Air Quality, Atmosphere & Health (2021) 14:617–628
https://doi.org/10.1007/s11869-020-00965-w

Air quality change during the COVID-19 pandemic lockdown over the Auvergne-Rhône-Alpes region, France

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Received: 29 August 2020 / Accepted: 4 November 2020 / Published online: 19 January 2021

Abstract

Under the rapid spread of coronavirus diseases (COVID-19) worldwide, a complete lockdown was imposed in France from March 17th to May 11th, 2020 to limit the virus spread. This lockdown affected significantly the atmospheric pollution levels due to the restrictions of human activities. In the present study, we investigate the evolution of air quality in the Auvergne-Rhône-Alpes region, focusing on nine atmospheric pollutants (NO_2, NO, PM_{10}, $PM_{2.5}$, O_3, VOC, CO, SO_2, and isoprene). In Lyon, center of the region, the results indicated that NO_2, NO, and CO levels were reduced by 67%, 78%, and 62%, respectively, resulting in a decrease in road traffic by 80%. However, O_3, PM_{10}, and $PM_{2.5}$ were increased by 105%, 23%, and 53%, respectively, during the lockdown. The increase in ozone is explained by the dropping in NO and other gases linked to human activity, which consume ozone. Thus, the increase of solar radiation, sunshine, temperature, and humidity promoted the O_3 formation during the lockdown. Besides, rising temperature enhances the BVOC emissions such as isoprene. In addition, volatile organic component (VOC) and SO_2 remain almost stable and oxidation of these species leads to the formation of ozone and organic aerosol, which also explains the increase in PM during the lockdown. This study shows the contribution of atmospheric photochemistry to air pollution.

Keywords COVID-19 · Air quality index · Pollution · Lockdown · Auvergne-Rhône-Alpes · Lyon

Introduction

The new coronavirus discovered in Wuhan in China in late December 2019 has spread easily and sustainably. This infectious virus has caused many effects in almost all countries around the world. Because of the high propagation rate of COVID-19 between people, several countries have taken measures of safety to limit the spread of the virus. Accordingly, several human activities were suspended including industrial activities, tourism, and transport, while all scientific and cultural meetings were postponed across the globe. On 15th June the number of COVID-19 confirmed cases in Italy has reached 236,989; in Spain 243,928; in The UK 295,893; in India 332,424; in the USA 2,057,838; in Brazil 850,514; and in France 152,767 (WHO 2020).

The coronavirus disease has reached France on 24, January 2020 and the first imported cases in Europe were also detected in France (Bernard et al. 2020). The number of confirmed cases was progressively increased which lead to the announcement of limited safety measures on February 28th. While on March 17th, 2020, the French authority has implemented a nationwide lockdown as a response to the rapid spread of COVID-19 (Pullano et al. 2020). These strict safety measures have impacted negatively almost all economic activities in the whole world. In contrast, the environment has taken advantage of lockdown as the activities generating pollutants were reduced or suspended such as industrial activities, local transport and travel in and out the home country, and population mobility (Lal et al. 2020). Accordingly, several studies were carried out to evaluate the impact of imposed lockdown on the environment (Agarwa et al. 2020; Mandal and Pal 2020; Kerimray et al. 2020; He et al. 2020a, b; Bao and Zhang 2020; Zhu et al. 2020; Yao et al. 2020; Chu et al. 2020; Shakoor et al. 2020; Gautam 2020; Pata 2020).

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The present study investigates the impact of imposed lockdown on air quality using the main atmospheric pollutants including the nitrogen dioxide (NO_2), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), volatile organic component (VOC), sulfur dioxide (SO_2), and carbon monoxide (CO), retrieved from 79 air quality monitoring stations of Auvergne-Rhône-Alpes region, France. This will allow identifying the principal sources of pollution and helping regulators to set pollution reduction targets at a level that would minimize the risk to the health of the exposed population. This study was focused more precisely on Lyon city (center of Auvergne-Rhône-Alpes region), as it is considered to be the most urbanized area with a high vehicle density (Anzivino and Venzac 2018) and which was largely affected by air pollution.

Methodology

Study area

Auvergne-Rhône-Alpes region is one of the most populated regions in Europe and the leading French industrial region. It is characterized by high population density and the large expansion of its territory combining large agglomerations of 5 metropolises: Lyon (1,622,331; region prefecture), Grenoble (510,368), Saint-Etienne (372,308), Clermont-Ferrant (264,704), and Chambéry (186,355), and 12 departments namely: Ain, Allier, Ardèche, Cantal, Drôme, Isère, Loire, Haute-Loire, Puy-de-Dôme, Rhône, Savoie, and Haute-Savoie (Fig. S1). It is located in the southeastern quarter of France, bordering on Switzerland and Italy. Auvergne-Rhône-Alpes occupies an area about 69,711 km^2, and a population of 8,037,059 inhabitants, with a density of 115 inhabitants/km^2. It is bordered by five other administrative regions: Bourgogne-Franche-Comté to the north, Centre-Val de Loire to the northeast, Nouvelle-Aquitaine to the west, Occitanic to the south-west, and Provence-Alpes-Côte d'Azur to the south-east. It is also bordered by Italy (Aosta Valley and Piedmont) to the east and Switzerland (Cantons of Geneva, Valais, and Vaud) to the north-east.

The average annual temperatures for this region are ranged from 5 to 15 °C, while the highest average annual temperatures are characterizing the south part of the region, which is under the Mediterranean influence. Auvergne Rhône-Alpes region is the sunniest French region (1976 h/year), it is characterized by very variable climate, the summers are pretty hot and quite humid because of some Mediterranean influences. Besides, the winters are very cold due to the presence of the mountains and dry in the south. Because of the different climates around the region, the vegetation is miscellaneous, there are numerous regional and national parks and lush forests but also southerner plants.

Pollution data sources

The data covering the whole area of the Auvergne-Rhône-Alpes region were analyzed, in terms of mass concentration of the different pollutants between 3rd February and 15th June 2020. The daily average mass concentrations of several air pollutants, including nitrogen oxides (NOx, NO, and NO_2), sulfur dioxide (SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), carbone monoxide (CO), ozone (O_3) (8 h diurnal average, from 08:00 AM until 16:00 PM), and volatile organic component (VOC) from 79 monitoring stations spread over the region were extracted and used (Fig. S1). Data used in the present study is available in Atmo-Auvergne-Rhône-Alpes online portal for air quality data dissemination (Atmo 2020a).

