Environmental Research 187 (2020) 109652

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Correlation between environmental pollution indicators and COVID-19 pandemic: A brief study in Californian context

Muhammad Farhan Bashir[a], Ben Jiang MA[a], Bilal[b,*], Bushra Komal[c], Muhammad Adnan Bashir[d], Taimoor Hassan Farooq[g], Najaf Iqbal[f,h], Madiha Bashir[e]

[a] School of Business, Central South University, Changsha, 410083, Hunan, China
[b] Accounting School, Hubei University of Economics, Wuhan, China
[c] Business School, University of International Business and Economics, Beijing, China
[d] School of Economics, Nankai University, Tianjin, China
[e] Education Department, Government of The Punjab, Pakistan
[f] Hunan University of Arts and Science, Changde, China
[g] Central South University of Forestry and Technology, Changsha, 410083, Hunan, China
[h] Wuhan University of Technology, Wuhan, China

ARTICLE INFO

Keywords:
COVID-19
Environmental pollution
California
PM 2.5
PM 10

ABSTRACT

In December 2019, the novel coronavirus COVID-19 outbreak was first detected in Wuhan Hubei province, China. The April 24, 2020, the Centers for Disease Control and Preventions (CDC) has confirmed more than 39,000 cases, including > 1800 deaths. California's Governor Gavin Newsom ordered mandatory stay at home after World Health Organization (WHO) declared COVID-19 as a global pandemic in early March. We have evaluated the correlation between environmental pollution determinants and the COVID-19 outbreak in California by using the secondary published data from the Centers for Disease Control and the Environmental Pollution Agency (EPA). We employed Spearman and Kendall correlation tests to analyze the association of PM 2.5, PM 10, SO_2, NO_2, Pb, VOC, and CO with COVID-19 cases in California. Our findings indicate that environmental pollutants such as PM10, PM2.5, SO_2, NO_2, and CO have a significant correlation with the COVID-19 epidemic in California. Overall, our study is a useful supplement to encourage regulatory bodies to promote changes in environmental policies as pollution source control can reduce the harmful effects of environmental pollutants.

1. Introduction

Coronaviruses (CoVs) consist of several viruses that transfer from animals to humans. The novel coronavirus (COVID-19) is the third coronavirus to be declared as a pandemic in 21st century after Severe Acute Respiratory Syndrome (SARS) and the Middle East Respiratory Syndrome coronavirus (MERS) also achieved similar status in 2003 and 2012 respectively (Ramadan and Shaib, 2019; Zhong et al., 2003). On December 31, 2019, the World Health Organization (WHO) country office in Wuhan reported symptoms of patients suffering from unexplained low respiratory infections. It was initially declared as 'pneumonia of unknown etiology because of the limited information available about the cause of the disease. On January 12, 2020, WHO announced that infection in Wuhan belongs to coronaviruses, and on February 11, 2020, it was declared as COVID-19 (Cascella et al., 2020). COVID-19 comprises of 65 nm - 125 nm in diameter and is a single-stranded RNA as nuclei material (Shereen et al., 2020). Moreover, WHO has declared COVID-19 as a global pandemic due to its widespread transmission, a significant number of deaths, and higher infections and mortality rate as compared to previous coronaviruses outbreaks.

On March 11, Director-General of WHO briefed media outlets regarding COVID-19's spread in 114 countries and total confirmed infected and deaths were 118,000 and 4291 to date respectively (Bashir et al., 2020). In the USA, the first infected person has been reported in Washington state, and the lack of coordinated efforts at state and federal levels resulted in widespread outbreak with the USA having the most number of infected people and deaths (Dong et al., 2020). As of April 22, 2020, the Centers for Disease Control has reported 826,024 confirmed patients and 45, 365 deaths in the USA. In response to the COVID-19 outbreak, the federal government introduced precautionary measures such as public gatherings, travel restrictions, the mandatory 14-day quarantine period for suspected patients. The CDC has also

* Corresponding author. Accounting School, Hubei University of Economics, China.
E-mail addresses: bilal@hbue.edu.cn, bilalsharif313@gmail.com (Bilal).

