Air Pollution Impacts During 2020 COVID-19 Pandemic: Emphasis on Urban, Suburban and Rural Zones

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Abstract

Air quality improvements pollution changes due to COVID-19 restrictions have been reported for many urban developments and large metropolitan areas, but the respective impacts at rural and remote zones are less frequently analysed. This study evaluated air pollution changes across all Portugal (68 stations) considering all urban, suburban and rural zones. PM_{10}, $PM_{2.5}$, NO_2, SO_2, ozone was analysed in pre-, during, and post-lockdown period (January-May 2020) and for a comparison also in 2019. NO_2 was the most reduced pollutant in 2020, which coincided with decreased traffic. Significant drop (15– 240%) of traffic related NO_2 was observed specifically during lockdown period, being 55% for the largest and most populated region in country. PM was affected to a lesser degree (with substantial differences found for largely populated areas (Lisbon region 30–40%; North region: up to 95%); during lockdown traffic-related PM dropped 10–70%. PM_{10} daily limit was exceeded 50% less in 2020, with 80% of exceedances before lockdown period. SO_2 decreased by 35%, due to suspended industrial productions, whereas ozone concentrations slightly (though not significantly) increased (83 vs. 80 μg m^{-3}).

1. Introduction

In January 2020 the World Health Organization (WHO) declared a global health emergency because of the novel coronavirus disease (COVID-19) that has been uncontrollably spreading all over the world[1]. Since then, the pandemic has affected our whole society; WHO has registered 123 million cases worldwide with a total of 2.7 million mortalities[2]. To limit the spread of pandemic, governments in countries around the world have imposed various restrictions, which led to reduction of people movement, decrease in transport (road and aviation), and even suspended industrial activities[3]. While COVID-19 has caused many adverse changes to our society and economies[4, 5] and even to environment (in a form of newly created medical waste[6]), some studies have emphasized a possible improvement of the state of the environment[7]. People confinement, restricted public transport and ceased airlines international flights have also resulted in changes in air pollutant emissions, with information many information for megacities (Rio de Janeiro and Sao Paolo[8, 9]; and highly populated urban zones and cities[10, 11, 12 13, 14, 15, 16, 17]. On more global scale, during the COVID-19 pandemic, $PM_{2.5}$ dropped approximately 12% worldwide across the most polluted cities worldwide, with the greatest reduction in capitals of America, Asia and Africa[18]. While the current studies even show that there might be causality between air pollution and COVID-19 infection spread[19, 20], the main focus of the COVID air pollution studies is typically on large and densely populated urban areas[21, 22, 23] during relatively a short (or part of) period of lockdowns. The changes in air pollution trends during the lockdown in rural or remote places have been reported to much lesser degree. Ceased air and road transport and restricted human movements during the lockdowns allow for a unique situation for prediction modelling and visualization of potential air pollution mitigation scenarios. However, the complete perspective requires first information on air pollution changes not only in urban but also in rural and remote areas. This work thus evaluates the air pollution evolution (PM_{10}, $PM_{2.5}$, NO_2, SO_2, ozone) in pre-, during and post-lockdown period (January 1- May 2020) in whole Portuguese territory (continent and islands; 7 regions) considering all rural, suburban, urban zones. To provide wider context, air pollution data are assessed and also compared to the same period of the previous year.

2. Material And Methods

2.1 Air quality network

The assessment of air quality in Portugal is conducted by the Portuguese Environment Agency (APA). The air quality measurement stations are managed by the Regional Development and Coordination Commissions (CCDR) of the region in which they operate. The classification of seven regions of Portuguese territory (five for the continent – North, Centre, Lisbon and Tejo Valley (Lisbon TV), Alentejo, Algarve, two for islands – Madeira, and Azores) was also adopted for this work (Table 1S of the Supplementary Material). Each monitoring station is characterized based on its type of agglomeration zone (rural, suburban or urban). The predominant influence of anthropogenic emissions further determines sub-type of each site as traffic, industrial or background. The air pollution data are measured continuously at the all monitoring stations from which they are transmitted, in almost real time, to regional "centres". From these they are communicated to the central information system of QualAr database[24], based at APA[25]. The data are then made available to the public through QualAr portal[26]. Table 1 and Fig. 1S of the supplementary material summarized the characteristics of monitoring stations per each district. All 68 monitoring stations were considered in this work.