Meteorological conditions

The meteorological conditions strongly influence the formation and the evolution of many atmospheric pollutants (Zhang 2019; Chen et al. 2020a, b). Meteorological conditions data used in the present study including maximum and minimum temperatures, relative humidity, wind speeds, solar radiation, sunshine duration, and rainfall, for the period extending from 3rd February to 15th June in the Lyon, were downloaded from the weather station of Lyon-Bron (Info climat 2020).

Meteorological parameters influencing air pollution

The wind is a fundamental element for the dispersion, dilution, and orientation of pollutant plumes. Under high wind speed, the dispersion of the pollutant is greater, while, in the lower wind speed is likely for air pollution accumulation. Strong winds can direct a plume to a specific area, thereby concentrating pollution. Rain cleans the atmosphere from several pollutants because the falling water interacts with the pollutants present during its fall and then transform or deposit them on the ground. For nitrogen oxides, leaching is an efficient phenomenon permitting the decrease of NOx concentrations; however, chemical interaction between NO_2 and water leads to the formation of acid rain. Likewise, the particle matter (PM) can be cleaned from the air by the rain. Concerning ozone, despite his very low soluble in water, leaching contributes also to reduce its concentrations. Both high and low temperatures influenced the air atmospheric pollution emissions, formation, and evolution, for example, the volatility of organic species like VOC increase with temperature, which may increase their ratio in the gas phase and thus their condensation and conversion especially into particles (Kourtchev et al. 2016). Sunshine duration, solar radiation, and relative humidity (RH) can strongly affect atmospheric photochemistry such as O_3 and OH radical formation, and also particle process formation including nucleation, condensation, and growth (Li et al. 2018; Lu et al. 2019a, b).

Results and discussion

The normal situation of NO_2, O_3, PM_{10}, and $PM_{2.5}$ mass concentration over Auvergne-Rhône-Alpes region

Figure 1 shows the mapping of the normal situation of NO_2, O_3, PM_{10}, and $PM_{2.5}$ mass concentration distribution over Auvergne-Rhône-Alpes. The highest NO_2, $PM_{2.5}$, and PM_{10} levels are recorded in the middle at Rhône and Loire departments, which are characterized by high population and car densities (Anzivino and Venzac 2018). Nevertheless, only NO_2 levels exceed European limit values (40 μg/m^3), especially in Rhône and Loire departments and in the north of the Ain department. The industrial activities located in the south of the Lyon metropolis contribute significantly to the increase in PM level, either by direct emissions or by VOC conversion via photochemical reactions (Kourtchev et al. 2016; Palm et al. 2016; Sbai et al. 2020). Thus, sulfate particles can represent a significant amount of PM in the center of the region due to the SO_2 emission by industrial activities located in several areas in the Rhône department (Fig. S2). The moderate ozone mass concentration observed in Rhône and Loire departments can be especially due to its consumption by NO_2 because this area is characterized by high levels of NO_2 (Fig. 1). The departments affected by the highest O_3 mass concentration are Allier, Cantal, and Puy de Dôme; they are characterized by low population and car density. Moreover, higher solar radiation and sunshine in this area promote the formation of ozone (O_3), but stay below European Limit values (120 μg/m^3 daily 8 h mean) (European Commission 2019).

Spatial changes for main air pollutions (NO_2, O_3, $PM_{2.5}$, and PM_{10}) affecting the air quality during COVID-19 pandemic lockdown

Spatial pattern of nitrogen oxides (NO_2) mass concentration

The NO_2 mass concentration before, during, and after lockdown is presented in a form of maps in Fig. 2. The

