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COVID-19 national lockdown in morocco: Impacts on air quality and public health

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ABSTRACT

On April 20th, 2020, 2,403,410 cases of corona Virus were confirmed globally. This date matches the end of the first strict lockdown in Morocco.. The number of Morocco confirmed cases attended 2990 and 143 deaths were recorded. Due to the pandemic, all avoidable activities in the country were prohibited since the kingdom announced the general lockdown on March 20th, 2020. This study aims at comparing the air quality status, before the pandemic and during the confinement. It was performed in Casablanca and Marrakech from Morocco. The main objective is to show whether COVID-19 compelled lockdown may have saved lives by restraining air pollution than by preventing infection. We used the difference-in-difference and the Theil and Sen non-parametric approaches for univariate time series. We defined the before quarantine period as between February 16th and March 19th and the during quarantine as between the March 20th and April 20th. We assessed changes in air quality during vs. before the quarantine period in 2020 and compared these with corresponding changes in the same lunar calendar periods in 2016–2019. Then we calculated the avoided cause-specific mortality attributable to the decreases in NO_2 and $PM_{2.5}$ based on the concentration-response functions from previous studies. We found that NO_2 dropped by −12 μg/m^3 in Casablanca and − 7 μg/m^3 in Marrakech. $PM_{2.5}$ dropped by −18 μg/m^3 in Casablanca and − 14 μg/m^3 in Marrakech. CO dropped by −0.04 mg/m^3 in Casablanca and − 0.12 mg/m^3 in Marrakech. This air pollution reduction had created human health benefits. It reduced mortality, and saved lives mainly from cardiovascular diseases. Further investigation may be undertaken to explore the reduction in the concentrations of industry-related pollutants.

1. Introduction

On December 31st, 2019, Coronavirus disease 2019 (COVID-19) was identified in the city of Wuhan, China as an infectious disease [1,2]. On the April 20th, 2020, COVID-19 has led to more than 165,000 deaths worldwide with a global mortality rate of 6.8% [3]. Due to the contagious nature of COVID-19, most countries declared the lockdown, hence businesses and industrial activities decreased, global air travel reduced. Cars and trucks stayed off the roads [4–6].

Morocco reported the first COVID-19 case on March 2nd, 2020. There were 39 reported cases and 1 death. On March 16th, 2020, the government announced the obligation of physical distancing and border closures. Gathering places closed. On March 20th, 2020, the lockdown followed. Since then, the unofficial transit going in and out of Moroccan cities was shut down. Most transportation was prohibited and almost all avoidable outdoor human activities stopped all around the country. On April 20th, 2020, the end date of the first strict lockdown period, Morocco announced 2990 confirmed cases and 143 deaths, thus a mortality rate of 4.8% [7].

Beyond the slowdown in the spread of the COVID-19 virus, the restrictive measures implemented by the authorities around the world have a second, less expected effect: that of reducing ambient air pollution which mortality rate has contributed to 7.6% of all deaths in 2016 worldwide [4]. In China, Nitrogen Dioxide (NO_2) dropped by 30% and carbon emissions by 25% [4]. In India, the concentrations of Particulate Matter with a diameter of less than 10 μm and 2.5 μm (PM_{10} and $PM_{2.5}$) reduced by 50% and NO_2 has also shown considerable decline [8]. In Spain, the concentration levels of NO_2 have declined by 64% in major cities [9]. In Northern Italy, a drastic reduction in NO_2 emissions was observed, as well [6]. [10] showed that the severe limitation of people movements following the lockdowns in the region, determined a significant reduction of pollutants concentration, mainly due to vehicular

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traffic (PM_{10}, $PM_{2.5}$, BC, benzene, CO, and NO_x). Emissions have also dropped in the USA [11]. Morocco has also experienced an improvement in air quality with a significant reduction in NO_2 and a relative reduction in $PM_{2.5}$ [12]. In the city of Salé for example, PM_{10} and NO_2 concentrations dropped respectively by 75% and 96% during the period between March 11th, 2020, and April 2nd, 2020 [13].