2.2 Air pollution data

The state of emergency due to the spread of COVID-19 pandemic was enforced in 19 March until 2 May 2020, with a strict consequent phases until 1 June 2020[27]. Up to this date, various limitations still apply in Portugal (among other restrictions for public gatherings, obligatory use of masks in enclosed public spaces such as transport, shops or public offices, restricted working hours for bars and restaurants, etc.). Air pollution data was thus retrieved from the public QualAr database for all five months of 2020, specifically between January 1 and May 31. The data from the same period of the previous year 2019 were also considered for comparison.

All air pollutants available online by QualAr were considered, namely: PM_{10}, $PM_{2.5}$, O_3, NO_2, and SO_2. For particles, daily (24 h) average concentrations are published whereas it was maximum hourly average for O_3, NO_2, and SO_2, CO and benzene could not be included in the study as online database contained less 1% data for the evaluated periods (days). Air quality standards in Portugal[28, 29] are based on the existent European legislation govern by Directive 2008/50/EU[30], for a reader convenience the respective standards and the limit values are summarized in Table 2S).

2.3 Traffic data

There are 15 principal motorways in continental Portugal (Fig. 2S). As there is no public database that would provide summarized information on number of vehicles in Portugal, the existing data regarding traffic counts were retrieved from available (annual and quartile reports) of companies[31, 32] that ensures the majority operations of motorways system in country. Additional information was then retrieved from public reports and research projects, published on web portals of city halls of Metropolitan Areas of Lisbon and of Oporto[33, 34, 35].

2.4 Statistical analysis

All statistical tests for this study were performed by SPSS (IBM SPSS Statistics 26) and Microsoft Excel 2013 (Microsoft Corporation). Medians and means were compared through the non-parametric Mann−Whitney U test as the obtained data did not display normal distributions (confirmed by Shapiro−Wilk's test). Statistical significance was set as $p<0.05$.

3. Results And Discussion

3.1 Air pollution monitoring network

As shown in Table 1 and Fig. 2S, most of the monitoring sites were situated in the districts of North and Lisbon TV. These two regions accounted for 67% of all monitoring stations in while they compose approximately 35% of the Portuguese territory area (Table 1S). Centre region accounted for 13% of the monitoring sites, whereas in Alentejo (30% of the total area) and Algarve district (5%) there are 7 and 6% of the monitoring stations, respectively. Portuguese islands represent a much smaller area (~ 3.5%) and hence a limited amount of monitoring stations (6%).

Evaluating the zone impact of each station (*i.e.* rural *vs*. suburban and urban) it is noteworthy that monitoring stations in urban zones are predominantly situated in North and Lisbon TV regions (47%). This is understandable considering that these two regions contain the two largest Metropolitan Areas in the country (of Oporto and Lisbon, respectively), with approximately 45% of the total Portuguese population (17 and 28% for area, respectively, in 2019)[36]. In fact, monitoring sites of urban zones account for 55 and 83% in each of these regions, respectively. In addition, the North was the region with the highest number of monitoring sites in suburban zones (10%), whereas the monitoring stations for rural areas are relatively uniformly distributed among all regions (4–6 % in North, Centre, Lisbon TV and Alentejo, 1–3% in the remaining regions).

Evaluating the specific emission sources, 40% of all monitoring sites with traffic influence were situated in Northern monitoring network where it consists 28% of all the district' stations. In addition, 65% of all background sites were situated in the most populated regions of Lisbon TV (67% the district' stations) and in North (63%). On the national perspective, monitoring stations under influence of industrial emissions were the least existent (10%), being uniformly distributed between North, Lisbon TV and Alentejo region.

3.2 Traffic data

Evaluation of daily average traffic (on motorways) in 2018–2020[31, 32] is shown in Fig. 3S. It is clear that quarterly (Q1–Q4) evolution trends of traffic were the same between 2018 and 2019, with the highest peak always observed during the summer months, *i*.e. 3rd quarter (Q3: 25530 *vs*. 25916 vehicles day^{-1}, respectively). Furthermore, when compared to previous year, in 2019 traffic showed a consistent growth of 3.7%, for each quarter as the following: 5.6 % for Q1, 6.3% for Q2, 1.5% for Q3 and 2.1% for Q4. It noteworthy, that heavy vehicle traffic showed a higher growth rate (4.5%) than light vehicles (3.6%). In agreement, additional data showed that road transport supply (for transport of passengers) increased to 29.4 billion seats-km, with 83.1% of its total being made available on regular transport[34]. The number of national transport services increased by 9.2% to 20.5 million, while 543.1 million passengers were carried, representing an increase of 5.5% compared to the previous year of 2018[34].

