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Original article

# Effect of environmental pollution PM2.5, carbon monoxide, and ozone on the incidence and mortality due to SARS-CoV-2 infection in London, United Kingdom

Sultan Ayoub Meo [a,*], Abdulelah Adnan Abukhalaf [a], Waqas Sami [b], Thanh D Hoang [c]

[a] Department of Physiology, College of Medicine, King Saud University, Riyadh, Saudi Arabia
[b] Department of Public Health, University of Health Sciences, Lahore, Pakistan
[c] Walter Reed National Medical Center, Bethesda, MD, USA

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ABSTRACT

*Objectives:* COVID-19 pandemic raised several queries on the relationship between the environment pollution and occurrence of new cases and deaths. This study aims to explore the effect of environmental pollution, particulate matter (PM 2.5 μm), carbon monoxide (CO) and Ozone ($O_3$) on daily cases and daily deaths due to Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infection in a largest metropolitan city London, United Kingdom.
*Methods:* For this study, we selected London, one of the highly populated capitals, and markedly affected due to COVID-19 pandemic. The data on the SARS-CoV-2 daily new cases and deaths were recorded from UK-gov Web "Coronavirus COVId-19 in the UK, 2020". The daily environmental pollutants PM 2.5 μm, CO and $O_3$ were recorded from the metrological web "(London Air Pollution, Air Quality Index- AQI, 2020)". The daily cases, deaths, PM 2.5 μm, CO and $O_3$ were documented from the date of the occurrence of the first case of SARS-CoV-2 in London, February 24 to November 2, 2020.
*Results:* The SARS-CoV-2 cases and deaths were positively related with environmental pollutants, PM2.5, $O_3$ and CO levels. Additionally, with 1 μm increase in PM2.5 the number of cases and deaths significantly increased by 1.1% and 2.3% respectively. A 1 unit increase in CO level significantly increased the number of cases and deaths by 21.3% and 21.8% respectively. A similar trend was observed in $O_3$, with 1-unit increase, the number of cases and deaths were significantly increased respectively by 0.8% and 4.4%.
*Conclusions:* Environmental pollutants, PM2.5, CO and $O_3$ have a positive association with an increased number of SARS-CoV-2 daily cases and daily deaths in London, UK. Environmental pollution management authorities must implement necessary policies and assist in planning to minimize the environmental pollution and COVID-19 pandemic.


## 1. Introduction

Environmental pollution develops a hazardous situation, and causes significant wide-ranging damage to the regional environment, human health and living organisms (Meo et al., 2020a). Worldwide, people are migrating from rural areas to the metropolitan cities (Mathias, 2020). The metropolitan cities are facing the challenging issues of overcrowded population, large number of motor vehicles, and constructions of unplanned industries. These factors increase the environmental pollution both at regional and international levels. The environmental pollutants are mainly consisting of "dust, fumes, smoke, carbon dioxide, carbon monoxide, nitrogen oxides", particulate matter, hydrocarbons and other organic compounds (US Environmental Protection Agency, EPA, 2020; Pandey and Singh, 2019). Worldwide, many metropolitan cities are affected by environmental pollution.

London, a capital city of United Kingdom, is one of the highly populated, and congested metropolitan cities, is facing major health care challenges of environmental pollution and a rapidly increasing number of SARS-CoV-2 cases. On Dec 4, 2020, the total number of SARS-CoV-2 cases in United Kingdom, are 1659260,

* Corresponding author.
*E-mail addresses:* sultanmeo@hotmail.com, smeo@ksu.edu.sa (Meo SA).
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deaths 59,699 compared to worldwide total number of cases of SARS-CoV-2 are 64,350,473 (2.57%) and deaths 1,494,668 (3.99%) (World Health Organization, WHO 2020). In London, where the total number of SARS-CoV-2 cases are 161,626 compared to total number of cases in the entire United Kingdom are 165260 (9.74 %) (London Data, 2020). One of the reasons of rising cases of SARS-CoV-2 in London may be the environmental pollution which makes the city more susceptible to infectious diseases such as SARS-CoV-2 infections (London Data, 2020). It has already been reported that environmental pollution and weather conditions have an impact on the pattern of health and disease (Meo et al., 2020b).