https://doi.org/10.1016/j.envres.2020.109652
Received 23 April 2020; Received in revised form 5 May 2020; Accepted 6 May 2020
Available online 13 May 2020
0013-9351/

directed American citizens to maintain social distancing and advised the general public to wear face masks and use personal protective equipment. Later on, observing looming crises, states across America declared mandatory lockdowns and enforced stricter rules to combat the COVID-19 pandemic (Piguillem and Shi, 2020). Although research teams are sparing no effort in finding the cure for COVID-19 to date, unfortunately, little or no success has been achieved, and "social distancing" is the only way to fight this novel disease (Shereen et al., 2020).

California is one of the most affected states (Fig. 1) in the USA, which reported case on March 4 and currently has fifth-most infected patients. One of the primary reasons for such high infection ratio is low air quality, GHG emissions and environmental pollutants, which makes Californians more susceptible to infectious diseases such as COVID-19. As of April 24, 2020, California Department for Public Health has confirmed more than 39,000 cases, including > 1800 deaths in California State (Fig. 2).

Implementation of lockdown restrictions adopted by states and the federal government has resulted in economic activities such as industrial projects, construction projects, and transportations observing the stagnant phase (Greenstone and Nigam, 2020). Although COVID-19 will carry severe economic impact, the other side of the coin may lessen some of the COVID-19's unfortunate facts. As states are following social distancing and quarantine for more than a month, reduced human interference in the natural environment has given nature a "healing time." One significant impact being observed is on air quality, which is being experienced by everyone and recorded in various official reports. Smog has given way to blue skies, there are increased activities in marine life, and pollution level in metropolitan cities has decreased significantly. These positive impacts have allowed us to reconsider our impact on the surroundings of us, and the situation today is a "reset" for nature and humans, giving us a prospect to observe and analyze the human impact over the environment (Parodi and Liu, 2020). Thus, we infer that quarantine measures have improved air quality in the USA; therefore, motivating us to examine the air quality and impact of environmental pollutants' association with COVID-19 in California.

2. Environmental quality in California

During the last three decades, the state of California has witnessed exponential growth in investments, which has improved the living standards of its people and a higher vehicular fleet on the road is evident in fact. However, the Californians have paid the high cost of these developments due to continuous deteriorating air quality in the state. California, according to one of the recent reports from the CDC, has the worst air quality in the USA. Furthermore, ten[1] of the top-25 most polluted cities in America belong to California, and which despite several environmental initiatives from California state officials shows the severity of environmental pollution in California. According to WHO press release, annually seven million die due to exposure from fine particles in the polluted air (WHO, 2019) and Centers for Disease Control estimates that around 360,000 people die in the USA alone due to pollution.

California (32°32′N to 42°N, 114°8′ W to 124°26′W) has adverse environmental issues mainly due to economic activities as it has a gross state product of $3 trillion, the fifth-largest economy in the world (larger than UK, India, or France). The implementation of mandatory lockdown in California to prevent COVID-19 transmission has resulted in a drastic reduction of environmental pollution up to 60% in California (Parodi and Xiu, 2020). Similar executive actions taken by governments across the world have negative bearings on the economy, but air quality has drastically improved because of these actions (McKibbin and Fernando, 2020).

3. Environmental pollution standards in California

As mentioned earlier, environmental pollution is one of the primary environmental issues in California, and according to the Environmental Pollution Agency, average micrograms per cubic meter emission in California is 12.8, which is 50% higher than the national emission average of 8.4. Environmental pollution in California has worsened in recent years, as at some point, 90% of Californians inhale more than one pollutant every year. As a result, the California Air Resources Board (CARB) has introduced health-based legislation, especially for elderly and children, to limit the pollutant emission in the state. Currently, the Environmental Pollution Agency considers emissions of PM2.5, PM10, nitrogen oxides, carbon monoxide, Sulfur oxide and Ozone as "criteria" pollutants to safeguard the environment. On the other hand, the CARB has introduced further environmental reforms to record emissions of Lead, Vinyl Chloride, Visibility Reducing Particles and Hydrogen Sulfide as four additional pollutants to protect the environment.