On the contrary, due to the restrictions associated with COVID-19, the average daily traffic decreased during the first quarter of 2020: 12% in a comparison with 2019 and 7% when compared with 2018 (Fig. 3S). Due to the state emergency and the limitations of the consequent return phases, the predicted traffic drop is expected being even higher during the second quarter of 2020, but up to this date (31st July 2020) the respective data has not been released by the responsible organizations. Furthermore, the available data shows that light vehicles were more impacted by the traffic reductions than heavy vehicles, with the respective decrease of 12 and 2% respectively[32].

3.3 Air pollution data: 2019 vs. 2020

3.3.1. Particulate matter

The levels of air pollutants, namely PM_{10}, $PM_{2.5}$, NO_2, SO_2 and O_3 in seven Portuguese regions are summarized Fig. 1, which show the statistics across all monitoring stations for the three types of zoning (rural – urban). Specifically, in 2019 daily levels of PM_{10} measured at 68 monitoring stations demonstrated large variations of the obtained data (Fig. 1a), with detailed descriptive statistics summarized in Table 3S. Average daily PM_{10} means were between 12 and 20 μg m^{-3} (absolute range 1–74 μg m^{-3}) in rural zone of the five regions of the Continental Portugal, 18–21 μg m^{-3} (2–82 μg m^{-3}) in suburban zones and 20–24 μg m^{-3} (1–116 μg m^{-3}) in urban ones. Regions of Portuguese islands showed lower concentrations, especially at rural zones with the corresponding means of 11 μg m^{-3} (Madeira, range 2–71 μg m^{-3}) and 7 μg m^{-3} at Azores (2-–17 μg m^{-3}). These results demonstrated that for all 7 regions daily PM_{10} concentrations were the lowest at rural zones being significantly ($p < 0.05$) different (approximately 15% in Algarve – 60% for North) that the respective means at urban zones (or suburban for Alentejo). Regarding the EU limits daily (50 μg m^{-3}), for urban zones the exceedances were observed in 30% of the rural stations: two in Centre, one in Lisbon TV, one in Madeira one in Alentejo (the respective monitoring station is with industrial influence due to the industrial power plan). It though necessary to point out that EU legislation stipulates a tolerance of exceedance 35 per year and in that regard all the monitoring stations fulfilled the conditions as the registered exceedances occurred 1–7 times per the same station (Table 3S). Furthermore, it is necessary to enhance that the raw data were considered in this work and the possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. In all the other regions (North, Algarve and Azores islands), no concentrations higher than daily limit were registered in rural zones. On the contrary, suburban and urban zones of Portugal exhibited exceeded the daily limits in all regions/zones. These were especially high for North (total of 57) and in Lisbon TV (64), which were the regions with the higher number of stations. In Centre, the limits were approximately 3 times less (21 times), whereas in Alentejo and Algarve the exceedance were even less frequent (6 and 12 times, respectively); in all stations the margin of tolerance (35 exceedance) fulfilled in all monitoring sites.

In 2020 the levels of PM_{10} (Fig. 1a, Table 4S) were slightly lower in a comparison with the previous year. Daily means of PM_{10} for Continental Portugal were observed as the following: 8 μg m^{-3} (North) to 17 μg m^{-3} (Algarve) in rural zones, 17 μg m^{-3} (Alentejo) – 24 μg m^{-3} (Centre) in suburban one, and 17 μg m^{-3} (North) and 25 μg m^{-3} (Algarve) for urban zones. These results showed that in rural zones, PM_{10} concentrations in 2020 were significantly lower than in the previous year ($p < 0.05$; overall mean of 12 μg m^{-3} *vs.* 17 μg m^{-3} in 2020), with the respective percentage being between 30% (Lisbon TV) and 80% in Alentejo. In urban zones the respective PM were lower in 2020 only in Centre and Lisbon TV regions (~ 30%), whereas PM no differences were observed in North and Alentejo region. Within the urban areas, ambient air pollution is often dominated by motor vehicles traffic), but due to the variables such as number of junctions, distance to roadways, traffic flows, surrounding road length, and others the respective pollution may vary greatly[37,38, 39]. It is assumed that the lesser traffic in 2020 (Fig. 3S) might be the cause for the lower PM levels in some of the urban zones.