The incidence of SARS-CoV-2 may be linked to living in ''urbanization, habitat destruction, live animal trade, intensive livestock farming and global travel'' (Barouki et al., 2020). The impact of environmental pollution requires further studies. The present study aims to investigate the effect of environmental pollutants ''particulate matter PM2.5, carbon monoxide (CO), and Ozone ($O_3$) on the daily incidence and deaths due to SARS-CoV-2 infection in London, UK''.

## 2. Materials and Methods

The present study was steered in the ''Department of Physiology, College of Medicine, King Saud University, Riyadh, Saudi Arabia''. In this study we selected London, UK, one of the highly populated metropolitan capitals, affected by the environmental pollution and SARS-Co-2 infection. Data were extracted from publicly accessible databases. The information on SARS-CoV-2 daily cases and deaths were collected from the UK-gov Web "(Coronavirus COVId-19 in the UK, 2020)". The daily information on meteorological conditions, environmental pollution, daily pollutants, particulate matter PM2.5, CO and $O_3$ were obtained the metrological web-(London Air Pollution, Air Quality Index- AQI, 2020). The daily cases, deaths, pollutants, particulate matter PM2.5, CO and $O_3$ were recorded from the date of appearance of first case of ''SARS-CoV-2'' in the London, from February 24, 2020 to November 02, 2020.

*Ethical Statement*: For this study the data on the daily new cases and deaths due to COVID-2019 pandemic, particulate matter PM2.5, CO and $O_3$ related information were obtained from the UK-gov Web "Coronavirus COVId-19 in the UK, 2020)", and weather web ''AQI'' from the publicly available data bases, hence ethical approval was not required.

### 2.1. Statistical analysis

The data was analyzed using ''R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria''. One-sample Kolmogorov-Smirnov test was used to evaluate the assumptions of Normal and Poisson distributions. Median (25th−75th quartiles) are reported for non-normally distributed quantitative variables (number of cases, deaths, PM2.5, CO and $O_3$). Spearman Rho Correlation was applied to assess the relationship between various pollutant parameters with the number of cases and deaths at 1% level of significance. After fulfilling the assumptions, the Poisson regression analysis was performed to predict the number of cases and deaths from pollutant parameters. Goodness of Fit tests and Model tests for all regression analysis were significant. An $\alpha = 0.05$ was considered as statistically significant.

## 3. Results

The median (25th−75th quartile) number of new daily cases reported in London between 24th February to 2nd November 2020 were 168 (57.5–567) and deaths 4 (1–15), whereas the median PM2.5, CO and $O_3$ levels were 24 (18–38), 2 (1–4) and 21 (15–28) respectively (Fig. 1). The number of cases significantly increased with the increase in PM2.5 level ($\rho = 0.341$, $p < 0.001$), a similar trend was observed where $O_3$ level was significantly positively related with the number of cases ($\rho = 0.222$, $p < 0.001$). Moreover, a positive association was noticed between the number of cases and CO level, but it did not achieve a level of significance ($\rho = 0.120$, $p = 0.057$).

In addition, the number of deaths also significantly increased with the increase in levels of PM2.5 ($\rho = 0.395$, $p < 0.001$), CO ($\rho = 0.125$, $p = 0.047$) and $O_3$ ($\rho = 0.450$, $p < 0.001$). Results are presented in Figs. 2, 3 and 4.