Furthermore, the CARB has also made it mandatory to reduce environmental pollutants emissions in California, which causes medical issues, i.e., tuberculosis and cancer, among others as repeated exposure to these pollutants increases not only serious health issues but also harms human life expectancy. Currently, environmental measures have been adopted to regulate 200 environmental pollutants to reduce their emissions into the atmosphere to assess the effectiveness of CARB initiatives. Additionally, environmental agencies encourage cooperation among different regions of California state to limit emissions of environmental pollutants from all sources.

4. Research methodology

California state is cultural, media, and the innovation centre of the world and is also the most populated state with 39.5 million people, highest for any state in the USA. The dataset in the current research project is taken from March 4, 2020, to April 24, 2020, to examine the impact of environmental pollutants in California. The dataset of environmental pollution indicators such as PM 10, PM 2.5, Sulfur dioxide (SO_2), Volatile organic compounds (VOC), Carbon monoxide (CO), Nitrogen dioxide (NO_2) and Lead (Pb) was taken from Environmental Pollution Agency (EPA). Data for COVID-19 cases and mortality is collected from the California Department of Public Health (CDPH). As the dataset for the current research project was not normally distributed; hence we have used Spearman and Kendall correlation tests as an empirical methodology to observe environmental pollutants' correlation with COVID-19 in California.

5. Results and discussion

Table 1 provides the empirical estimations of environmental pollutants' association with COVID-19 in California. We find that PM 10, PM 2.5, SO_2, CO, and NO_2 have a significant correlation for total cases and total mortality in the state in both Spearman and Kendall correlation. However, the magnitude of correlation coefficients of PM 10, PM 2.5, SO_2, Pb, and NO_2 are higher in the Spearman correlation test. Our findings show that environmental pollutants are significantly correlated with COVID-19 cases and deaths in California.

Wu et al. (2020) analyzed the impact of fine particulate matter and suggested that only 1 μg/m^3 in $PM_{2.5}$ is associated with a 15% increase in the COVID-19 death rate. Yao et al. (2020) empirically analyzed the death rate of COVID-19 and spatial correlation of PM10 and PM2.5 in China by using multiple linear regression and suggested that higher concentration of PM10 and PM2.5 has a positive correlation with deaths caused by COVID-19. Furthermore, the researchers suggested that pollution caused by the Particulate Matter influences the prognosis

[1] Top ten most polluted cities in California are Los Angeles, Visalia, Bakersfield, Fresno, Sacramento, San Diego, San Jose, Redding, El Centro, Chico.

