Assessing the PM_{10} and O_3 Concentrations Changes during and after Easing the Lockdown (COVID-19) in the North-western Cities of Morocco: An Overview

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Abstract: In order to limit the propagation of COVID-19 among the Moroccan population, all industrial activities have been suspended since March 20th 2020. The present study investigates the possible change in atmospheric pollutants (ozone O_3, particulate matter PM_{10}) rate during the imposed lockdown. We explore air quality change in Morocco's North-Western cities using the Copernicus Atmosphere Monitoring Service (CAMS) regional model that provides estimated emissions of pollutants into the atmosphere. The results show an apparent decrease in PM_{10} levels during the lockdown, which points out the impact of human activities on air quality. The ozone shows an increasing tendency, which is probably linked to improved photochemical reactions due to the rise of sunlight passing by the atmosphere, resulting in decreased PM concentrations. This period that the world is experiencing has drastically impacted socio-economic sectors, but it has proved that human activities are the main factor influencing the environment.

1 INTRODUCTION

The North-West part of Morocco is known for concentrating the most important industrial activities, and it covers the most urbanized cities, including Casablanca (the economic capital), Tangier, Rabat (The country's capital), Salé, and Kénitra, among other cities. However, Casablanca and Tangier house the central industrial units in the Moroccan Kingdom, generating different pollutants.

Road transportation also contributes to air pollution, especially with the urban evolution over the last decades, which leads to increasing demand for motor vehicles. According to khatmi et al. (1998), Casablanca is impacted by year-round air pollution while, in 2015, the care density reached 104 vehicles/1000 inches (OICA, 2015). Despite the importance of the transport sector for the country's economic growth, it is also considered as a polluting sector of the air and contributes to Morocco's greenhouse gas emissions by 15% (Inchaouh and Tahiri, 2017). In recently published work by Mejjad et al., 2021a, the manufacturing of face masks generates a greenhouse gas footprint of 224 kT CO_2 eq./y calculated in Casablanca Settat and Rabat-Salé-Kénitra regions, while for the whole of Morocco is around 640 kT CO2 eq./y. Although the increase of human activities emissions of pollutant into the air caused over Morocco in 2014, 2,200 deaths, while about 50% of adults' deaths were from Casablanca, Marrakech, and Tangier (Croitoru and Sarraf, 2017).

As human activities are the primary source contributing to air quality deterioration (Sbai et al., 2020; Manisalidis et al., 2020; Christidou and Dimitriou, 2011), the suspension of these activities during the COVID-19 pandemic is the best occasion to assess the air quality change and evaluate the impact of human activities on the environment. The rapid spread of COVID-19 around the world has led the world health organization (WHO) to recommend specific safety measures to be taken by countries authorities in the whole world to contain the virus

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propagation and limit the human-to-human contagion through halting all economic and social activities, including industrial activities and transportation. Accordingly, likewise all the world countries, the Moroccan authority has taken many safety measures to avoid the increase of daily recorded cases, which translated by the suspension of all human activities from March 20th to 11th June 2020, while the whole country was under imposed lockdown during this period.

According to HCP, 2020 (in *tradingeconomics.com)*, there was a decrease in automotive and metallurgical products by 20.3% and 14.7%, respectively, while the manufactories of pharmaceutical, chemicals, and paper products increased by 17.5%, 8.2%, and 9.5%. The Gross Domestic Product (GDP) transport in Morocco has also known a significant decline during the COVID-19 in the first quarterly of 2020 (HCP, 2020). The effect of coronavirus on the economy is evident in almost all countries globally and represents the world's worst economic and social crisis (Ozili, 2020; Shakeel et al., 2020, Mejjad et al., 2021b). Conversely, an indirect positive impact of COVID-19 on the environment was reported in many studies related to coronavirus and the environment, where the enforced lockdown has indirectly contributed to air and beaches water quality improvement and environmental noise decrease (Sbai et al., 2021; Suresh et al., 2020; Zambrano-Monserrate et al., 2020; Chauhan and Singh, 2020; Lal et al., 2020; Dantas et al., 2020; Dutheil et al., 2020; Kerimray et al., 2020; Kerimray et al., 2020; Li et al., 2020; Mahato, Pal and Ghosh, 2020; Tobías et al., 2020; He et al., 2020; Nakada and Urban, 2020; Sharma et al., 2020). However, few studies have analyzed this change in Moroccan cities (Salé; Otmani et al., 2020; Tangier; Cherif et al., 2020).