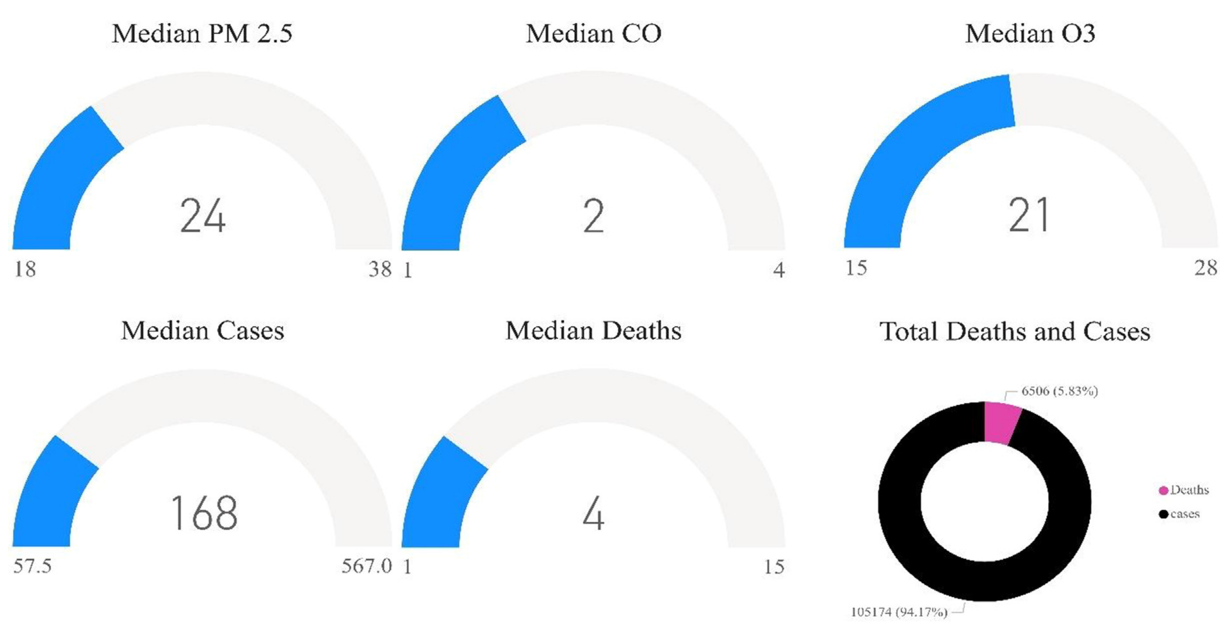


**Fig. 1.** Median PM2.5, CO, $O_3$ levels and number of cases and deaths during the period February 24 to November 2, 2020.

