction and speed of the wind during and after the COVID-19 confinement.

Discussion

Like other cities around the world (29), Oran also experienced an increase in the concentrations of ground-level ozone during the confinement imposed by the

Table 2. The results of the Shapiro-Wilk test applied to evaluate the ozone concentrations in Oran during and after confinement for the working day, Friday, and Saturday.

	Shapiro-Wilk test	P value
Working day	0.98726	0.4852
Friday	0.98718	0.4802
Saturday	0.9775	0.09764

Table 3. The results of the paired Student's t-test applied to evaluate the ozone concentrations in Oran during and after confinement for the working day, Friday, and Saturday.

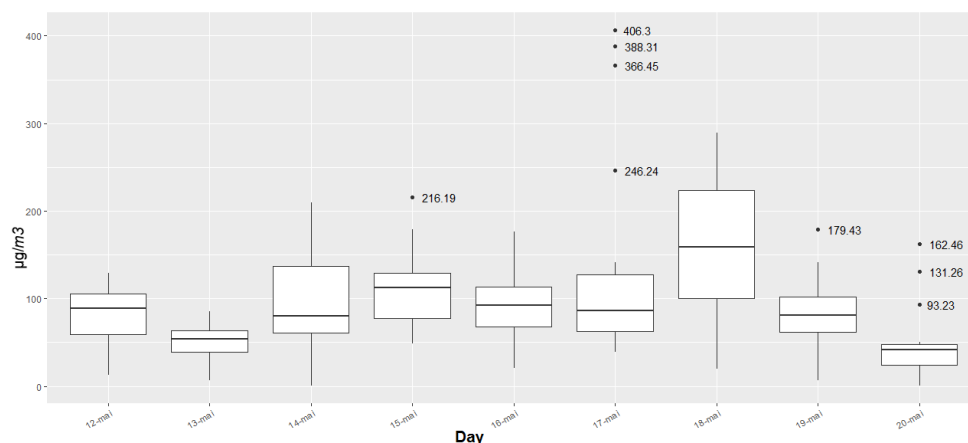|	t	df	P value
Working day	18.762	95	$<2.2 \times 10^{-16}$
Friday	23.171	94	$<2.2 \times 10^{-16}$
Saturday	14.943	95	$<2.2 \times 10^{-16}$

t: t test statistics; df: degrees of freedom.

Figure 6. Box plot of some of the values recorded during confinement, showing the extreme values of the ozone concentrations.
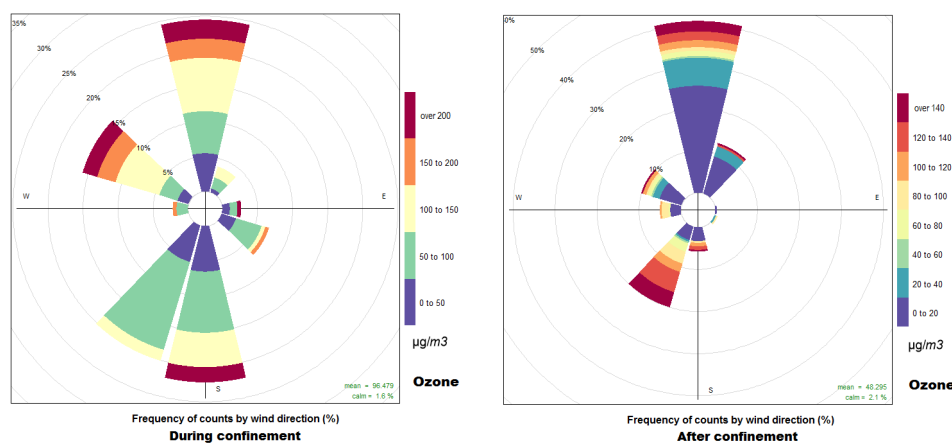

Figure 7. Level of ozone pollution in Oran according to the direction and speed of the wind during and after the COVID-19 confinement.

COVID-19 pandemic. This result is consistent with the results reported by Sicard et al who explained it mainly, by an unprecedented reduction in the NOx emissions in the studied cities (12).