Thus, the present work sought to assess the change in air quality before, during and after the lockdown. Furthermore, the study provides a general picture of the lockdown impact on the environment by evaluating the variation of PM_{10} and O_3 in the North-Western part of Morocco.

2 METHODS

2.1 Study Area

Morocco is situated in the northern part of Africa. The northern coastal regions house the most important industrial activities (Fig.1). Numerous human activities were concentrated in the Casablanca and Tangier cities, including industrial and urban activities (Cherif et al., 2019). The Casablanca-Settat Region is the highest urbanized region in Morocco with more than 11 million inhabitants (HCP, 2014), while the cities of this region (Casablanca; Mohammedia; El Jadida) have known since the 70s the growth of human activities through the progress of different sectors such as industrialization, agriculture, tourism, land use, and maritime transportation, among others (Mejjad et al., 2018; Mejjad et al., 2020a, Mejjad et al., 2020b, Mejjad et al., 2021c). While the region of Rabat-Salé-Kénitra also has known the development of human activities in the last decades and houses many industrial units in the province of Kénitra (El Khodrani et al., 2020; El Jalil et al., 2020; Bounakhla et al., 2009). These regions were the most affected by COVID-19, while fewer confirmed cases were detected in the Saharan areas (Daraa-Tafilalt) and in the regions where the human densities and activities are relatively low.

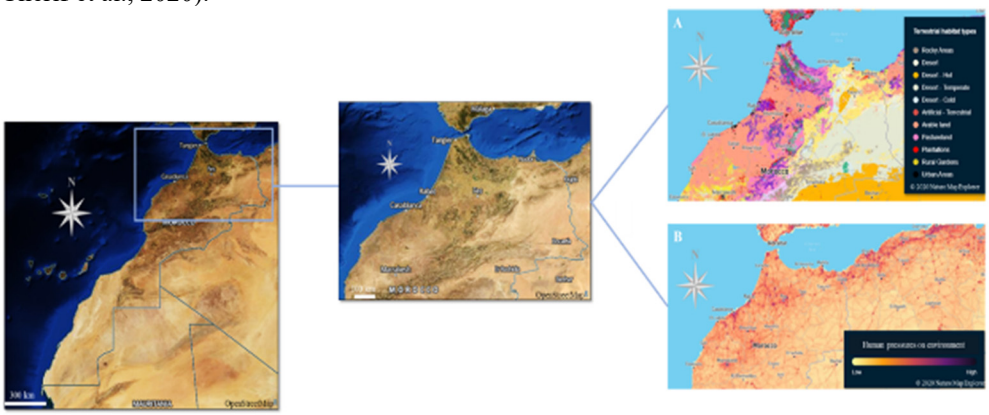

Figure 1: Location of the study area.

2.2 Copernicus Atmosphere Monitoring Service (CAMS) Data

The maps of pollutant indicators used in the present study were obtained by a Copernicus Atmosphere Monitoring Service (CAMS) regional model that provides estimated emissions of pollutants into the atmosphere during COVID-19 in European countries downloaded from (https://atmosphere.copernicus.eu/european-air-quality-information-support-covid-19-crisis). CAMS delivers a variety of daily values based on combinations between information received from atmospheric numerical models, satellite and ground-based (in situ) by a process named data assimilation (European Centre for Medium-Range Weather Forecasts (ECMWF), CAMS, 2020). The ECMWF delivers the CAMS global products. As these Maps cover the North-West and North-East parts of Morocco, we used this data to evaluate air quality change during COVID-19.

In the present study, we downloaded maps acquired before enforced the lockdown in Morocco (March 12th 2020), during the lockdown (March 25th, 13 and 23 April, 13 and 25 May), during the removal of the lockdown. The easing of the lockdown measures was applied gradually, in phases, and according to the cases registered in each prefecture and province, the kingdom was divided into two zones, A and B (Zone A: is not under lockdown and Zone B: is under lockdown). The 1st phase of easing the lockdown for some provinces and prefectures included Tetouan, Meknes, Settat, and El Hoceima (June 11th 2020). The 2nd phase of removing the lockdown has known the second classification of provinces and prefectures according to the number of detected cases, which comprised Casablanca, Fez and more cities (June 25th 2020) (Fig. 2).