According to the World Health Organization (WHO), 4.2 million deaths have been caused by ambient air pollution worldwide in 2016. The latter is estimated to cause about 29% of lung cancer deaths, 24% of stroke deaths, 25% of heart disease deaths, and 43% of other lung diseases. Moreover, air pollution has attributed to 26% of respiratory infection deaths, 25% of chronic obstructive pulmonary disease (COPD) deaths, and about 17% of ischemic heart disease and stroke. It is noteworthy that chronic respiratory and cardiovascular diseases may be linked to COVID-19 as the death rate caused by the virus is higher among those with these diseases [4,14]. As for Morocco, each year more than 13,000 deaths are due to air pollution. This represents about 7% of all deaths, thus the 8th largest mortality risk factor. According to the global report "Toxic Air: The Price of Fossil Fuels" of the international NGO Greenpeace MENA, annual deaths due to air quality degradation in Morocco are estimated at 5100 in 2018 [15].

Obviously, COVID-19 is a threat for public health, nevertheless, the accompanying lockdown measures, instigating improved air quality, may have positive effects on human life and well-being. For instance, Chen et al. estimate that improved air quality in China, during the quarantine period, avoided a total of 8911 NO_2-related deaths and 3214 $PM_{2.5}$-related deaths [16].

The present study has started in April 2020 to highlight the impacts

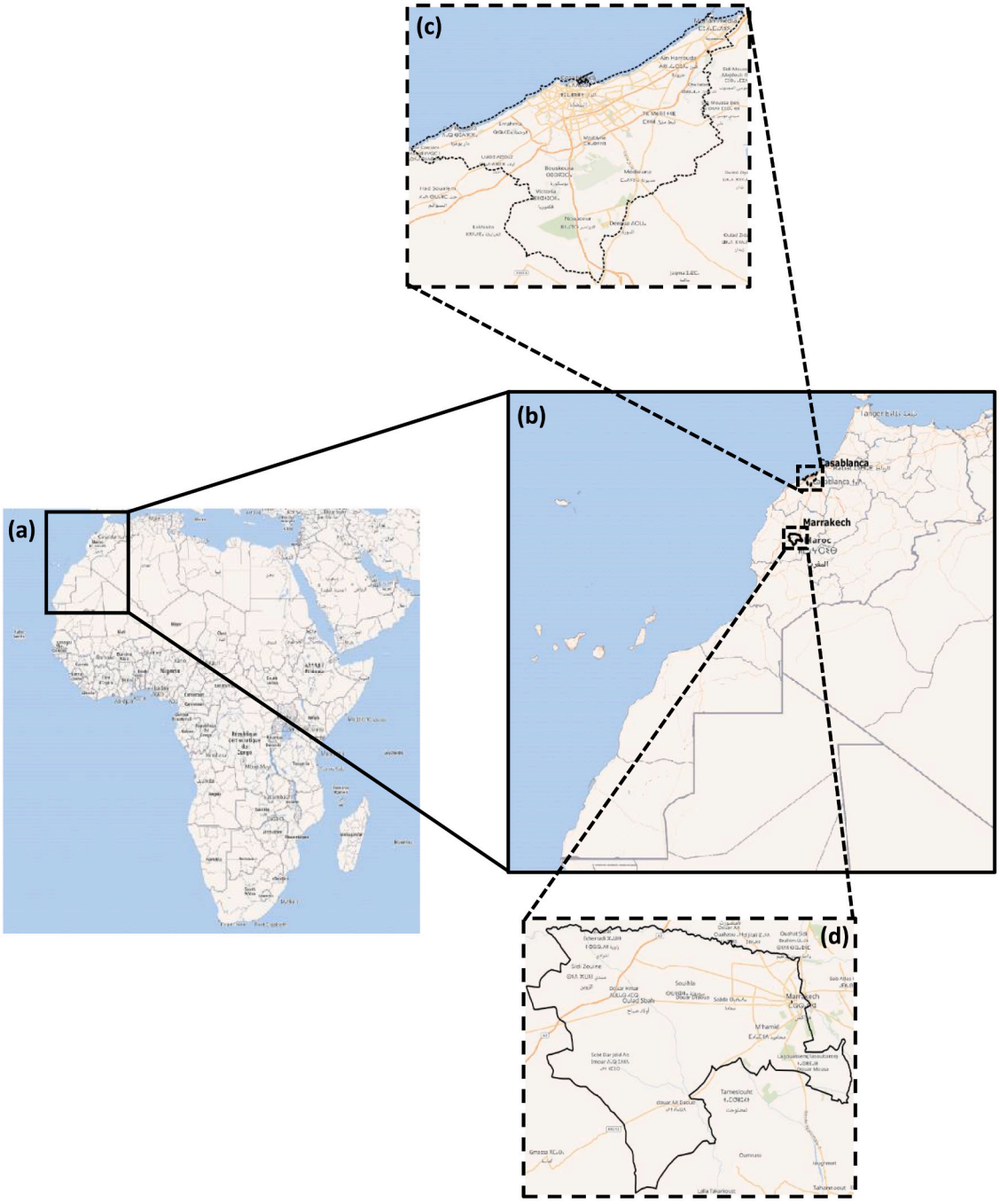

Fig. 1. Location of the study area. (a) Africa, (b) Morocco, (c) Casablanca, (d) Marrakech.

of COVID-19 lockdown on air pollution levels in Morocco and the potentially avoided cause-specific mortality during population quarantine episode. We have adopted the same approach as [16]. The novelty of our study resides in being held in an African country characterized by a special geographic position and a moderate and subtropical climate. To the best of our knowledge, this work reports on the first case study that links COVID-19 to positive consequences on health in Morocco. It tries to verify whether this infection has inadvertently saved more people than it has killed so far. Insights into these aspects are expected to contribute to a better understanding of an air pollution free scenario and help in considering alternative inclusive action plans for upgrading air quality in Morocco in the upcoming years.

The remainder of this paper starts with presenting the materials and methods including the study area, the used data and, the adopted approach. It then presents the found results and the discussion section.

2. Materials and methods

2.1. The study area

Morocco is an African country located in the extreme northwest of the continent (Fig. 1). It is located in the southern part of the Mediterranean basin and is considered among the most vulnerable countries to climate variability and transboundary air pollution [17]. Casablanca and Marrakech are the studied cities. They are, respectively, the first and the fourth populous cities in Morocco with more than 3,000,000 and 900,000 residents, as reported by the World Population Review webpage [18]. Casablanca is