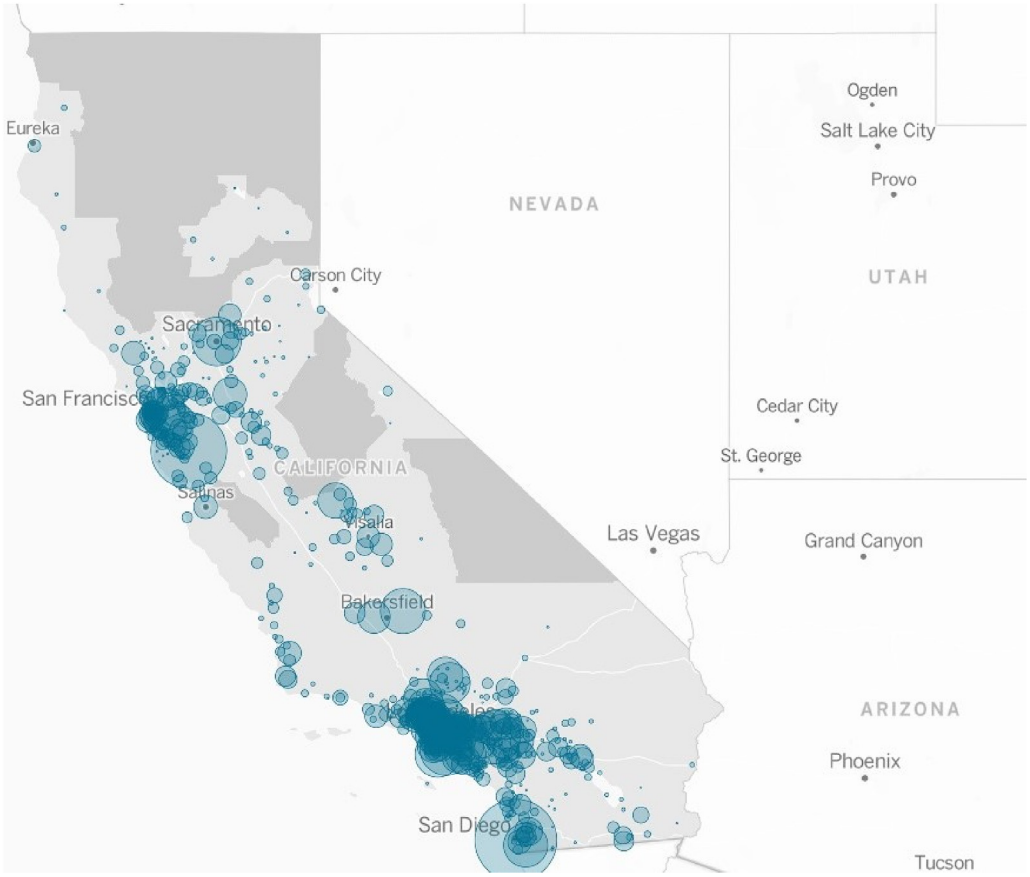

Fig. 1. COVID-19 outbreak in California, USA (Source: California Department of Public Health).

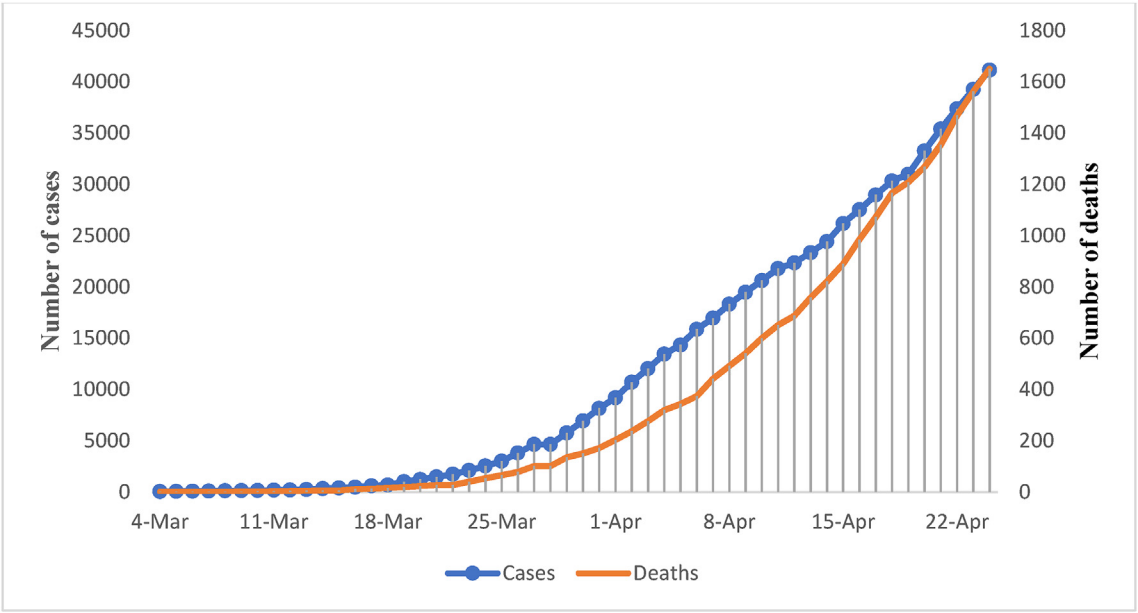

Fig. 2. Total cases and deaths from COVID-19 in California.

of the patients. Fattorini and Regoli (2020) analyzed the association of air quality and COVID-19 outbreak in Italy. They concluded that continuous exposure to environmental pollution (PM10 and PM2.5) in Northern Italy is the primary cause of COVID-19 cases. Similarly, Wang et al. (2020), Piazzalunga Expert (2020), and Sharma et al. (2020) for the case of China, Italy, and India supported similar findings.