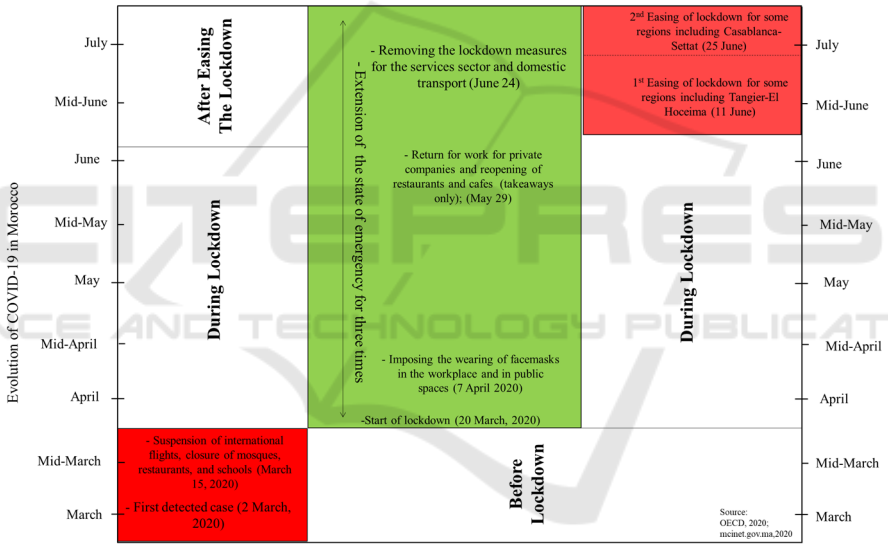

Figure 2: Evolution of COVID-19 in Morocco from the start to the removal of lockdown

3 RESULTS AND DISCUSSIONS

Nearly almost all countries worldwide were under partial or total lockdown because of the COVID-19 spread, which caused the suspension of industrial activities and road traffic, undoubtedly leading to the shutdown of pollutants levels in the air. We investigate the COVID-19 lockdown effect on air quality by comparing the O_3, PM_{10} values recorded before and during the quarantine.

3.1 Meteorological Conditions

The meteorological conditions, including temperature, wind speed, precipitation, and relative humidity, are the key factors influencing atmospheric pollutants' distribution (Zhou et al., 2018; Zhang et al., 2015; Li et al., 2011).

The meteorological parameters such as temperature, wind speed, humidity, and precipitation recorded during 13 and 25 March; 13 and 23 April; 13, May 25th; and 11, 25 and 30 June are presented in Fig.3. Substantial temperature variation in the Northwest, Northeast, East and West of Morocco

characterizes the period from March to June (Fig. 3). The humidity was relatively high during the periods extending from March to early May and decreased progressively from late May. The humidity rate is higher in coastal cities (Tangier, Rabat, and Casablanca) than in continental cities like Er-rachidia. The average temperatures show a similar trend and increase progressively during the lockdown in the months known as a transition season (March-April) (Rodríguez et al., 2001) and reached 40°C in late May in continental cities (Fez and Er-rachidia).