located in the central-western part of the country on the Atlantic Ocean coast (Fig. 1). In economic and demographic terms, Casablanca is one of the most important cities in Africa and is the largest city in the Maghreb. Marrakech is a large city in the Kingdom of Morocco. It is the chief town of the inland mid-southwestern region of Marrakech-Safi and located to the north of the piedmont of the snow-capped Atlas Mountains (Fig. 1). Within the country, the cities of Casablanca and Marrakech account together for more than 50% of the people infected by COVID-19. On April 20th, 2020, it has been reported that the region of Casablanca-Settat has reached exactly 840 cases leading the most regions affected by COVID-19. It is followed by the region of Marrakech-Safi which reached 739 cases of Coronavirus. Moreover, Casablanca and Marrakech are often chosen for air pollution research studies, as they are the urban areas where serious pollution concerns may be met, especially with the important population rate increase between 2004 and 2014; this rate reaches 11% in Casablanca and 12% in Marrakech [17,19].

2.2. Methods

To assess air pollution reduction due to the lockdown, we used a difference-in-difference approach that we validated through the non-parametric approach proposed by Theil and Sen for univariate time series [20,21]. Specifically, we defined the before quarantine period as between February 16th, 2020 and March 19th, 2020 and the during quarantine as between March 20th, 2020 and April 20th, 2020. We assessed changes in air quality during vs. before the quarantine period in 2020 and compared these with corresponding changes in the same lunar calendar periods in 2016–2019. We assessed the statistical significance of the obtained trends using the modified Mann-Kendall test proposed by Hamed and Ramachandra Rao for autocorrelated time series [22]. The test is performed at a significance level of 5%.

In order to quantify the impact of the found change in air quality on health, we calculated the avoided cause-specific mortality attributable to the decreases in NO_2 and $PM_{2.5}$ over the study area based on the concentration-response functions (CRF) from previous studies by [23,24], and the cause-specific mortality data from the IHME in 2017 [25]. In addition to total non-accidental mortality, the cause-specific mortality for cardiovascular disease, hypertensive disease, stroke, chronic respiratory diseases, and chronic obstructive pulmonary disease (COPD) was also calculated. The attributable fraction (AF) method was used to estimate the daily avoided cause-specific mortality from air pollution reduction as done by [16]. AF is defined as follows:

$$AF = 1 - e^{-\beta\Delta c} \quad (1)$$

β is the cause-specific coefficient of the CRF, it is expressed as the percentage change in daily mortality associated with a 10 $\mu g/m^3$ increase in daily NO_2 or $PM_{2.5}$. β values are available in the study by [16]. Δc is the air quality changes due to the quarantine. AF is then multiplied by the daily cause-specific number of deaths and the total number of days during the quarantine period (32 days) to estimate the cause-specific avoided deaths.