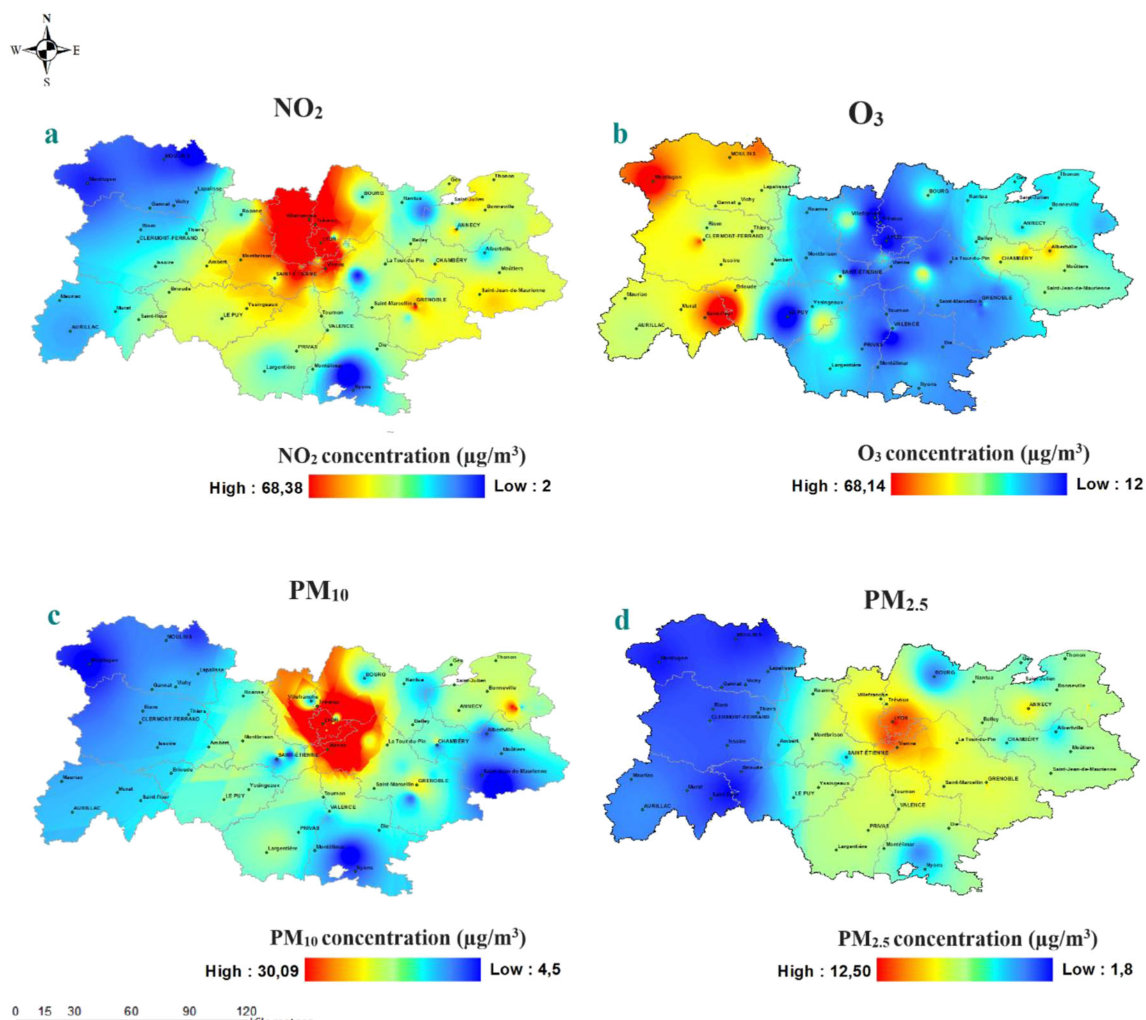

Fig. 1 Normal spatial distribution for NO_2, O_3, PM10, and PM2.5 mass concentrations for March 10th, 2020

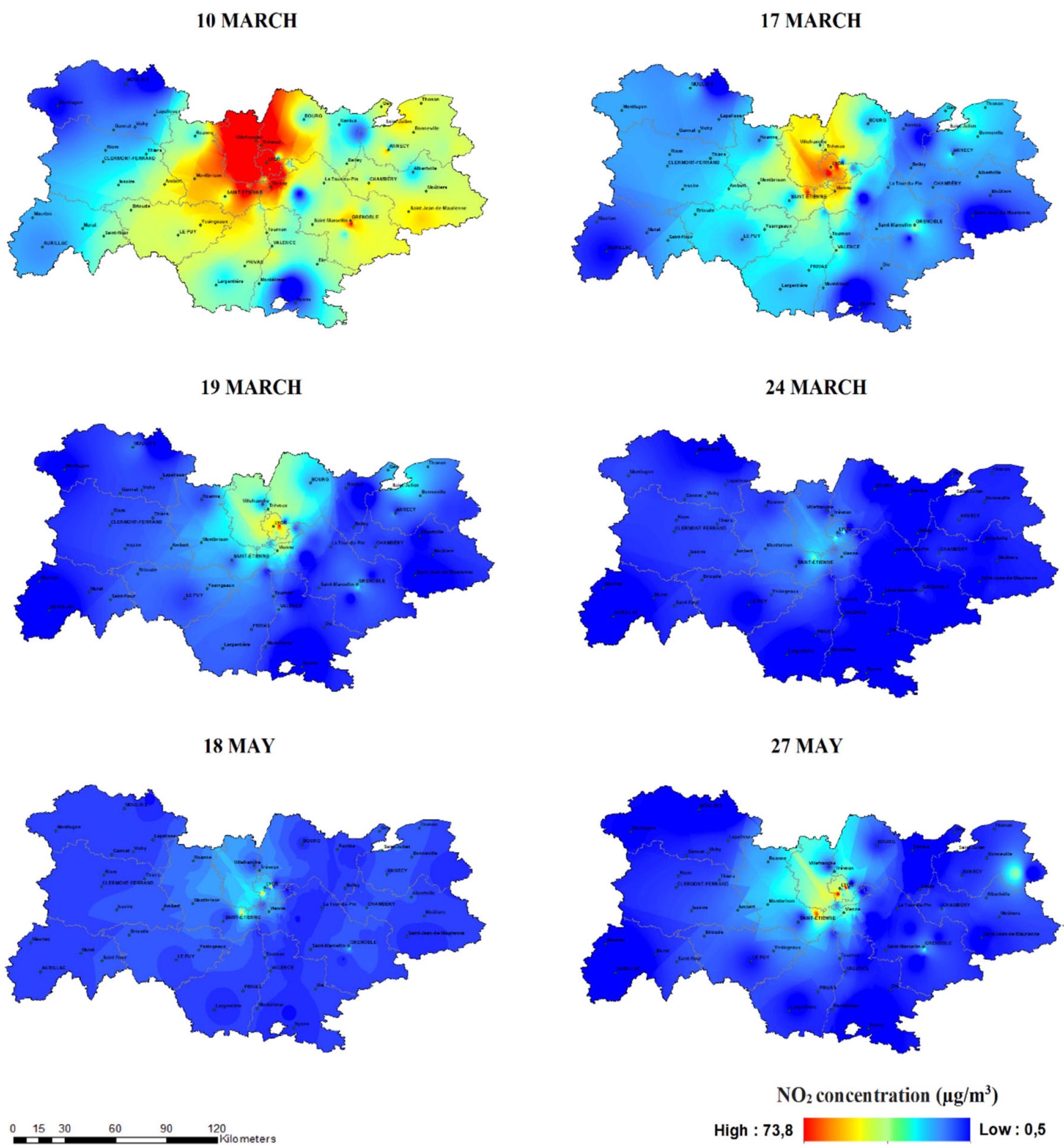

Fig. 2 Spatial distribution for NO_2 mass concentrations before (March 10th), during (March 17th, 19th, and 26 th), and after lockdown (May 18th and 27th)

reduction of road activities during lockdown reached 80% in the Auvergne-Rhône-Alpes region (Fig. S3); hence, atmospheric level of NO_2 may be affected. On March 10th, the NO_2 mass concentrations were high in the center (Rhône and Loire departments) and medium in the west of the region. Since the lockdown was implemented by the French authority on March 17th, 2020 (Pullano et al. 2020), the NO_2 level has decreased by 67.9% (at Saint Etienne) and 53.6% (at Annecy) during the lockdown (Table 1), because almost all the human activities were halted except power generation. It is also noticed that the NO_2 levels tend to increase, which is due to the beginning of easing the imposed lockdown restrictions on 11th and May 27th. Thus, these results indicate the improvement in air quality and prove that human activities are the main source for nitrogen dioxide rather than natural events and that lockdown some time will be mandatory to reduce pollution and improve air quality.