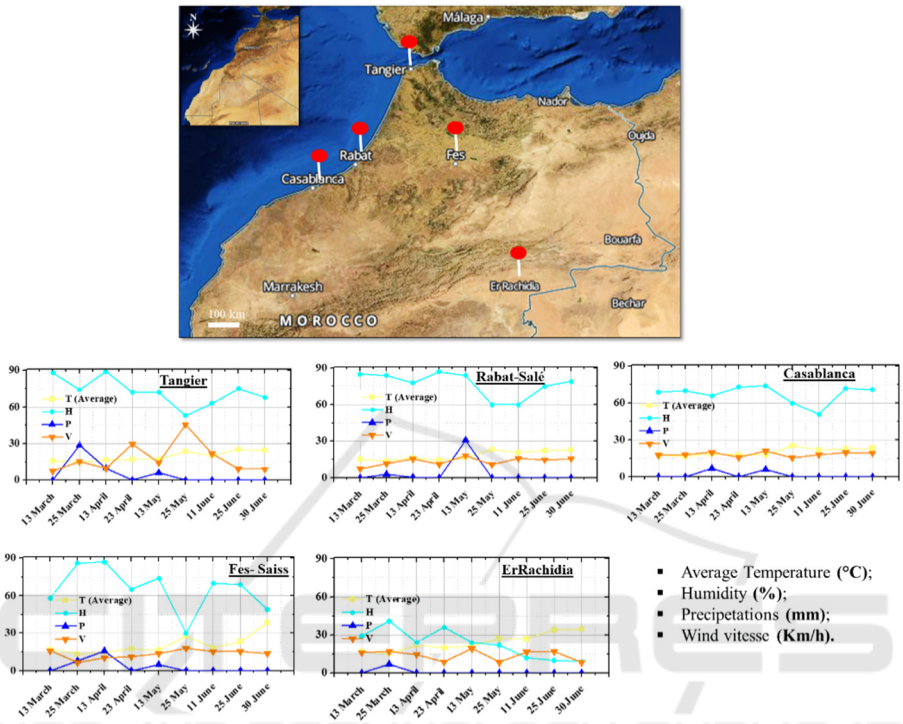

Figure 3: Meteorological conditions during 13 and 25 March; 13 and 23 April; 13, May 25th; and 11, 25 and 30 June (Source: www.wunderground.com).

3.2 Spatial Mass Concentrations Changes of O_3 and PM_{10} before, during, and after the Lockdown Period

3.2.1 Spatial Pattern of Ozone (O3) Mass Concentration.

Figure 4 shows the spatial evolution of the Ozone mass concentration over *North-Western* cities of Morocco for March 12th (before lockdown); 13th, April 23rd and 13th, May 25th (During lockdown); June 11th (1rdphase easing the lockdown) and 25th, 30th, June (2nd phase easing the lockdown). A crucial increase in ozone levels was observed during the lockdown (March 17th). This increase in O_3 could be attributed to the drastic drop in ozone titration by NO_2 and NO (Mahato et al., 2020; Siciliano et al., 2020; Freitas et al., 2020) and some other pollutants related directly to human activities and road traffic, such as volatile organic component (VOC), SO2, CO (Han and Naeher, 2006). On March 13th (before lockdown), the O_3 mass concentration varied between 75 and 105 µg/m^3; the values were less critical in Tangier, Tetouan, Fez, Méknes, Rabat and Casablanca and high in the western region. The concentrations were increased during the lockdown and reach values up to 120 µg/m^3 on May 25th, higher than daily permissible values recommended by WHO and Moroccan limit values (100 µg/m^3; 110 µg/m^3) respectively (Chirmata et al., 2018; WHO, 2006). Moreover, the values were higher in western cities characterized by low human and car density, which means low NOx levels. As the photochemical reactions are a significant source of an oxidizing factor in the atmosphere, such as ozone (Hu et al., 2019), the increase of ozone can also be explained by the improvement of photochemical reactions due to the rise of sunlight passing by the atmosphere resulting in decreased PM concentrations (Li et al., 2019; Dang and Liao, 2019). On the other hand, the

augmentation of solar radiation during the lockdown (especially during April-March-June) shows that the growth of O3 is usual during this period of the year due to higher solar radiation, especially under high humidity. Krug et al. (2019) have reported that the seasonal effects may often have impacts on ozone production (being high during hot days). Recently, some research showed that the growth in daylight hours might be a crucial factor causing higher O_3 levels (Collivignarelli et al., 2020).

During the first stage of easing the lockdown (June 11th), the ozone values show a slight decrease in the whole study area and reach 100 µg/m3except for some cities classified as zone (A), the O_3 values reach 80 µg/m^3. The ozone has declined in the following days that have known the second phase of lockdown easing (from June 25th), which included this time Casablanca-Settat, Rabat- Salé- Kénitra, Fez- Méknes, and Tangier- El Hoceima-Tetouan regions while the values were ranged from 70 to 100 µg/m^3.