3. Air quality, health, and population data

The number of daily confirmed COVID-19 cases and deaths in Morocco were collected from the official website set by the ministry of health for that purpose [7]. Air quality data (daily concentrations of NO_2, PM_{10}, and CO) recorded in air quality stations were gathered from the National Weather Service in charge of air quality management in Morocco. PM_{10} concentrations were then converted to $PM_{2.5}$ data for each station, using a conversion factor of 0.4 [26]. We focused on NO_2, $PM_{2.5}$, and CO because they are traffic-related air pollutants whose emissions must obviously reduce as a result of the national traffic ban and home quarantine in Morocco during the lockdown.

Up to date city-level demographics are obtained from the World Population Review webpage [18]. Country-level air quality related mortality including the incidental to chronic disease is collected from the Institute for Health Metrics and Evaluation (IHME) [25].

4. Results and discussion

4.1. Improvement in air quality

Graphs in Fig. 2 show the evolution of NO_2, $PM_{2.5}$, and CO in the cities of Casablanca and Marrakech before and during the quarantine. They also mention related Theil-Sen (TS) slopes and their significance (when in bold, they are significant). TS represents the magnitude of the trend during one day from the study period which counts 65 days. Multiplying this number of days by the TS gives the magnitude of the trend during the whole study period. TS assessment helps to validate the difference-in-difference estimate (DDE) presented in Table 1. Overall, TS and DDE have the same order of magnitude.

Hence, DDE shows that, because of the quarantine, NO_2 dropped by -12 $\mu g/m^3$ in Casablanca and -7 $\mu g/m^3$ in Marrakech. $PM_{2.5}$ dropped by -18 $\mu g/m^3$ in Casablanca and -14 $\mu g/m^3$ in Marrakech. CO dropped by -0.04 mg/m^3 in Casablanca and -0.12 mg/m^3 in Marrakech. All TS calculated slopes for the 2020 period are statistically significant and confirm the negative trends and order of magnitude of the DDE. TS slopes for the period 2016–2019 are not statistically significant.

These findings are in complete agreement with many studies around the world. In Milan, Italy, [10] showed that the total lockdown led to a significant decrease in NO_2, $PM_{2.5}$ and CO. The same finding is maintained in China [4], India [8], Spain [9] and in Morocco, as well [13].

The findings are also in agreement with the results of [12], that have used $PM_{2.5}$ from MERRA-2 and NO_2 from SENTINEL 5P, to confirm the positive effect of COVID-19 lockdown on air quality in Morocco. Nevertheless, the authors pointed out a peculiar situation of ozone (O_3) during the lockdown where no steady trend was noticed in this pollutant time series. This may be due to the spatio-temporal variation of ozone because of local and large-scale effects. [12] have shown that the particulate pollution in Morocco is partly due to the synoptic weather factors, and that a significant part of the NO_2 and O_3 emissions may be mainly incoming from the northern borders of the country. In fact, [17]