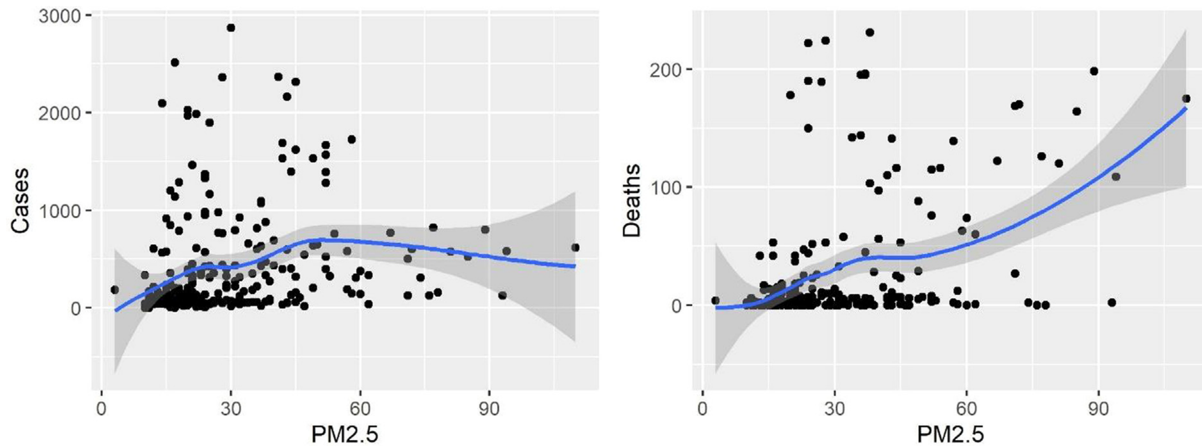


**Fig. 2.** Relationship of PM2.5 with number of SARS-CoV-2 cases and deaths.

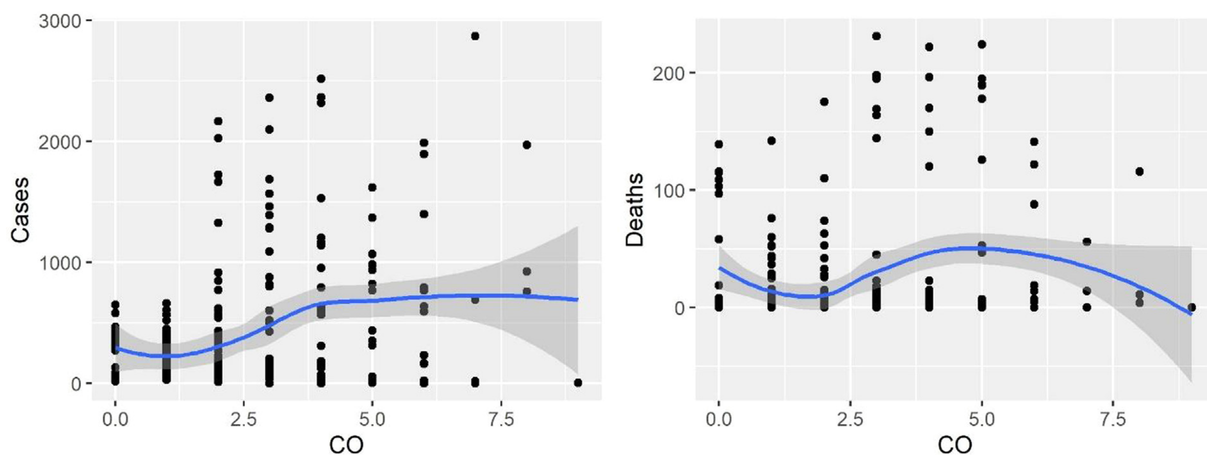


**Fig. 3.** Relationship of carbon monoxide (CO) with number of SARS-CoV-2 cases and deaths.

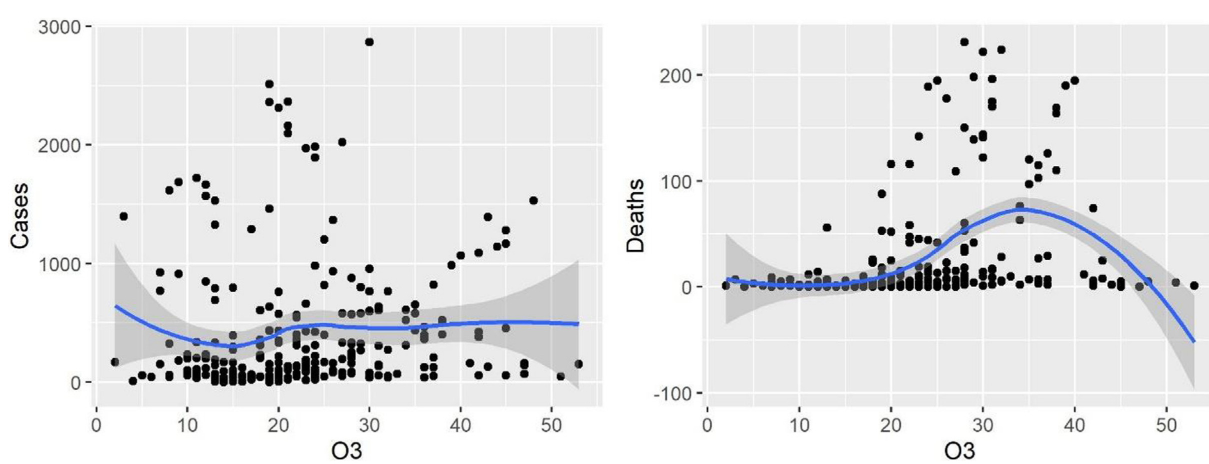


**Fig. 4.** Relationship of Ozone ($O_3$) with number of SARS-CoV-2 cases and deaths.

Results presented in Tables 1 and 2 demonstrates that, 1 μm increase in PM2.5 the number of cases and deaths significantly increased by 1.1% and 2.3% respectively. Whereas 1 unit increase in CO level the number of cases and deaths again significantly increased by 21.3% and 21.8% respectively. A similar trend was observed with $O_3$ pollutants, results showed that with an increase of 1 unit in $O_3$ the cases and deaths were significantly increased by 0.8% and 4.4%.

## 4. Discussion

Environmental pollution is a growing global public health concern. It changes the environment, weather conditions, and increases the risk for respiratory (Meo et al. 2020b), nervous system (Meo et al. 2019c), cardiovascular (Meo and Suraya, 2015d), and endocrine (Meo et al. 2020e). Environmental pollutants have various sources of emission, biological, physical, chemical, and

**Table 1**
Poisson Regression – PM2.5, CO and $O_3$ relation with the number of SARS-CoV-2 cases.

| Pollutant Parameters | B | S.E | Exp (β) | p-value |
|---|---|---|---|---|
| PM 2.5 | 0.011 | 0.0002 | 1.011 | p < 0.001* |
| CO | 0.193 | 0.0015 | 1.213 | p < 0.001* |
| $O_3$ | 0.008 | 0.003 | 1.008 | p < 0.001* |

**statistically significant at 5% level of significance; S.E = Standard Error; β = Coefficient Estimates; Exp (β) = Exponentiated Values.