The analysis of PM_{10} levels across the urban zones with traffic emissions specifically *(i.e.* 22 monitoring urban-traffic sites) showed that in terms of monthly evolution (Fig. 2a) PM_{10} started to decrease in February 2020, with the minimal levels observed in April (when the state of emergency was implemented) and then increased in May (state of emergency ended). However, when comparing both years (Fig. 2b), the largest concentration drops were observed, as expected in month of April (10–70% in Madeira and Algarve) but also February (up to 70% in North). These data may be in agreement with the road transport trend that shows a significant decrease during the first trimester (January– March; Fig. 3S). However, correlations between the road transport changes on monthly basis (when available) and traffic-related pollutants would provide much deeper understanding of respective association. At the same time, as the traffic density decreased on the international level (due to the restrictions taking place in majority of European countries), PM_{10} levels at rural ones were most likely affected due to the lesser transport of long-distance emissions.

On the contrary, in suburban sites, PM_{10} in 2020 (Fig. 1) were higher (overall 21 μg m^{-3} *vs.* 20 μg m^{-3}), though these differences were not statistically significant, with the highest changes observed in North and Centre region (20 and 30%). On European level road transport contributes only ~ 11% of PM in EU, the main sources of PM_{10}[40] are commercial, institutional and households sector (39%) and industrial processes (20%), which could be linked with the unchanged trends of PM in suburban zones. In terms of PM_{10} legislation, 24 h limit was exceeded in all three types of zones in 2020. However, majority of the exceedances were observed in urban zones (87%, Table 4S) and furthermore, 80% of these exceedances occurred in January and February (*i.e.* before the state emergency regulations took place). In addition, it is necessary to highlight that in 2020, for the respective period of 5 months, PM_{10} daily limits were exceeded approximately 50% less (107 *vs.* 218 in 2019). Thus, the results indicate that PM concentrations were positively influenced in 2020, most likely also by the lower vehicle road traffic. It is necessary to highlight that Algarve was the only region that exhibited in 2020 very different evolution of PM at urban traffic sites (and higher concentrations at urban traffic sites during all 5 months of 2020) than rest of the territory (Fig. 2a). While previous work emphasized the impacts of long–range transport of mineral dust from North Africa with high frequency and prevalence namely in southern parts of Portugal[41, 42] it needs to be highlighted that the respective data (urban traffic) is based on 1 monitoring station (Table 1). Thus these values will need to be confirmed when the final registry of APA is released.

Concerning the fine fraction, 2019 average daily $PM_{2.5}$ means (Fig. 1b) were between 5 and 9 μg m^{-3} (absolute range 1–47 μg m^{-3}) in rural zone of the five regions of the Continental Portugal, 9–21 μg m^{-3} (1–60 μg m^{-3}) in suburban zones and 5–15 μg m^{-3} (1–53 μg m^{-3}) in urban ones. In agreement with PM_{10}, these results demonstrated that for all 7 regions daily $PM_{2.5}$ concentrations were the lowest at rural zones being significantly ($p < 0.05$) different (approximately 15% in Alentejo – 90% for Centre) that the respective concentration at urban zones. In 2019, for the considering period, the overall mean (7 μg m^{-3} across 68 monitoring stations) was well below the annual target (Table 1S), though these results need to be implicated carefully, once the considered work of this study included 5 months (*i.e.* 42% of the calendar time).Worldwide, Portugal is among the countries with the better air quality in terms of $PM_{2.5}$[43]; in 2017 it ranked as 7th country in European Union with the lowest $PM_{2.5}$ across 27 members[40]. Furthermore, it is noteworthy that for fine fraction, that out of the three different zones, suburban areas presented the highest $PM_{2.5}$ (overall mean of 16 μg m^{-3}) with 80–265% higher concentrations than the respective levels at each regions of the rural zones. Still, the exposure concentration obligation (20 μg m^{-3}; calculated based on the levels of $PM_{2.5}$ at suburban and urban background sites) are typically obliged[40].