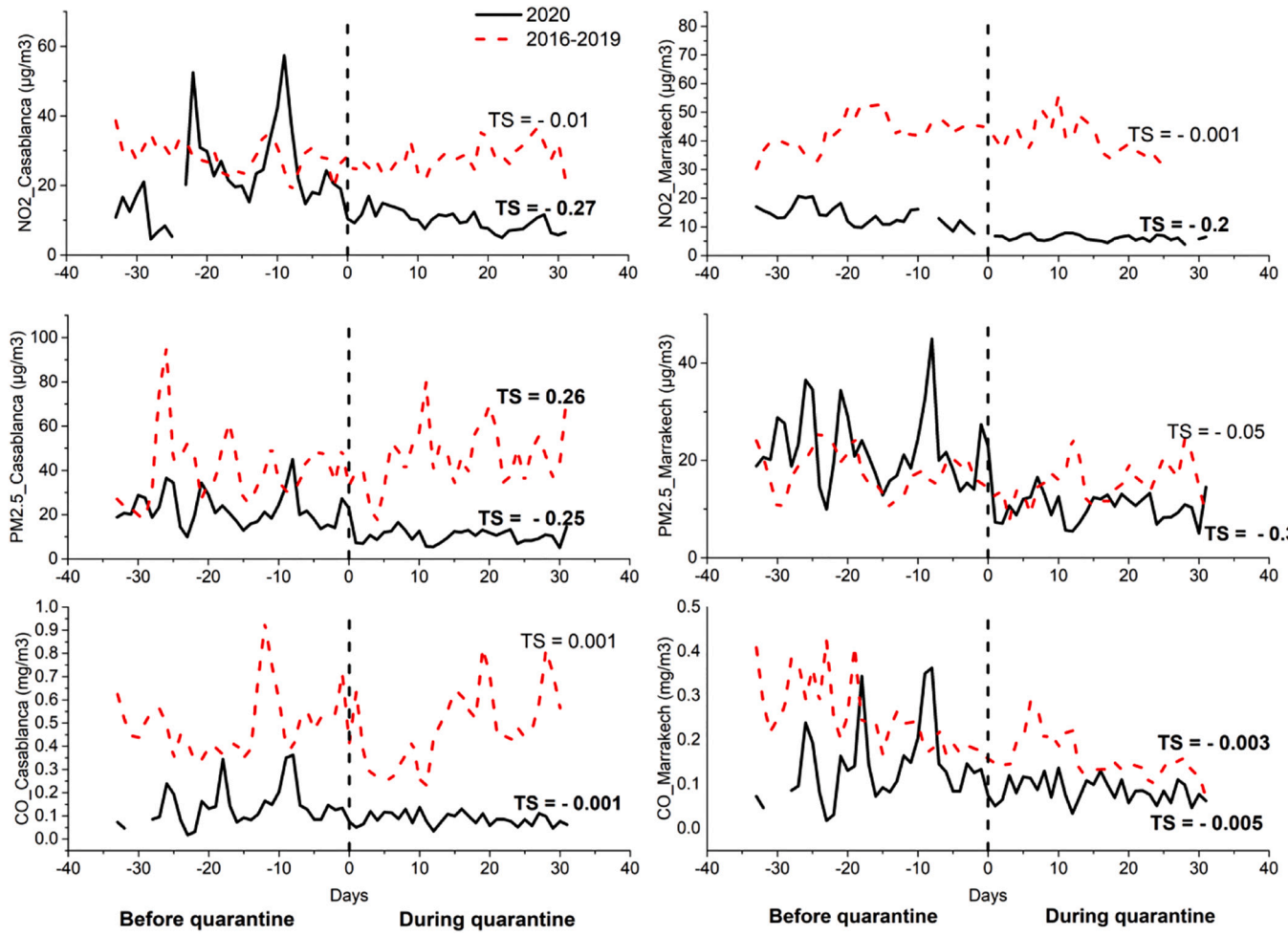

Fig. 2. Air pollution changes due to the quarantine in Casablanca and Marrakech using TS.
Bold character: statitically significant.

Table 1
Air pollution changes due to the quarantine in Casablanca and Marrakech using DDE.

	During vs before in 2020		During vs before in 2016–2019		Difference in difference	
	Casablanca	Marrakech	Casablanca	Marrakech	Casablanca	Marrakech
NO_2	−12.5	−7.5	−0.28	−0.74	−12.21	−6.76
$PM_{2.5}$	−11.63	−16.26	5.87	−2.48	−17.5	−13.78
CO	−0.06	−0.21	−0.02	−0.1	−0.04	−0.12

used the PM_{10} daily measurements in Casablanca and Marrakech to assess their relationship with the atmospheric circulation. PM_{10} correlations with climate indexes (North Atlantic Oscillation (NAO) and Mediterranean Oscillation (MO)) has demonstrated the relationship between MO and PM_{10} averages and has shown that particulate pollution in the country is partly induced by continental northeasterly to southwesterly flow. This flow is triggered by the Saharan trough and managed by the High-pressure area in the north of the country. Thereupon, the authors created and calculated a new climate index to characterize the oscillation, in the country's southern desert, between the Saharan depression and the Azores high. The time series of the new Saharan Oscillation Index (SaOI) were calculated, and the assessed SaOI correlations confirm the relationship between this index, PM_{10} averages and MO and NAO indexes. On account of this, assigning air pollution reduction to the national government lockdown may appear obvious, even though the confinement measures applied by the bordering countries may also have contributed to this drop through the reduction of the transboundary pollution contribution.