**Table 2**
Poisson Regression- PM2.5, CO and $O_3$ relation with the number of SARS-CoV-2 deaths.

| Pollutant Parameters | B | S.E | Exp (β) | p-value |
|---|---|---|---|---|
| PM 2.5 | 0.023 | 0.0005 | 1.023 | p < 0.001* |
| CO | 0.197 | 0.0067 | 1.218 | p < 0.001* |
| $O_3$ | 0.043 | 0.0012 | 1.044 | p < 0.001* |

** statistically significant at 5% level of significance; S.E = Standard Error; β = Coefficient Estimates; Exp (β) = Exponentiated Values.

spreading behaviors (Jeong et al., 2019). The present study findings are showing increasing trends of SARS-CoV-2 cases and deaths with environmental pollutants PM.2.5, CO and $O_3$ levels in London, United Kingdom.

Literature acknowledged that the environmental pollution increases the incidence and mortality of respiratory infections (Kan et al 2005). (Kan et al 2005) reported that the coronavirus outbreak increased by 6% with a relative risk of mortality for each 10 μg per cubic meter increase in the mean of total respirable particulate matter PM-10, which also comprises of PM2.5 and larger particles. Similarly, (Croft et al 2018), and (Croft et al., 2020) found that short-term or long-term upsurges in particulate matter PM2.5 from traffic and various combustion sources are a potential risk for high incidence of influenza, and hospitalizations with culture-negative pneumonia and influenza.

Earlier studies have also established a link between high concentrations of ambient fine particles, PM2.5 and respiratory infections (Cannon et al., 2018; Gandini et al., 2018). Similarly, the present study results revealed a positive correlation between the environmental pollutants PM2.5, CO and $O_3$ and number of cases and deaths of SARS-CoV-2.

(Razzaq et al. 2020) established a relationship between air pollution mainly ground ozone $O_3$ and COVID-19 cases in the states of the US. The authors found a positive relationship with high environmental pollution and increase susceptibility of COVID-19 cases. Similarly, (Lolli et al., 2020) investigated the role of air pollution on transmission of SARS-CoV-2 infections. The authors concluded that air pollution (PM2.5) shows a positive correlation at lesser degree. COVID-19 pandemic transmission prefers dry and cool weather conditions as well as polluted environment.

Bianconi et al (2020) reported the risk of particulate matter exposure, "PM2.5 and PM10 with the COVID-19 cases and deaths" across the Italian regions. They also concluded that PM pollution plays a role in the outbreak of COVID-19 cases in Italian regions.

Zhu et al. (2020) found a significant positive association between air pollutants including PM2.5, PM10, CO, $O_3$ with COVID-19 infection. In another study, (Frontera et al 2020) reported that the regions with high air pollutants, "PM2.5 and NO2" have high incidence and mortality due to SARS-CoV-2 infection. Similarly, the present study findings show an increasing trend of COVID-19 cases and deaths with environmental pollution in London, UK

More recently, (Meo et al. 2020a; Meo et al. 2020f) reported that PM2.5, CO, and $O_3$ concentrations generated due to wildfire was associated with increases in the COVID-19 cases and deaths in various regions of the California, USA. The literature show that environmental pollution and weather conditions possibly affect the transmissibility of SARS-CoV-2 infection (Meo et al. 2020g; Meo et al. 2020h).

Liu and Li (2020) showed that ground-level ozone was positively correlated with county-level mortality rates. High ground-level ozone and nitrogen dioxide concentrations contribute to a greater COVID-19 mortality rate. Similarly, Comunian et al. (2020) reported that short-term and long-term exposure to high concentrations of pollutants, particulate matter were linked to an increased in COVID-19 infection. Pozzer et al. (2020) suggested that environmental pollution is a major cofactor for increasing risk of deaths due to COVID-19 pandemic.