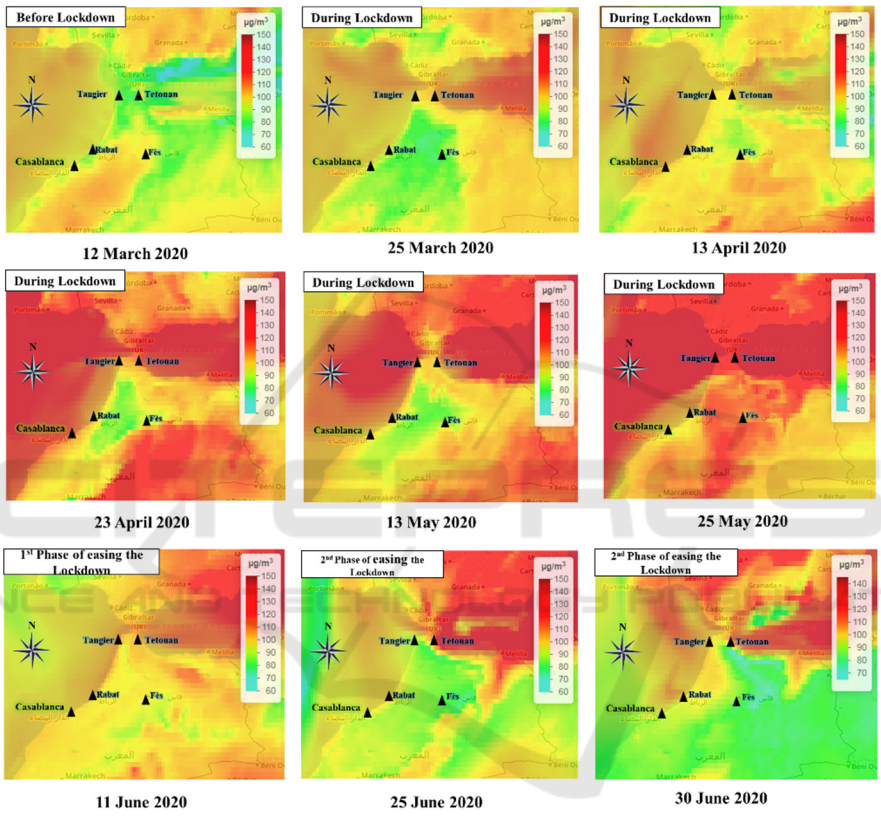

Figure 4: Map of O_3 daily max concentration, (***Credit: ECMWF, Copernicus Atmosphere Monitoring Service (CAMS)***)

3.2.2 Spatial Pattern of PM_{10} Mass Concentration

The particle matter (PM) is an essential indicator of air quality strongly related to primary sources like road traffic, coal combustion, biomass burning, dust mineral, and chemical fuel emissions (Zhang et al. 2018). The secondary sources are related to volatile organic compounds (VOC) and biogenic VOC conversion to particle via atmospheric oxidation involving O3 and O.H. oxidation (Ortega et al., 2016; Liu et al., 2018; palm et al., 2016 and 2017; Sbai and Farida, 2019; Yalçin et al., 2020). Sea salt, like iodine, can be a product of ultra-fine particles after oxidation, especially under high O_3 levels (Saiz-Lopez and Plane 2004; Gómez Martín et al., 2013; Sbai and Bentayeb, 2019). NO_2 and SO_2 can produce ammonium particles and sulfate particles after atmospheric oxidation (Wang et al., 2019; Khoder, 2002). The spatial distributions of diurnal PM_{10} mass concentrations are presented in Fig.5. A substantial change was observed during the lockdown compared to before and during the lockdown.

The PM_{10} levels were ranged between 20 and 25µg/m^3 in Casablanca, Rabat, and Tangier some days before enforcing the lockdown, below the limit values recommended by WHO (WHO, 2006). PM_{10} dropped in the North-West area of Morocco during

the lockdown and reached 10µg/m^3 on April 13th. In the North-East, the PM_{10} mass concentrations were very high (~ 50µg/m^3) compared to the North-West cities, attributed to the dust mineral particles, because the Saharan dust is a substantial primary source of PM (Kabatas et al., 2012). The PM_{10} values were higher during March and April (during lockdown), especially in the West, which can be explained by the transport of dust particles from the Sahara in the northeast, which is in good accordance with studies that reported that the Saharan-dust proliferation occurs during the transition seasons (March-April), (Rodríguez et al., 2001; Gerasopoulos et al., 2006; Kallos et al., 2007; Mitsakou et al., 2008; Querol et al., 2009; Kabatas et al., 2012). Moreover, we show a reduction of PM_{10} after lockdown (June 11th) in the northeast, and this can be explained by the decrease in wind speed (Fig.4) and dust particles transport. Besides, we have recorded a substantial decrease in PM level in all regions of the study area during the lockdown; this is due to the decrease of the main primary sources of PM, such as road traffic and industrial activities, especially in the industrial pole of the country (Casablanca and Tangier) (Kumar et al., 2020). In addition, the precipitations were more frequent during the lockdown period. This variation of meteorological conditions was adequate for reducing atmospheric pollutants concentrations during the lockdown, especially for the coastal cities but unfavourable for continental cities.