4.2. COVID-19 vs air quality daily deaths

Fig. 3 (a) and (b) show the cumulative number of deaths by COVID-19 in Morocco and the change in the number of daily mortalities, respectively. The results prove that the number of deaths increases between March 23rd, 2020 and May 4th, 2020 and decreases notably since then. The rate of change in daily mortality decreases with time and reaches the nil value by June 20th, 2020.

According to the global report "Toxic Air: The Price of Fossil Fuels" of the international NGO Greenpeace MENA, Morocco is within a lengthy list of countries that suffer relatively from high estimated numbers of deaths annually due to air quality degradation. This number is estimated at 5100 in 2018 [15]. Dividing this value over 365 days helps obtain the daily average deaths due to air pollution and yields 14 deaths every day. This average fixed value was plotted against the daily reported deaths

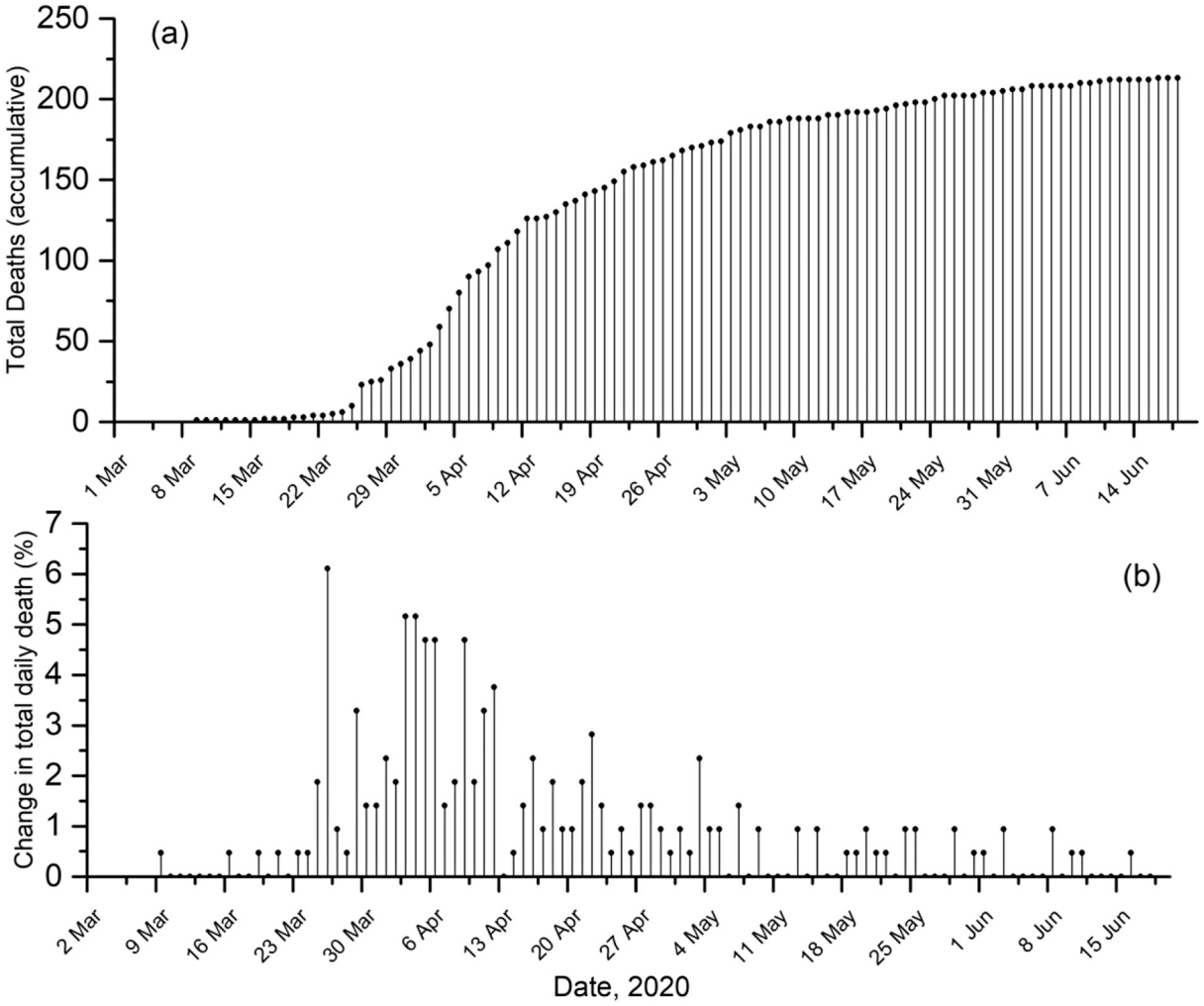

Fig. 3. (a) Cumulative number of deaths by COVID-19 in Morocco (b) Change in the number of daily mortalities.

due to COVID-19 in Morocco (Fig. 4). Moreover, it is worth noting that outdoor air pollution by particulate matter death rate in Morocco is estimated at 63.1 per 100,000 inhabitants [27], that of Covid-19 is of 0.59 per 100,000 inhabitants as estimated by the Coronavirus resource center of the Johns Hopkins University (https://coronavirus.jhu.edu/data/mortality).

All these results show a tremendous difference in deaths caused by COVID-19 and air pollution in Morocco.

4.3. Did COVID-19 save lives?

Table 2 shows the avoided cause-specific deaths due to air pollution reduction because of the COVID-19 home quarantine in Casablanca and Marrakech. We estimate that reduction in NO_2 during the quarantine period avoided a total of 185 NO_2 related deaths (95% CI 145–223) in Casablanca and 30 (95% CI 24–37) in Marrakech. Reduction in $PM_{2.5}$ avoided a total of 48 $PM_{2.5}$ related deaths (95% CI 70–89) in Casablanca and 15 (95% CI 10–19) in Marrakech. More than 60% of the avoidable deaths were from cardiovascular diseases. Cause-specific CRFs from single-pollutant models were used [16,24]. The study of Chen et al. in China confirms our results through the avoidable deaths found because of air quality improvement during COVID-19 lockdown [16].