The SARS-CoV-2 can be easily transported through the air and pollutants. Air is a highly suitable transmission method in which microorganisms including "bacteria, fungi, viruses, parasites, and spores may move around the environment of various regions (Zhou et al, 2020; Setti et al., 2020). The environmental particulate matters play a role as a carrier of numerous microorganisms including viruses. The particulate matters increase the effectiveness of the viruses spread and provide suitable environment for its persistence (Setti et al., 2020). Moreover, PM2.5 along with microorganisms can be easily inhaled deep into the lungs, mainly those pollutants which are smaller than PM2.5 microns, fine and ultrafine particulate matters. This may facilitate the virus to enter, grow within the respiratory system and cause infections (Setti et al., 2020). The literature is supported by some evidences that exposure to environmental pollutants, PM has been causally linked to organ dysfunctions mostly involving the respiratory system (Schraufnagel et al., 2019) and also severe course of SARS-CoV-2 infection (Leikauf et al., 2020).

The environmental pollution PM 2.5, CO and $O_3$ may act as a carrier of the infection, impair the immunity, making the people more susceptible to pathogens, and as a worsening pathogenic factor for the disease*** (Zhou et al 2020). In't Veen et al. (2020) reported a correlation between severity of SARS-CoV-2 infection and air pollution. The mechanisms by which air pollution might facilitate SARS-CoV-2 infection include a possible link between upregulation of the angiotensin converting enzyme receptor by air pollution and the host being prone to more severe COVID-19.

The present study findings have evidences that particulate matter PM2.5, CO and $O_3$ are the possible sources of carrier or transport vector for SARS-CoV-2 virus. Moreover, CO is a highly toxic gas which can damage the lungs. This mechanism supports the hypothesis that the environmental pollutants particulate matters PM2.5, CO, $O_3$ resulted in an increase in the SARS-CoV-2 cases and deaths.

### *4.1. Study strengths and limitations*

This is the first study added in literature that has investigated the effect of environmental pollution particulate matter PM2.5, CO and $O_3$ on the incidence and mortality trends of SARS-CoV-2 infection in a largest metropolitan city, London. We selected the main pollutants, PM2.5, CO and $O_3$, as these pollutants are sharp to decline deep into the lungs. The limitation of this study is that, we were unable to consider other pollutants such as PM 2.10, carbon dioxide, and weather conditions which may also affect the dynamics of the COVID-19 epidemic. Further studies are suggested to develop a comprehensive understanding of the various environmental factors involved in COVID-19 pandemic.

## 5. Conclusions

The present study results identified a relationship between environmental pollutants, particulate matter PM2.5, carbon monoxide and Ozone with number of cases and deaths due to SARS-CoV-2 infection in London, UK. These environmental pollutants act as triggering factors for the current pandemic situation. The findings have outcomes for policymakers and health officials about the impact of environmental pollution, particulate matter PM2.5 and CO on the epidemiological trends of daily new cases and deaths due to the COVID-19 pandemic. Environmental pollution management authorities must implement necessary policies and assist in planning to minimize the environmental pollution and COVID-19 pandemic both at regional and international level.

## 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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## References

Barouki, R., Kogevinas, M., Audouze, K., Belesova, K., Bergman, A., Birnbaum, L., et al., 2020. The COVID-19 pandemic and global environmental change: Emerging research needs. Environ. Int. 146,. https://doi.org/10.1016/j.envint.2020.106272 106272.

Bianconi, V., Bronzo, P., Banach, M., Sahebkar, A., Mannarino, M.R., Pirro, M., 2020. Particulate matter pollution and the COVID-19 outbreak: results from Italian regions and provinces. Arch. Med. Sci. 16, 985–992. https://doi.org/10.5114/aoms.2020.95336.

Cannon, J.B., Lefler, J.S., Blagev, D.P., Korgenski, E.K., Torosyan, N., Hansen, G.I., Kartchner, D., Pope, C.A., 2018. Short-term elevation of fine particulate matter air pollution and acute lower respiratory infection. Am. J. Respir. Crit. Care Med. 198, 759–766.

Croft, D.P., Zhang, W., Lin, S., Thurston, S.W., Hopke, P.K., Masiol, M., Thevenet-Morrison, K., Van Wijngaarden, E., Utell, M., Rich, D., 2018. The association between respiratory infection and air pollution in the setting of air quality policy and economic change. Ann. Am. Thorac. Soc. 16, 321–330.

Croft, D.P., Zhang, W., Lin, S., Thurston, S.W., Hopke, P.K., van Wijngaarden, E., Squizzato, S., Masiol, M., Utell, M.J., Rich, D.Q., 2020. Associations between Source-Specific Particulate Matter and Respiratory Infections in New York State Adults. Environ. Sci. Technol. 54, 975–984.