Several studies were carried out around the worldwide cities and have provided the positive impact of enforced lockdown as a response to the COVID-19 outbreak on air quality. In 44 cities located in the northern part of China, the NO_2 values were decreased by 24.7% because of the drop in human mobility by 69.8% and suspension of industrial activities (Bao

Table 1 Summary of air pollution concentrations before and during COVID-19 pandemic for nitrogen dioxide (NO_2), particulate matter ($PM_{2.5}$ and PM_{10}), and ozone (O_3) for main cities in the region

Pollutant	Cities	Station	Average mass concentration (μg/m^3)		Difference (%)
			Before lockdown[a]	During lockdown[b]	
NO_2	Lyon	Lyon center	36.8	12.0	− 67.4
	Grenoble	Grenoble les Frenes	28.0	10.6	− 62.1
	Saint Etienne	Saint-Martin d'Heres	34.0	10.9	− 67.9
	Annecy	Annecy Loverchy	27.4	12.7	− 53.6
	Chambery	Chambéry Pasteur	28.4	11.3	− 60.2
	Valence	Valence urbain center	26.1	9.3	− 64.4
$PM_{2.5}$	Lyon	Lyon center	12.1	18.5	52.9
	Grenoble	Grenoble les Frenes	12.5	13.4	32.8
	Saint Etienne	Saint-Martin d'Heres	11.6	15.7	35.3
	Annecy	Annecy Loverchy	9.4	11.8	20.7
	Chambery	Chambéry Pasteur	6.7	13.2	97
	Valence	Valence urbain center	11.6	15.4	32.8
PM_{10}	Lyon	Lyon center	20.0	24.5	22.5
	Grenoble	Grenoble les Frenes	17.5	20.1	14.9
	Saint Etienne	Saint-Martin d'Heres	20.0	20.9	4.5
	Annecy	Annecy Loverchy	18.6	20.7	11.3
	Chambery	Chambéry Pasteur	9.8	17.4	77.6
	Valence	Valence urbain center	16.6	20.7	24.7
O_3	Lyon	Lyon center	33.5	68.9	105.7
	Grenoble	Grenoble les Frenes	30.3	61.4	102.6
	Saint Etienne	Saint-Martin d'Heres	27.9	61.6	120.7
	Annecy	Annecy Loverchy	31.6	66.2	109.5
	Chambery	Chambéry Pasteur	32.4	63.0	94.4
	Valence	Valence urbain center	37.8	66.5	75.9

[a] Average mass concentration for 1 month before lockdown period

[b] Average mass concentration during lockdown period before consecutive rainy days

and Zhang 2020). The same case is observed in Almaty (Kazakhstan), where the NO_2 levels were reduced by 35% (Kerimray et al. 2020) while in Barcelona (Spain), it was reduced by half during the lockdown period (Tobías et al. 2020). In the whole world, the restriction of human activities has led to an apparent reduction of nitrogen dioxide (Dantas et al. 2020; Bao and Zhang 2020; Ogen 2020).

Spatial pattern of ozone mass concentration

Figure 3 represents the spatial evolution of the ozone mass concentration over the Auvergne-Rhône-Alpes region from March 10th to May 27th, 2020. The results indicate an increase of O_3 levels from the beginning of the lockdown (March 17th) and this increase has become clearer on May 18th, especially in the center and south of Auvergne-Rhône-Alpes region. The results show that ozone mass concentration increased by 120.7, 109.5, 105.7, 102.6, 94.4, and 75.9% in Saint Etienne, Annecy, Lyon, Grenoble, Chambery, and Valence, respectively (Table 1). This behavior could be attributed to the drastic drop in NO levels (Fig. S4), which leads to the reduction of the O_3 consumption (Sharma et al. 2020). The ozone destruction flux via the main NO_X photochemical reactions has been calculated (Table 2); the flux has been reduced from 1.51×10^{23} (molecule cm^{-3} s^{-1}) before the lockdown to 6.28×10^{22} (molecule cm^{-3} s^{-1}) during the lockdown, which represent a reduction of 40% of O_3 destruction. This partially explains the increase in ozone during the lockdown. Similar results were found in almost all studies done in worldwide cities (Mahato et al. 2020; Siciliano et al. 2020). Besides, the significant ozone levels