Our results should be interpreted carefully because of the potential common impacts NO_2 and $PM_{2.5}$ may have on health. The risk of double counting is minor because, as suggested by the literature, effect estimates for NO_2 and $PM_{2.5}$ were similar between single-pollutant and two-pollutant models [23,28].

5. Conclusions

In the course of the present work, the effect of the imposed lockdown in Morocco in order to restrict the rapid spread of COVID-19 pandemic, on the air quality has been assessed based on NO_2, $PM_{2.5}$ and CO concentrations. We showed that COVID-19 lockdown measures have caused a reduction in the concentration levels of the traffic-related pollutants (NO_2, $PM_{2.5}$ and CO) and then the improvement of air quality in the country. This unprecedented situation, that may be also due to the reduction of the transboundary pollution because of the lockdown measures in the bordering countries, has created human health benefits, reduced mortality in non-COVID-19 deaths and saved lives mainly from cardiovascular diseases. Deaths could potentially have highly exceeded the current confirmed deaths attributable to COVID-19 in Morocco (229 deaths as of July 3rd, 2020).

Our results are in complete agreement with the worldwide studies that confirmed the systematic link between COVID-19 lockdown and improvement in air quality levels and echoes the findings by [16] that focused on assessing the number of lives saved because of COVID-19 accompanying measures.

Specifically, our findings show the human health benefits related to cardiovascular diseases mortality that can be achieved if control measures are taken to reduce emissions from vehicles. Traffic restrictions or efforts to accelerate the transition to clean transportation are good