Frontera, A., Cianfanelli, L., Vlachos, K., Landoni, G., Cremona, G., 2020. Severe air pollution links to higher mortality in COVID-19 patients: The "double-hit" hypothesis. J. Infect. 81, 255–259.

Gandini, M., Scarinzi, C., Bande, S., Berti, G., Carna, P., Ciancarella, L., Costa, G., Demaria, M., Ghigo, S., Piersanti, A., Rowinski, M., 2018. Long term effect of air pollution on incident hospital admissions: Results from the Italian Longitudinal Study within LIFE MED HISS project. Environ. Int. 121, 1087–1097.

In 't Veen, J.C.C.M., Kappen, J.H., van Schayck, O.C.P., 2020. Luchtverontreiniging: een determinant voor COVID-19? [Air pollution: a determinant for COVID-19?]. Ned Tijdschr Geneeskd. 164, D5153.

Jeong, C.H., Wang, J.M., Hilker, N., Debosz, J., Sofowote, U., Su, Y., Noble, M., Healy, R. M., Munoz, T., Dabek-Zlotorzynska, E., Celo, V., 2019. Temporal and spatial variability of traffic-related PM2.5 sources: comparison of exhaust and non-exhaust emissions. Atmos. Environ. 198, 55–69.

Kan, H.D., Chen, B.H., Fu, C.W., Yu, S.Z., Mu, L.N., 2005. Relationship between ambient air pollution and daily mortality of SARS in Beijing. Biomed. Environ. Sci. 18, 1–4.

Leikauf, G.D., Kim, S.H., Jang, A.S., 2020. Mechanisms of ultrafine particle-induced respiratory health effects. Exp. Mol. Med. 52, 329–337.

Liu, S., Li, M., 2020. Ambient air pollutants and their effect on COVID-19 mortality in the United States of America. Rev Panam Salud Publica. 44, e159. 10.26633/RPSP.2020.159.

Lolli, S., Chen, Y.C., Wang, S.H., Vivone, G., 2020 Oct 1. Impact of meteorological conditions and air pollution on COVID-19 pandemic transmission in Italy. Sci. Rep. 10 (1), 16213. https://doi.org/10.1038/s41598-020-73197-8.

London Data store. Available at: https://data.london.gov.uk/dataset/coronavirus–covid-19–cases. Cited date, Nov 30, 2020

Lerch, Mathias, 2020. International migration and city growth in the global south: an analysis of IPUMS data for seven countries, 1992–2013. Popul. Dev. Rev. 46 (3), 557–582.

Meo, S.A., Abukhalaf, A.A., Alomar, A.A., Alessa, O.M., 2020a. Wildfire and COVID-19 pandemic: effect of environmental pollution PM2.5 and carbon monoxide on the dynamics of daily cases and deaths due to SARS-CoV-2 infection in San-Francisco USA. Eur. Rev. Med. Pharmacol. Sci. 24 (19), 10286-10292. 10.26355/eurrev_202010_23253.

Meo, S.A., Abukhalaf, A.A., Alomar, A.A., Al-Beeshi, I.Z., Alhowikan, A., Shafi, K.M., Meo, A.S., Usmani, A.M., Akram, J., 2020b. Climate and COVID-19 pandemic: effect of heat and humidity on the incidence and mortality in world's top ten hottest and top ten coldest countries. Eur. Rev. Med. Pharmacol. Sci. 24, 8232-8238.

Meo, S.A., Aldeghaither, M., Alnaeem, K.A., Alabdullatif, F.S., Alzamil, A.F., Alshunaifi, A.I., Alfayez, A.S., Almahmoud, M., Meo, A.S., El-Mubarak, A.H., 2019c. Effect of motor vehicle pollution on lung function, fractional exhaled nitric oxide and cognitive function among school adolescents. Eur. Rev. Med. Pharmacol. Sci. 23, 8678-8686. 10.26355/eurrev_201910_19185.

Meo, S.A., Suraya, F., 2015d. Effect of environmental air pollution on cardiovascular diseases. Eur. Rev. Med. Pharmacol. Sci. 19 (24), 4890–4897.