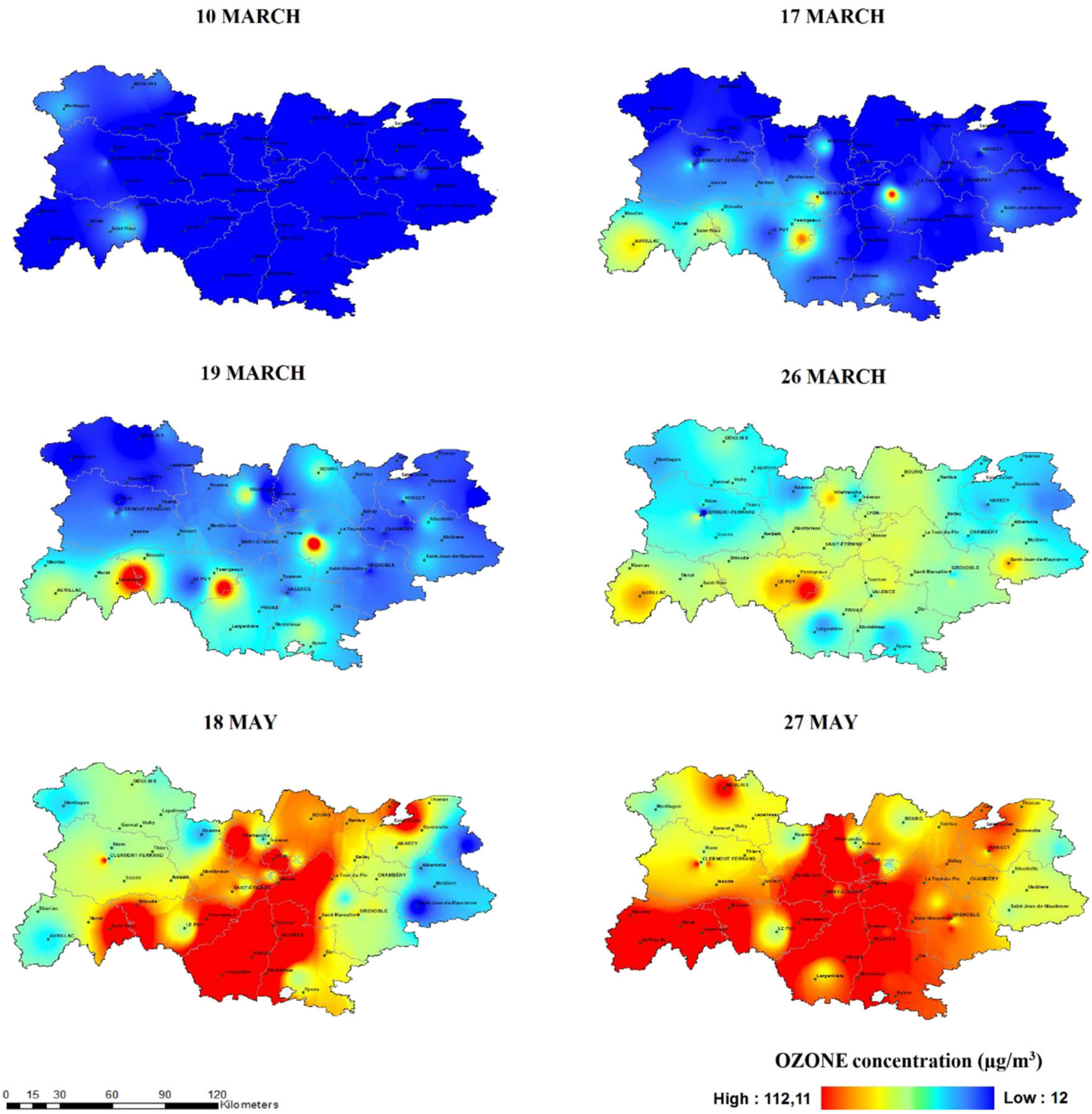

Fig. 3 Spatial distribution for O_3 mass concentrations before (March 10th), during (March 17th, 19th, and 26th), and after lockdown (May 18th and 27th)

detected in rural areas can be explained by the transport of air masses over long distances from urban areas. In addition, the presence of methane (CH_4), an important ozone precursor with a long chemical lifetime (about 9 years), contributes significantly to O_3 formation in rural areas (Atmo 2020b).

Table 2 Ozone production and depletion flux via NOx photochemical reactions under low an high NOx levels

Reaction	Rate constant (molecule^{-1} cm^3 s^{-1})	Flux (molecule cm^{-3} s^{-1})	
		Befor lockdown (high NOx level)	After lockdown (low NOx level)
$NO_2 + hv \geq NO + O(^3P)$	5.0×10^{-3}	3.28×10^{9}	6.05×10^{8}
$O(^3p) + O_2 \geq O_3$	1.5×10^{-14}	4.04×10^{12}	4.04×10^{12}
$NO + O_3 \geq NO_2 + O_2$	2.0×10^{-14}	1.51×10^{23}	6.28×10^{22}
$NO_2 + O_3 \geq NO_3 + O_2$	3.2×10^{-17}	8.05×10^{-6}	4.03×10^{-6}
Net flux	-	1.51×10^{23}	6.28×10^{22}

Spatial pattern of particulate matter PM_{10} and $PM_{2.5}$ mass concentration

Figures 4 and S5 show the spatial distribution of $PM_{2.5}$ and PM_{10} mass concentrations. Conversely to the most pollutants, the $PM_{2.5}$ and PM_{10} have increased during the lockdown and show the same trend while the lower concentrations were registered on March 10th (before lockdown), May 18th and 27th (after lockdown), and the higher levels were recorded during the lockdown on March 17th, 19th, and 26th. The results show also that the $PM_{2.5}$ mass concentration increased by 97, 52.9, 35.3, 32.8, and 20.7% in Chambery, Lyon, Saint Etienne, (Grenoble and Valence), and Annecy, respectively. Furthermore, the PM_{10} mass concentration increased by 77.6, 24.7, 22.5, 14.9, 11.3, and 4.5% in Chambery, Valence, Lyon, Grenoble, Annecy, and Saint Etienne, respectively (Table 1).

Residential wood heating which is the main emitter of PM_{10} and $PM_{2.5}$ in cold weather can contribute to 80% of total particle emissions in this region (Atmo 2020c). Thus, domestic housing could contribute to emissions of PM during the lockdown where the people spent more time confined in their homes, which increases the consumption of wood heating and consequently much PM emission. In addition to primary sources (heating, vehicles exhaust, and industrial activities), numerous secondary sources can also contribute to the PM emission, such as the atmospheric photochemistry (Ortega et al. 2016; Huang et al. 2015; Sbai and Farida 2019a). The SOA formation is enhanced during the lockdown period