In 2020, The lowest $PM_{2.5}$ concentrations were observed in rural zones where they ranged between 4 μg m^{-3} (Algarve) and 7 μg m^{-3} (Centre and Lisbon TV). The corresponding levels in suburban and urban areas were 30–90% higher with, respectively, overall means of 6 μg m^{-3} (Alentejo) and 12 μg m^{-3} (Lisbon TV) in suburban and 5–13 μg m^{-3} (Madeira and Centre region) in urban zones. In comparison with 2019, $PM_{2.5}$ emissions decreased in year after. Whereas the changes were statistically insignificant in rural zones (overall means of 6 μg m^{-3} *vs.* 7 μg m^{-3}), the highest differences was observed in suburban (10 μg m^{-3} *vs.* 16 μg m^{-3} in 2020), and urban zones (8 μg m^{-3} *vs.* 10 μg m^{-3}) being especially substantial for North (95%) and Lisbon TV region (~ 40%). While the data for urban traffic zones are limited (Fig. 5S), in agreement with the previous results, April was the month the lowest concentrations.

3.3.2 Gaseous pollutants

For the gaseous pollutants the overall mean of NO_2 concentrations in 2019 (Fig. 1c) were 12 μg m^{-3} (range of Azores 3 μg m^{-3} – North 16) for rural zones, 42 μg m^{-3} for suburban (33 μg m^{-3}in Centre to 64 μg m^{-3} in North) and 54 μg m^{-3} (37 μg m^{-3} in Algarve – 74 μg m^{-3} in North) for urban zones. These results shown the strong impact of anthropogenic emissions of level of NO_2, being typically considered as indicator of traffic emissions[44, 45]. On European level, approximately 40% of NOx emissions are contributed by road transport sector[40]. The population exposure to ambient NO_2 concentrations is especially relevant in urban areas because its emissions are close to the ground and are distributed across densely populated areas. Furthermore, the highest concentration of NO_2 were observed in suburban and urban zones of North region (i.e. 40% of coverage for traffic emissions monitoring in Portugal; Table 1). Concerning the limits for heath protection, 9 exceedances of hourly limit value in 2019 were registered in 5.9% (4 stations) of all monitoring station (North and Lisbon TV region), all of them being urban sites (and 3 traffic influence).

In 2020, the mean of NO_2 concentrations at rural zones (Fig. 1c) were between 2 μg m^{-3} (Algarve) and 10 μg m^{-3} (North). In suburban zones, depending on each region the respective levels were 3–7 times higher, with means between 14 μg m^{-3} in Alentejo and 64 μg m^{-3} in

North, whereas in urban zones the respective NO_2 levels were even higher (4–18 times in a comparison with in rural zones) with range of 29–53 μg m^{-3} in Algarve and North, respectively. In agreement with the previous year, the highest levels of NO_2 (up to 6 times) were observed for the zones (all) of North region. However, in 2020 NO_2 levels were significantly ($p < 0.05$) lower in a comparison with the previous year, being approximately half for the rural and 30% lower in suburban and urban zones as follows: overall mean 6 μg m^{-3} *vs.* 12 for rural zones, 33 μg m^{-3} *vs.* 43 μg m^{-3} in suburban and 43 μg m^{-3} *vs.* 56 μg m^{-3} in urban ones. Thus in 2020, NO_2 pollution was significantly lower ($p < 0.05$) in all types of zones and in all regions of Portugal. NO_2 was the pollutant with more significant changes during the two year and the restrictions associated with the COVID-19 pandemic seemed to have significant implications for NO_2 levels in air, both on local (direct) and international level, the latter being demonstrated by the much lower concentrations of the pollutant observed at rural sites in 2020. Concerning the urban traffic zones specifically (Fig. 2c), the concentrations of NO_2 were lower than in previous year in all regions between February and May. A significant decrease of NO_2 levels was though registered in March, April was the month with the minimal means in 2020 in all the regions (range 17–33 μg m^{-3}). It is noteworthy that in North the NO_2 levels were still almost twice higher (mean of 57 μg m^{-3}) during the state emergency period than in the rest of country. In addition, evaluating then decrease of NO_2 (Fig. 2d), the biggest changes between the two years were observed in March and April of 2020 when NO_2 decreased by 15% (North) and 240% (Algarve). Considering the two largest and most populated urban areas in country (Lisbon MA and Oporto MA in Lisbon TV and North region, respectively; Table 1S), NO_2 cumulative decrease was 55% (40 and 15%, respectively) which from the national perspective may represent several health benefits[46]. These results clearly confirm that NO_2 levels were significantly lowered during restrictions associated COVID-19 outbreak (especially in months of March and April). Finally, in 2020 over the period analysed in this work all monitoring stations fulfilled the limit value for the health protection and no exceedances were observed, unlike the previous year.