Due to scientific research, there is growing evidence that links chronic illnesses to environmental pollution, especially in urban areas. Therefore, monitoring the concentration of pollutants such as NO_2 and SO_2 has become quite important, in particular, because policy decisions in many countries to reduce environmental pollutants are linked to dangers associated with human health for children and HR values for SPM and NO_2 are 16.13 and 22.11 times higher than SO_2. Wu et al. (2020) analyzed the SO_2 exposure in Beijing and concluded that

Table 1
Empirical results.

	Pollutants	Cases	Mortality
Kendall Correlation Coefficient	PM 10	−0.287**	−0.267**
	PM 2.5	−0.359***	−0.339***
	SO_2	−0.333***	−0.309**
	CO	0.045**	0.079**
	VOC	0.044	0.032
	Pb	0.109	0.109
	NO_2	−0.514***	−0.485***
Spearman Correlation Coefficient	PM 10	−0.375**	−0.350**
	PM 2.5	−0.453***	−0.429***
	SO_2	−0.426***	−0.397**
	CO	0.083	0.123
	VOC	0.054	0.038
	Pb	0.178**	0.174**
	NO_2	−0.736***	−0.731***

***, ** * signifies shows significance at 10%, 5% and 1%.

environmental pollutants have resulted in 27,854 outpatient cases and loss of 477 million RMB in 2016 alone. Xue et al. (2020) investigated Spatio-temporal variations of Sulfur dioxide (SO_2) and Nitrogen dioxide (NO_2) in Shanghai and surrounding areas and concluded that better urban planning and application of strict emission control policy has led to lower the concentration of NO_2 and SO_2 in Shanghai.

Bernardini et al. (2020) inspected the association of environmental pollutants such as carbon monoxide Ozone, PM, and NO_2 on daily admissions into emergency facilities in regional hospitals of Umbria (Italy). According to empirical findings, 1860 patients were admitted into emergency facilities, and the coefficient of O_3 is significant at 1%, while other pollutants are insignificant and concluded that these pollutants have a significant impact on hospital admissions. Likewise, Ha (2020) and Adach et al. (2020) observed similar findings. Lead (Pb) has harmful bearings on the physiological conditions of humans and animals alike as exposure to lead results in weakness, anemia, brain, and kidney damage. Levin et al. (2020) explored the impact of Lead (Pb) and VOC (volatile organic compounds) over human health and the earth's atmosphere. They concluded that global warming is the key determinant of exacerbating Pb toxicity and implementing scientific and sustainable policies will contribute to protecting the environment. Sankhla et al. (2017) explored the impact of Pb, Zn, Cd, and Fe to conclude that human exposure to Lead and similar metals can result in cognitive and behavioural deficits and generate toxic effects on human organs, causing long-term health damage. Anyanwu et al. (2018) arrived at similar findings and stated that to achieve industrialization, developing countries set aside concerns about environmental safety and adopt state policies that contribute to pollution and contamination linked with Lead and volatile organic compounds.

The current research project, despite showing a strong correlation between environmental pollution indicators' and COVID-19 pandemic in California, has the following limitations. First, the current study only accounts for California, where data variability can be accurately measured. We have not accounted for socio-economic indicators; future studies can research in this direction. Secondly, the inclusion of datasets about social distancing and personal hygiene would be an interesting research contribution.