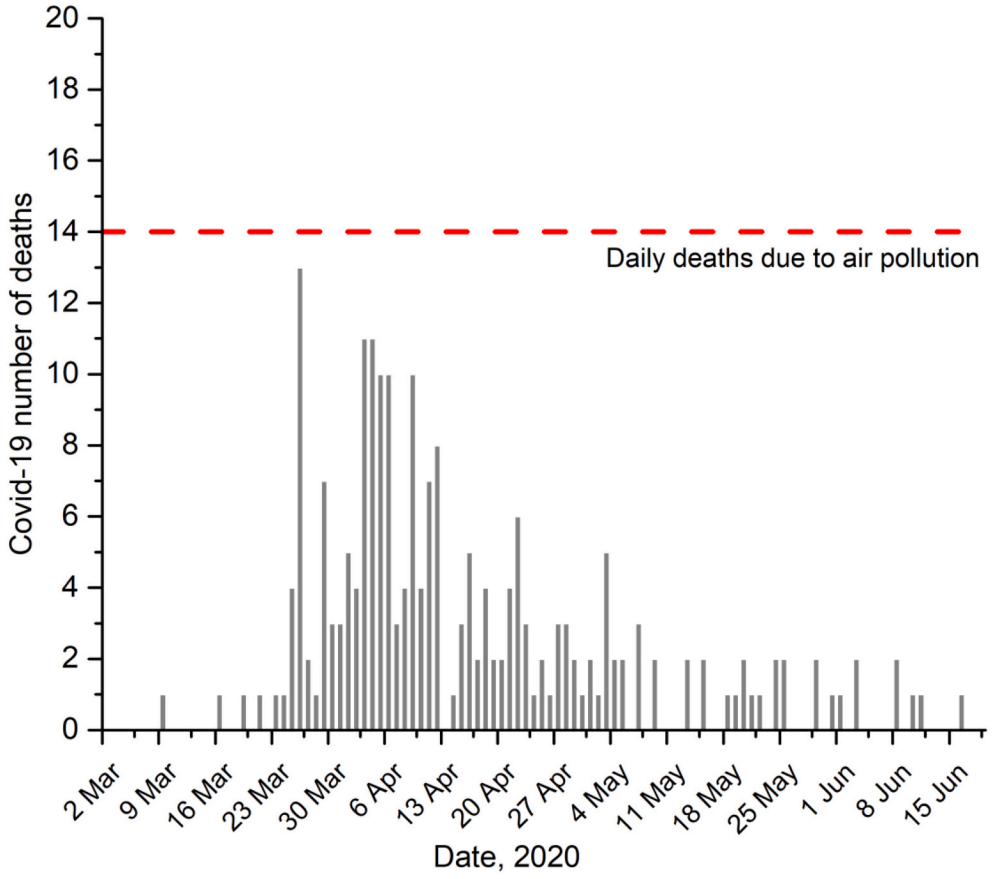

Fig. 4. Daily deaths due to COVID-19 vs. averaged daily deaths due to poor air quality.

Table 2
Avoided cause-specific deaths (95% confidence interval) due to air pollution reduction because of the home quarantine in Casablanca and Marrakech.

	Casablanca		Marrakech	
	NO_2	$PM_{2.5}$	NO_2	$PM_{2.5}$
Total	185 (145,223)	48 (70,89)	30 (24,37)	15 (10,19)
Cardiovascular Disease	96(76,126)	45 (30,59)	16 (12,21)	10(6,13)
Hypertensive heart disease	8(5,11)	4(1,6)	1(1,2)	1(0,1)
Chronic respiratory diseases	8(6,10)	3(2,5)	1(1,2)	1(0,1)
Stroke	23(13,30)	4(2,5)	9(5,13)	2(1,3)
COPD	5(7,9)	2(3,4)	1(1,1)	1(0,1)

examples of these measures. Nevertheless, the potential and common impacts that pollutants may have on health might impact our results and oblige to interpret them carefully. Also, and in many other studies, it has been shown that some pollutants such as the ozone (O_3) may have increased and thus have a reverse impact on health. Further investigation may be undertaken, mainly in Morocco, to explore ozone and other industry-related pollutants evolution and their impacts on human health. Assessing air pollution mortality after the lockdown is also a path that may confirm the need of control measures to reduce traffic emissions.

This paper and similar ones help to raise awareness about our responsibility towards the environment. It may also help to consider whether the COVID-19 lockdown scenario would be an efficient measure for preserving the environment and enhancing life quality in the urban ecosystem. However, cost effectiveness is one of the keys for policy-makers to implement any control measures mainly that the lockdown has caused lower mobility that impacted the economic activity and shrinking the economy is not a sustainable solution to encounter the environmental challenge.

Moreover, the contribution from the large-scale atmospheric patterns and meteorological forcing are to take into consideration in concluding from such a study as they impact pollutants concentration and dispersion. Overall, the interlinkages between COVID-19, economy, climate and transboundary pollution are complex and depend on the climatic conditions, the duration of the emergency and the reactions to it. Yet, like every crisis, the COVID-19 pandemic offers an important opportunity to draw lessons and to reconsider the way we treat the environment and the ecosystems.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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