SO_2 (Fig. 1d) maximum of 1 h mean concentrations ranged between 2–12 μg m^{-3} in rural zones, 3–13 μg m^{-3} and 3–29 μg m^{-3} in suburban and urban zones, respectively. The levels of SO_2 were especially high in North region, where for suburban and urban zones concentrations were 3–6 times higher than in the other regions. However, across all monitoring stations, 1 h limit alert threshold (500 μg m^{-3}) and 1 h limits value (350 μg m^{-3}) of SO_2 concentrations were fulfilled. In addition, in general SO_2 levels were below the 24 h limit value; in 2019 only 3 stations (North region) registered 1 h maximum concentrations above the daily limit value, but the 24 h concentrations during those exceedance were fulfilled. In 2020 (Fig. 1d) the 1 h maximum means ofSO_2 were 5 μg m^{-3} (range of 1–10 μg m^{-3}) in rural zones, and 9 μg m^{-3} (3–23 μg m^{-3}) and 10 μg m^{-3} (5–18 μg m^{-3}) in suburban and urban zones, respectively. For all three types of zones, the highest SO_2 were observed in North region (up to 6 times for suburban zones and 9 times for urban ones) than in other regions. The North region was also the only one where 1 h maximum concentrations exceeded one time the 24 h limit value (on urban industrial site). Finally, 1 h alert and 1 h limit were obliged in all 68 monitoring stations. Though SO_2 is a not a pollutant associated with traffic emissions, in 2020 the overall levels were approximately 65% lower than in the period of the previous year with overall means of 5 *vs.* 8 μg m^{-3} which could be due to suspended industrial emissions. Nevertheless, evaluating the industrial sites specifically (suburban and urban Table 1), the means obtained between both years were not significantly different (6.3 *vs.* 6.9 μg m^{-3}in 2019). In addition, the monthly evolution trend of did not show any change of patterns in the lock down period, however, assessment of 24 h means (oppose to 1 maxima used in this work) should be conducted when available.

Data for ozone in 2019 (Fig. 1e) that maximum 1 h mean ranged between 74 μg m^{-3} (North) and 104 μg m^{-3} (Algarve) of rural zones, 62 μg m^{-3} (North) and 90 μg m^{-3} (Alentejo) in suburban and 67 μg m^{-3} (North) and 101 μg m^{-3} (Algarve) in urban ones. These results show that registered 1 h maxima concentrations were higher ($p < 0.05$) at rural sites than those in suburban and urban ones, in agreement with other studies reporting the “ozone paradox” [47]. Production of background ozone exhibits both long-term trends and substantial annual variability [48] due to the variations in air-flow, air pressure or temperature[49, 50, 51]. In addition, peak ozone episodes are strongly influenced by emissions of its precursors, such as nitrogen oxides and volatile organic oxides, the latter being relevant in rural zones[52] and by meteorological conditions (being favoured by warm, stagnant high-pressure conditions). For all zones, the registered 1 h maxima were the lowest in north of country consistently increasing towards the south, being the highest in southern regions of country (Algarve and Alentejo for suburban zones, Fig. 1e); in agreement the north of the country being the coldest and south being the warmest with mean air temperature as the follows: 13.8°C in North, 15.1°C for Centre, 16,8 Lisbon TV, 16.9°C in Alentejo and 17.0°C in Algarve[53]. From the legislative perspective, the European hourly alert of 180 μg m^{-3} was exceeded once (North regions), whereas 1 h information threshold of 180 was reached once in Lisbon TV region (120 μg m^{-3}, expressed as daily 8 h mean) though could not be clearly assessed, once the continuous measurements of ozone are not public yet. Finally, in 2020 the overall levels of ozone slightly (though not significantly) increased (83 vs. 80 μg m^{-3}). One h maximum levels ranged between 79 μg m^{-3} (North) and 92 μg m^{-3} (Alentejo) in Continental Portugal whereas levels in islands were higher (92–97 μg m^{-3}). In agreement with previous year, suburban and urban sites of Continental Portugal exhibited, respectively, significantly lower concentrations of ozone as follows: 59–80 µg m^{-3} (North and Alenetejo), and 70–80 µg m^{-3} (Centre and Lisbon TV). However, no differences were observed between the levels during the two years with the means as 87 µg m^{-3} *vs.* 89 µg m^{-3} in 2020 and 2019 in rural sites, 73 µg m^{-3} *vs.* 79 µg m^{-3} for suburban, and 85 µg m^{-3} (in both years) at urban zones. The European hourly alert of 240 µg m^{-3} was not exceeded in 2020.