Meo, S.A., Al-Khlaiwi, T., Abukhalaf, A.A., Alomar, A.A., Alessa, O.M., Almutairi, F.J., Alasbali, M.M., 2020e. The nexus between workplace exposure for wood, welding, motor mechanic, and oil refinery workers and the prevalence of prediabetes and type 2 diabetes mellitus. Int. J. Environ. Res. Public Health 17, 3992. 10.3390/ijerph17113992.

Meo, S.A., Abukhalaf, A.A., Alomar, A.A., Alessa, O.M., Sami, W., Klonoff, D.C., 2020f. Effect of environmental pollutants PM 2.5, carbon monoxide, and ozone on the incidence and mortality of SARS-COV-2 infection in wildfire affected ten counties in California. Sci. Total Environ. 143948. doi.org/10.1016/j.scitotenv.2020.143948

Meo, S.A., Abukhalaf, A.A., Alomar, A.A., Alsalame, N.M., Al-Khlaiwi, T., Usmani, A.M., 2020g. Effect of temperature and humidity on the dynamics of daily new cases and deaths due to COVID-19 outbreak in Gulf countries in Middle East Region. Eur. Rev. Med. Pharmacol. Sci. 24, 7524-7533.

Meo, S.A., Abukhalaf, A.A., Alomar, A.A., Sumaya, O.Y., Sami, W., Shafi, K.M., Meo, A. S., Usmani, A.M., Akram, J., 2020h. Effect of heat and humidity on the incidence and mortality due to COVID-19 pandemic in European countries. Eur. Rev. Med. Pharmacol. Sci. 24, 9216–9225.

Pandey, V.C., Singh, V., 2019. Exploring the potential and opportunities of current tools for removal of hazardous materials from environments. Phytomanage. Polluted Sites, 501–516.

Pozzer, A., Dominici, F., Haines, A., Witt, C., Münzel, T., Lelieveld, J., 2020. Regional and global contributions of air pollution to risk of death from COVID-19. Cardiovasc. Res. 116 (14), 2247–2253. https://doi.org/10.1093/cvr/cvaa288.

Razzaq, A., Sharif, A., Aziz, N., Irfan, M., Jermsittiparsert, K., 2020. Asymmetric link between environmental pollution and COVID-19 in the top ten affected states of US: A novel estimations from quantile-on-quantile approach. Environ. Res. 191,. https://doi.org/10.1016/j.envres.2020.110189 110189.

Schraufnagel, D.E., Balmes, J.R., Cowl, C.T., De Matteis, S., Jung, S.H., Mortimer, K., Perez-Padilla, R., Rice, M.B., Riojas-Rodriguez, H., Sood, A., Thurston, G.D., To, T., Vanker, A., Wuebbles, D.J., 2019. Air pollution and noncommunicable diseases: a review by the forum of international respiratory societies' environmental committee, Part 2: air pollution and organ systems. Chest 155, 417–426.

Setti, L., Passarini, F., de-Gennaro, G., Di Gilio, A., Palmisani, J., Buono, P., Fornari, G., Perrone, M.G., Piazzalunga, A., Barbieri, P., 2020. Evaluation of the Potential Relationship between Particulate Matter (PM) Pollution and COVID-19 Infection Spread in Italy. BMJ Open 2020;10:e039338. https://doi.org/10.1136/bmjopen-2020-039338

Comunian, Silvia, Dongo, Dario, Milani, Chiara, Palestini, Paola, 2020. Air pollution and COVID-19: the role of particulate matter in the spread and increase of COVID-19's morbidity and mortality. Int. J. Environ. Res. Public Health 17 (12), 4487. https://doi.org/10.3390/ijerph17124487.

U.S. Environmental Protection Agency (EPA). Air Sensor Guidebook.Available: https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=519616. Cited date Nov 12, 2020.

World Health Organization (WHO). Available at: https://covid19.who.int/. Cited date Dec 4, 2020.

Zhou, F., Yu, T., Du, R., Fan, G., Liu, Y., Liu, Z., Xiang, J., Wang, Y., Song, B., Gu, X., Guan, L., Wei, Y., Li, H., Wu, X., Xu, J., Tu, S., Zhang, Y., Chen, H., Cao, B., 2020. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet 395, 1054–1062.

Zhu, Y., Xie, J., Huang, F., Cao, L., 2020. Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. Sci. Total Environ. 727, 138704.