As shown in Figure 4, this increase in Oran is remarkable for working day compared to that for Fridays and Saturdays.

This difference is explained by the fact that working day experiences a higher level of emission of ozone precursor pollutants such as NOx due to heavy road traffic compared to public holidays in Oran (15).

Furthermore, Table 3 confirms this increase from the results of the paired student's *t* test. It was verified that the data obtained from this test follow a normal distribution, so it can be concluded that this test is the optimum one (30).

This result was obtained thanks to a prior statistical processing of the data by detecting the extreme values as shown in figure 6.

The wind is an important element in the transport of pollutants. The study of the intensity and direction of the wind, during and after the confinement, allowed us to assess the ozone pollution in Oran in function of these parameters, as shown in Figure 7. This approach can be used to identify the origin of the pollution which can be either industrial, residential or resulting from road traffic.

The most intense ozone pollution during confinement follows two main directions. The first one is a north-south direction from the city center to the outskirts. The density of ozone precursors was high in the residential sector in this part of city. The second direction goes from South to North and is explained by the presence of industrial zones located in the south of the city. After the confinement, the North-South direction disappeared, and ozone formed in the city center was degraded by NOx from road traffic.

According to Figures 4 and 5, there is a reverse relationship between ground-level ozone concentrations and levels of relative humidity. Indeed, the ozone level is naturally low when the relative humidity of the air increases, this humidity reduces the air temperature by reducing the chain length of chemical amplifiers with peroxy radicals (HO2, RO2, and RC (O) O_2), as well as

decreasing the length of the NO_2 chain and limiting the photochemistry (31).

According to these figures, changes in ozone concentrations follow a pattern similar to changes in temperature. The usual increase in temperature leads to an increase in O_3, which was observed in Barcelona (8).

The overall increase in ozone concentration in Oran was 52%, which is higher than that reported in the other cities, as shown in Table 4.

This difference can be explained by the different amounts of sunlight recieved by Oran and European cities. This difference can also be explained by the significant difference between the mean daily maximum temperature in Oran during the confinement which occurred in May and that of the other cities whose confinement period corresponded generally to March 2020.

During the study period, the mean daily maximum temperature in Oran was 23.9°C while for the cities of Nice, Rome, Turin Valencia, and Wuhan, it was reported to be 14.9, 15.2, 13.4, 19.3, and 14.6°C, respectively (32). Obviously, humidity, wind speed, wind direction, population density, and ozone-producing sources, influence this phenomenon and deserve further study.

Conclusion

In May 2020, when a strict confinement imposed by the COVID-19 pandemic, a sharp reduction in the flow of road traffic led to an increase more than 70% in ozone concentration compared to June 2020 when the confinement was considerably reduced. As it was observed in other cities, this is probably due to the reduction of NOx emissions from road traffic which usually contributes to the degradation of ozone in urban areas. It can be concluded that the COVID-19 pandemic had a significant impact on the increase in ozone pollution in Oran during the confinement period. The use of portable and low-cost sensors made it possible to observe this phenomenon. This increase due to confinement was also shown by the statistical study of the collected data. In addition, the disappearance after confinement of a significant part of the ozone pollution in the north-south direction of the wind indicates the share of the densified downtown residential sector in this type of pollution. As a result, emissions of ozone precursors increased. The strict confinement in Oran resulted in the reduction of NOx emissions from road traffic, and subsequently, resulted in the lower ozone titration.

The impact of the COVID-19 pandemic on photochemical pollution in urban settings, which has been measured in Oran and other cities, is confirmed. However, the complexity of the tropospheric ozone formation phenomenon means that there may be remarkable differences between the studied cities.

Ethical issues
The authors certify that this manuscript is the original work of the authors, all data collected during the study are presented in this manuscript, and no data from the study has been or will be published elsewhere separately.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
All authors contributed to the structure, content, and writing of the paper. All authors read and approved the final manuscript.

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Table 4. Percentage increase in ozone concentrations during confinement (present study, 12).

City	Ozone increase (%)
Oran	52
Nice	24
Rome	14
Turin	27
Valencia	2.4
Wuhan	36

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