Conclusion

This work assessed air pollution levels and trend during COVID-19 period in Portugal (January–May 2020) in a comparison with the previous year. The issued lockdown of the country enforced by the Portuguese government resulted in some positive, yet non uniform, changes of air pollution. NO_2 was the pollutant that show the most consistent decrease all over the country and across all different zones of urbanizations, in accord with reduced transport. Considering that annually road transport causes between 184,00 and 242,000 premature deaths worldwide[54, 55] public health benefits from reduction of the respective emissions might be significant. Regarding particulate matter, the major decreases were observed in remote and urban zones, suburban areas were impacted to a lesser degree and most dominantly in terms of fine PM. Whereas improved air quality will persist in long-term is uncertain, nonetheless the restrictions of COVID-19 conducted on large scale and in many countries simultaneously will provide a unique opportunity to re-examine current air quality policies and possible recovery scenarios to for air pollution reduction on global level.

Declarations

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Tables

Table 1. Air pollution monitoring network in Portugal: summary of zone- and emission influence-specific monitoring sites in each region

Region	Stations n (%)	Type n (%)								
		Rural			Suburban			Urban		
		Background	Traffic	Industrial	Background	Traffic	Industrial	Background	Traffic	Industrial
North	22 (32)[a]	3 (14) [b]	–	–	6(27)	–	1(5)	5(23)	6(27)	1(5)
Centre	9 (13)	4 (44)	–	–	2(22)	–	–	1(11)	2(22)	
Lisbon TV	24 (35)	3 (13)	–	–	–	–	1(4)	13(54)	5(21)	2(8)
Alentejo	5 (7)	2(40)	–	1(20)	1(20)	–	–	–	–	1(20)
Algarve	4 (6)	1(25)	–	–	–	–	–	2(50)	1(25)	–
Madeira	3 (4)	1 (33)	–	–	–	–	–	1(33)	1(33)	–
Azores	1 (2)	1	–	–	–	–	–	–	–	–
Total	68	15	–	1	9	–	2	22	15	4

Note: [a]% considering the whole territory

[b]indicated % is estimated considering of abundance of a station/type in each district

Note: depending on the density and distribution of buildings, stations are classified as the folloing: rural – all other areas; suburban – largely built-up; urban area urban – continuously built-up urban area; background stations – pollution levels are representative of the average exposure of the general population or vegetation; traffic – situated in a close proximity to a single major road; industrial stations – situated in close proximity to an industrial area or an industrial source (EEA, 2019a)

Figures

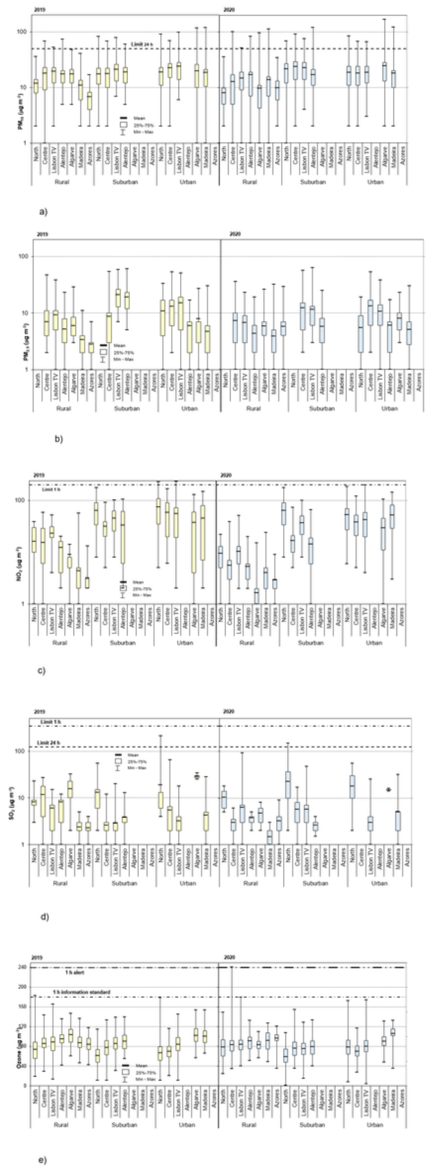

Figure 1

Concentrations of particulate and gaseous air pollutants (■ median, □ 25–75%, and range) in (January – May) 2019 and 2020 in Portugal: a) PM10, b) PM2.5, (c) NO2, (d) SO2, and (e) O3 Notes: Horizontal lines represent the respective standards (Decreto-Lei 118/2013.Distributions of each pollutant were significantly different ($p<0.05$) across the three zones and emissions sources. The concentrations of PM are expressed as 24 h averages whereas the gaseous pollutants are expressed as 1 h maxima. For better visualization vertical axis y uses different scale.