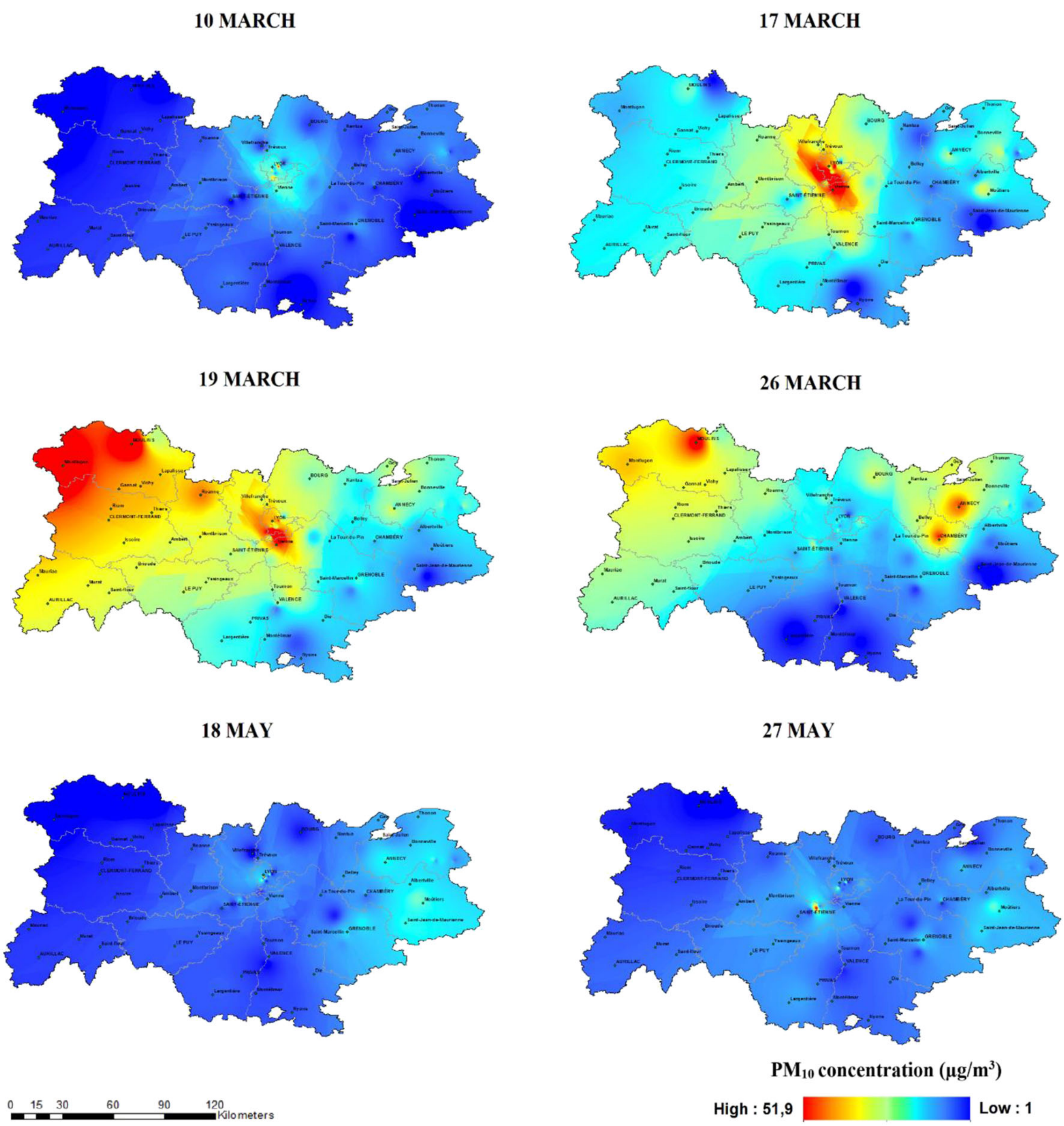

Fig. 4 Spatial distribution for PM10 mass concentrations before (March 10th), during (March 17th, 19th, and 26th), and after lockdown (May 18th and 27th)

because of the increase in O_3 that can produce the OH radical in the presence of humidity, according to the two reactions $O_3 + h\nu \rightarrow O_2 + O(^1D)$ and $O(^1D) + H_2O \rightarrow 2OH$ (Peng et al. 2015).

In the Rhône department, which is characterized by high levels of PM_{10} and $PM_{2.5}$ (Figs. 4 and S5), industrial activities were not significantly affected by lockdown, since VOC levels in three areas of this region (Fayzin ZI, Saint-Fons ZI, and Vernaison ZI) remain almost stable (Fig. 5e). This clearly shows that O_3/OH oxidation of VOCs is an important secondary source of PM_{10} and $PM_{2.5}$ in the metropolitan Lyon. In addition, in the Auvergne-Rhône-Alpes region, there are several parks and important forest areas (Fibois 2018), which may represent an important source of biogenic VOCs (BVOC), which can contribute to the PM formation. In our previous study, we found that urban air in Lyon can effectively contribute to the SOA formation via OH oxidation and ozonolysis (Sbai et al. 2020). Moreover, Sea salt especially iodine can contribute also to PM formation via OH and O_3 oxidation mainly under high O_3 levels (Saiz-Lopez and Plane 2004; Gómez Martín et al. 2013; Sbai and Farida 2019b). These particles could be transported by the wind towards the urban environment during the lockdown.

These results indicate that this region has experienced spatial PM_{10} and $PM_{2.5}$ level increase during the lockdown period, in contrast to the similar studies carried out in other cities around the world where the $PM_{2.5}$ and PM_{10} levels were declined during the enforced lockdown (Chauhan and Singh 2020; Dantas et al. 2020; Zambrano-Monserrate et al. 2020).

The evolution of air pollutions (PM_{10}, $PM_{2.5}$, NO_2, O_3, CO, and VOC) affecting the air quality in Lyon

Figure 5 summarizes the evolution of the PM_{10}, $PM_{2.5}$, NO_2, O_3, CO, and VOC in Lyon (center of the Auvergne-Rhône-Alpes region) between February 3rd and June 15th, 2020, to assess the effects of lockdown on air quality. We noticed a strong decrease in NO_2 during the first 2 weeks of lockdown.