Despite the easing of imposed lockdown on June 11th, the PM_{10} values are below 10µg/m^3 in Casablanca, Rabat, Tamera, Tangier, and Fez (Fig.5). These cities were ranked as zone B, which does not follow criteria established by the health authority and then they were excluded from the ease of lockdown measures. The values have increased during the second stage of removing the lockdown, and reach values ranged from ~10 to ~20 µg/m^3 on June 25th and from ~20 to ~40 µg/m^3 on June 30th. The restarting of human activities, including industrial activities and road traffic, is the origin of PM increases. Otherwise, the PM_{10} values do not exceed WHO's guidelines for air quality and the Moroccan air quality standards (Chirmata et al., 2018; WHO, 2006). The observed changes in PM_{10} values reflect the influence of human activities on the environment and the positive effect of the imposed lockdown caused by COVID-19, in good agreement with recent studies related to the impact of COVID-19 on air quality (Chen et al., 2020; Tobías et al., 2020; He et al., 2020; Otmani et al., 2020).

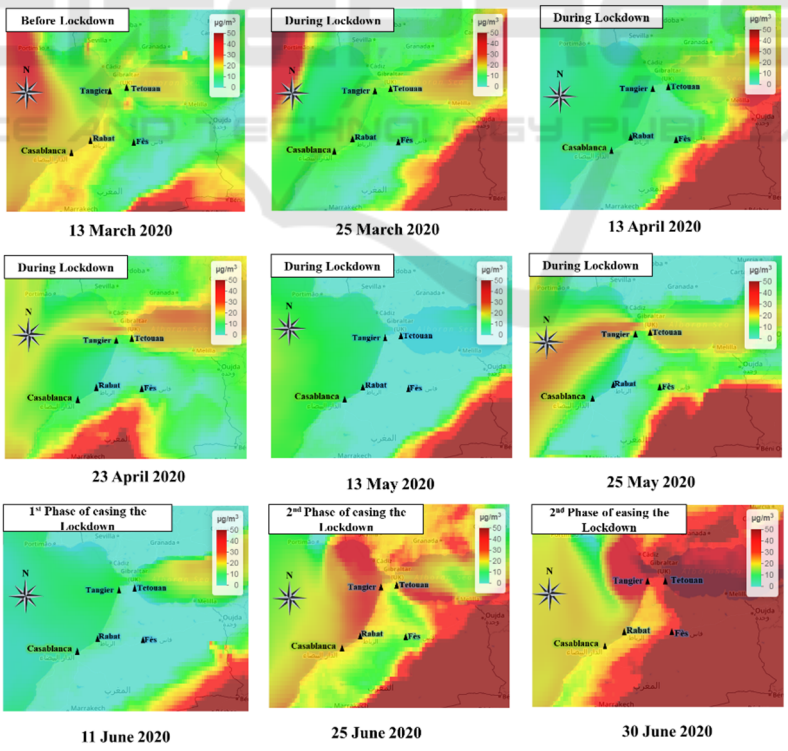

Figure 5: Spatial PM_{10} daily mass concentration change in the North-Western cities of Morocco (**Credit: ECMWF, Copernicus Atmosphere Monitoring Service (CAMS)**).

4 CONCLUSIONS

The present study gives an overview of air quality changes before, during, and after imposing the lockdown in North-East and North-West parts of Morocco and highlights the human activities effects on air quality. Generally, an apparent change in PM_{10} and O3 levels are shown in CAMS's daily maps. An apparent reduction of PM_{10} levels was observed during the imposed lockdown while the ozone levels have increased during the same period. The increasing trend of ozone concentrations is most likely related to the improvement of photochemical reactions due to the rise of sunlight passing by the atmosphere due to reducing PM levels.

The change in atmospheric pollutants levels is linked to the temporary suspension of human activities that contribute to air quality degradation, such as road traffic and industrial activities.

The air quality was monitored in every country globally, which revealed that humans are the main factor influencing environmental quality. All the studies focused on environmental assessment and monitoring have associated increased pollutant levels on air, soil, and water with human activities. Putting almost all human activities on pause as a response to COVID-19 has improved environmental quality and proved the human effect on the planet's environment.

Future research needs to be elaborated to investigate the air pollution levels change in Morocco, especially in cities known for high pollutant emissions, to explore whether air quality improvement has positively affected human health.

RECOMMENDATIONS

Indeed, the social and economic sectors were dramatically affected by the imposed lockdown and the suspension of all economic activities, including international trade, but the environment has taken advantage of these safety measures. The COVID-19 experience is an open invitation to stakeholders, decision-makers, society, and environmentalist actors to reconsider the impact of humans on the environment and elaborate new and more efficient policies and strategies to fight against environmental quality deterioration.

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