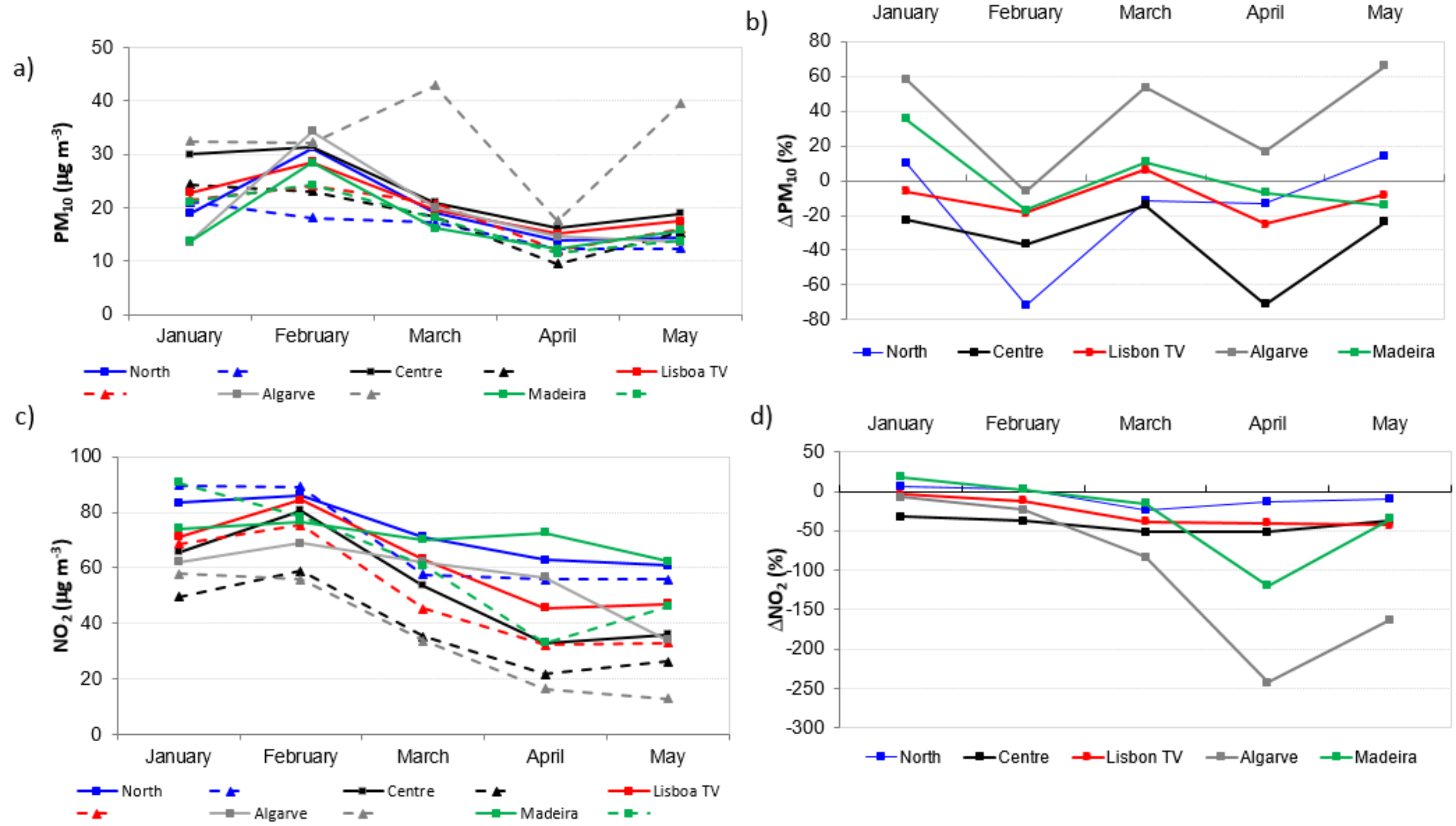

Figure 2

Please see the Manuscript PDF file for the complete figure caption.

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