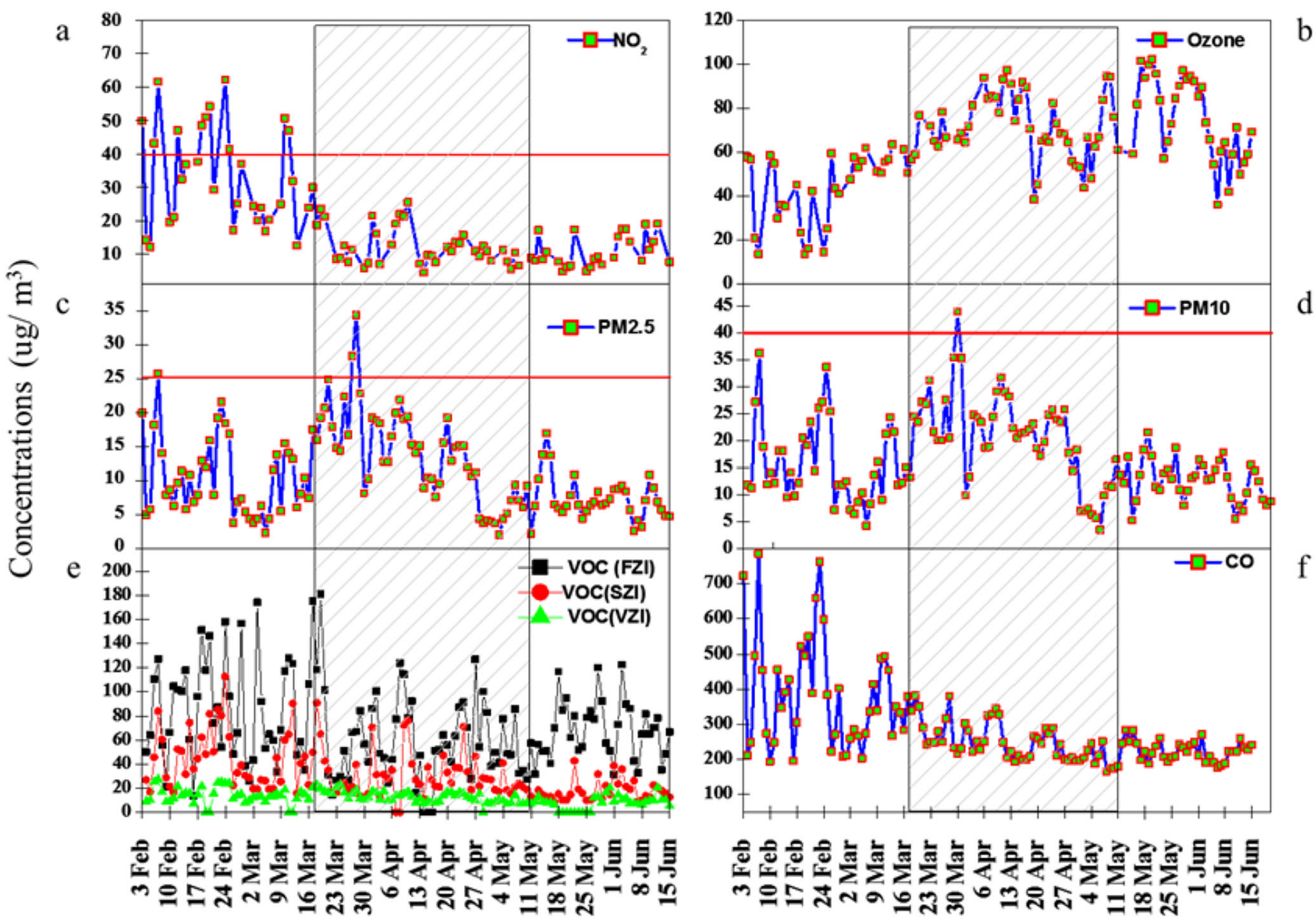

Fig. 5 Trend of average concentrations at Lyon Downtown for **a** NO_2 (24 h average), **b** ozone (8 h average daily maxima), **c** PM2.5 (24 h average), **d** PM10(24 h average), **e** VOC FZI (*Feyzin Zone Industriel*), VOC SZI (*Saint- Fons Zone Industriel*), VOC VZI (*Vernaison Zone Industriel*), 10, 15, and 6 km from Lyon downtown (at South), respectively, and **f** CO. Between 3rd Feb and 15th Jun, the horizontal red lines for NO2, PM2.5, and PM10 indicate the limit values; for the other pollutants, there is no exceedance of limit values (the dense area represented lockdown period)

However, a slight upward trend has emerged since the start of progressive removal of lockdown from May 11th. It should be noted that the NO_2 level dropped since February 23th, due to decreased road densities a week before strict lockdown (Fig. 5a). The O_3 levels have increased steadily since February 23th and remain almost stable during the lockdown (Fig. 5b). However, a significant decrease in ozone was observed after April 18th due to the consecutive rainy days and moderate sunshine (Fig. 6 b and d). The atmospheric oxidation of VOCs can represent an important source of ozone in Lyon since the VOC levels remained almost stable during lockdown (Fig. 5e) (Zhang et al. 2020).

Meteorological conditions such as solar radiation, humidity, temperature, sunshine, rainfall, and wind speed can affect ozone formation through modulating the rate of chemical kinetics reaction, the partitioning of reaction pathways, and efficiency of dry and humid deposition (Lu et al. 2019a, b). Lyon region is very sunny and characterized by a hot continental climate, which is more sensitive to ozone pollution. Solar radiation has increased regularly from 3rd February to 15th June (Fig. 5c), which can lead to an increase of atmospheric photochemistry and ozone formation. Figure 5a shows a continuous increase in temperature, which can lead to an increase in natural emissions of BVOC, in particular isoprene (Fig. S6). The atmospheric oxidation of BVOC contributes to the formation of ozone (Allison 2020). On other hand, despite the reduction in the carbon monoxide mass concentration (Fig. 5f), the O_3 formation may be influenced by CO reactivities, because under low NOx level, ozone depletion can occur; however, under high NOx level, CO can contribute to ozone formation according to the reaction mechanism depicted in Table 3.

Figures 5 c and d show the evolution of PM_{10} and $PM_{2.5}$, respectively, in Lyon between 3rd February and 15th June. PM_{10} and $PM_{2.5}$ present the same trend and show a continuous increase during the lockdown. However, this trend was perturbed by successive rainy days from 25th April (Fig. 6d), which removed all the suspended particles (Info climat 2020). The decrease of ozone, solar radiation, and the sunshine between 25th April and 11th May (Fig. 6 a, b, and c) can limit) can limit, and c) can limit, b, and c) can limit the formation of secondary particles resulting in the decrease of PM levels. Chen et al. (2020a, 2020b) show also an increase in PM during lockdown; they have found two pollution episodes with $PM_{2.5}$ exceeding 100 μg/m^3 in Shanghai, China.

Air quality index change during lockdown in Lyon

Air quality index (AQI) has been used in several cities around the world to quantify the presence of certain pollutants in ambient air. Their main purpose is to inform the public about air pollution and the associated potential health risk (Atmo 2020d). The AQI calculation is defined at the national level on the basis of regulatory thresholds (Table 4). Three

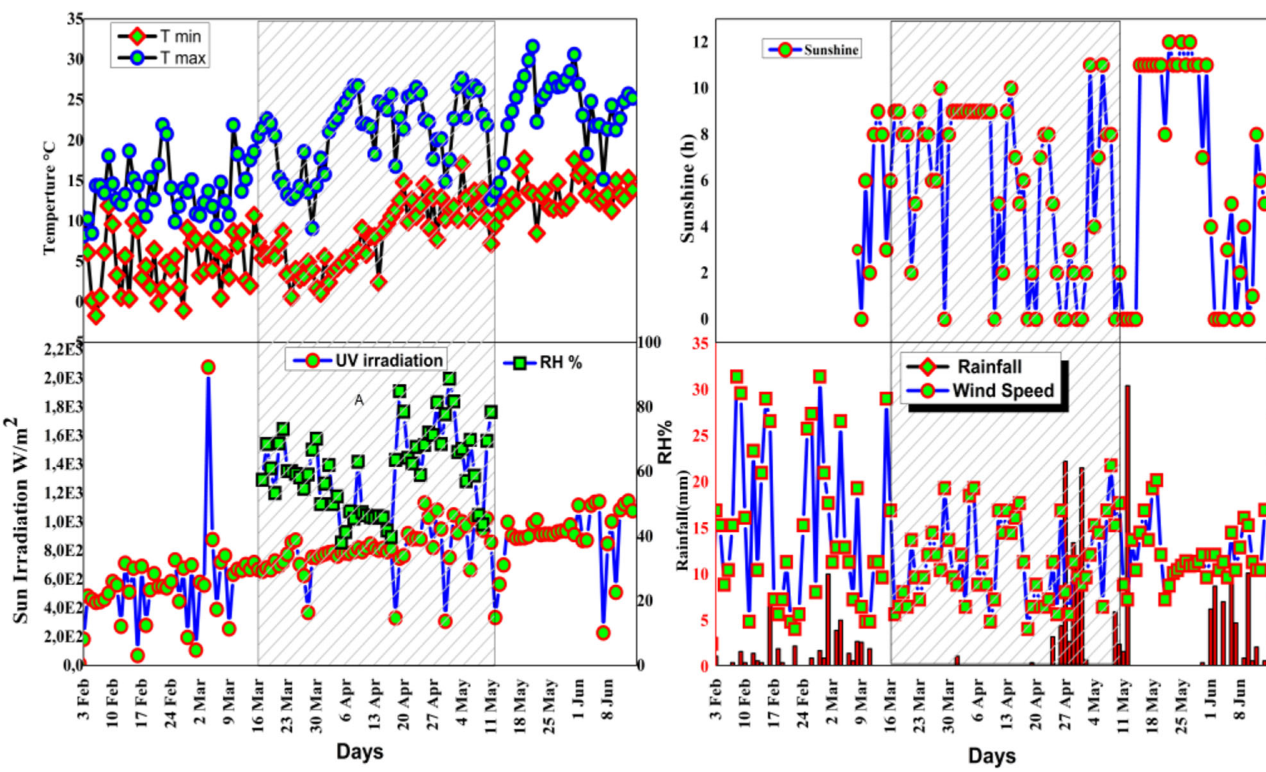

Fig. 6 Meteorological parameters pattern including temperature, humidity, rainfall, wind speed, sun radiation, and sunshine, at Lyon downtown between February 3rd and June 15th, 2020 (the dense area represented lockdown period)

Table 3 Carbon monoxide (CO) reaction mechanism showing O_3 depletion under low NOx level and O_3 formation under high NOx level

Low NOx level (during lockdown)	High NOx level (before lockdown)
$CO + OH + M \geq CO_2 + H$	$CO + OH + M \geq CO_2 + H$
$H + O_2 + M \geq HO_2 + M$	$H + O_2 + M \geq HO2 + M$
$HO_2 + O_3 \geq OH + 2O_2$	$HO_2 + NO \geq OH + NO_2$
Net: $CO + O_3 \geq CO_2 + O_2$	$NO_2 + hv \geq NO + O$
	$O + O_2 + M \geq O_3 + M$
	NET: $CO + 2O_2 \geq CO_2 + O_3$

pollutants were considered for AQI estimation, including NO_2, O_3, and PM_{10}. These species are considered as the main indicators of air pollution. For each of these pollutants, a sub-index is determined using daily mass concentration between February 3rd and June 15th, the final index corresponding to the highest sub-index. The air quality sub-index associated with O_3, NO_2, and PM_{10} at Lyon downtown shows that PM_{10} represents the main pollutant and the AQI is often attached to the PM_{10} mass concentration (Fig. S7). In addition, the AQI of the region generally varies between good and moderate, which indicates that there is no possibility of affecting public health. Despite the decrease of NO_2 level, the AQI level is not reduced during the lockdown due to a notable increase in PM. However, other studies have shown a drop in AQI; this decrease has been explained as a consequence of halting the human activities (Mahato and Ghosh 2020; Bao and Zhang 2020; He et al. 2020a, 2020b) (Table 3).

Air pollution in 2020 vs 2019

We have performed a comparison with data for main air pollution (NO_2, O_3, PM_{10}, and $PM_{2.5}$) of previous year 2019 and this year 2020 over the same period (17th Mars to 11th May) corresponding to the lockdown period for six cities in the region (Lyon, Saint Etienne, Grenoble, Annecy, Gaillard, and Valence) (Fig. S8). The results show that for all the cities, the NO_2 decreased whereas O_3 and the particles (PM_{10} and $PM_{2.5}$) increased. The difference between the level of pollutants in 2019 and 2020 changes depending on each city; this can be explained by the meteorological conditions and the industrial activities of each zone and also the lockdown measures (strict or loose).

Table 4 Correspondence grid for the index values with the thresholds of the inter-prefectural decree for the management of pollution episodes

Categories	AQI	PM_{10} (μg/m^3)	NO_2 (μg/m^3)	O_3 (μg/m^3)
Good	0–50	0 à 13	0–54	0–54
Satisfactory	51–100	14–27	55–109	55–104
Moderate	101–200	28–41	110–164	105–149
Poor	201–300	42–64	165–274	150–209
Very poor	301–400	65–79	275–399	210–239
Severe	401–500	≥ 80	≥ 400	≥ 240

Conclusion

In order to assess the air quality status of Auvergne-Rhône-Alpes during the lockdown period, we explored data related to atmospheric pollutants extracted from 79 air quality monitoring stations covering the whole region. The daily and hourly concentrations of air pollutants including $PM_{2.5}$, PM_{10}, NOx (NO_2 and NO), CO, O_3, SO_2, VOC, and isoprene have been obtained from the online portal for air quality data dissemination.

The results revealed a substantial change in all studied atmospheric pollutants except the VOC and SO_2 during the lockdown, as NO_2, NO, and CO have decreased, owing to restriction of road traffic. However, O_3, PM2.5, and PM10 have increased during the lockdown. The increase in ozone is attributed to the decrease in its titration by NO because the flux of ozone depletion via a photochemical reaction involving NO decreased by 40%. On the other hand, the reduction in ozone consumption by other gases is of anthropic origin. Moreover, weather conditions (temperature, solar radiation, RH, sunshine) have favored the formation of ozone during the lockdown. Thus, the oxidation of VOC and BVOC also can contribute significantly to O_3 and PM formation, because they have not been reduced during the lockdown. The AQI which represents good and moderate categories remains almost stable despite the decrease of NOx because PM and O_3 increase. It is noted that AQI shows that PM_{10} is the main pollutant in this region.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11869-020-00965-w.

Acknowledgments We thank the Atmo Auvergne Rhône Alpes website for allowing us to use the data and for technical information provided by Mr. Sébastien WAITZ.

Data availability All the data used in this study are freely available on the Internet. Air quality data can be obtained through Atmo Auvergne Rhône Alpes website.

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