6. Conclusion and policy implications

The effectiveness of mandatory lockdown measures to combat COVID-19 since McKibbin and Fernando (2020) was analyzed by studying the concentration of seven environmental pollutants in California state from March 4, 2020, to April 24, 2020. Reduction in economic activities, less road traffic, and statewide mandatory “stay at home orders” have contributed to lower environmental pollutant emissions. This study finds that PM2.5, PM 10, Nitrogen dioxide, Carbon Monoxide and Sulfur dioxide are significantly correlated with COVID-19 cases in California, and limited human exposure to these pollutants will contribute to defeating COVID-19. Similarly, the significance of PM 2.5 and PM10 suggests that the adoption of green environmental policies should be further promoted as it would shield human life, especially children and the elderly as they are most vulnerable to the outbreak of infectious diseases. As our findings indicate that particulate matter (PM2.5, PM 10) are the major pollutants in California, therefore we suggest that policies about air quality assessment must include transportation of air masses from manufacturing areas. Also, future studies must assess the environmental impact of NO_2, Ozone, and volatile organic compounds. Lastly, as meteorological conditions are of eminent standing, a comprehensive evaluation must be conducted to analyze its association with the outbreak of infectious diseases, i.e., COVID-19.

Author contribution statement

Muhammad Farhan Bashir: Data Curation, writing-original draft, software, Ben-Jiang MA: Resources, Bilal: Conceptualization, software, Bushra Komal: Writing- review & editing, Muhammad Adnan Bashir: Project administration, Madiha Bashir: Funding acquisition, Najaf Iqbal: Validation, Taimoor Hassan Farooq: Writing- revision & editing.

Declaration of competing interest

We certify that the manuscript titled.

“ **Correlation between environmental pollution indicators and COVID-19 pandemic: A brief study in Californian context**” (hereinafter referred to as ‘the Paper’) has been entirely our original work except otherwise indicated and it does not infringe the copyright of any third party.

The submission of the Paper to Environmental Research implies that the Paper has not been published previously (except in the form of an abstract or as a part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and that, if accepted, will not be published elsewhere in the same form, in English or any other language, without the written consent of the Publisher.

Acknowledgements

The authors would like to appreciate the valuable comments from the editors and anonymous reviewers to improve the quality of this viewpoint. The authors also acknowledge the financial support of the Mobile Health Ministry of Education- China Mobile Joint Laboratory Grant Number: 2020MHL02005.

References

Adach, W., Błaszczyk, M., Olas, B., 2020. Carbon Monoxide and its Donors-Chemical and Biological Properties. Chemico-Biological Interactions, pp. 108973.
Anyanwu, B.O., Ezejiofor, A.N., Igweze, Z.N., Orisakwe, O.E., 2018. Heavy metal mixture exposure and effects in developing nations: an update. Toxics 6 (4), 65.
Bashir, M.F., Ma, B., Bilal Komal, B., Bashir, M.A., Tan, D., Bashir, M., 2020. Correlation between climate indicators and COVID-19 pandemic in New York, USA. Sci. Total Environ. 728, 138835. https://doi.org/10.1016/j.scitotenv.2020.138835.
Bernardini, F., Attademo, L., Trezzi, R., Gobbicchi, C., Balducci, P., Del Bello, V., Menculini, G., Pauselli, L., Piselli, M., Sciarma, T., Moreti, P., Tamantini, A., QuartesanR, Compton, M.T., Sciarma, T., 2020. Air pollutants and daily number of admissions to psychiatric emergency services: evidence for detrimental mental health effects of Ozone. Epidemiol. Psychiatr. Sci. 29.
Cascella, M., Rajnik, M., Cuomo, A., Dulebohn, S.C., Di Napoli, R., 2020. Features, Evaluation and Treatment Coronavirus (COVID-19) StatPearls [Internet]. StatPearls Publishing.
Dong, E., Du, H., Gardner, L., 2020. An interactive web-based dashboard to track COVID-19 in real time. The Lancet Infectious Diseases.
Fattorini, D., Regoli, F., 2020. Role of the Atmospheric Pollution in the Covid-19 Outbreak Risk in Italy. medRxiv.
Greenstone, M., Nigam, V., 2020. Does Social Distancing Matter? University of Chicago,

Becker Friedman Institute for Economics Working Paper 2020-26.
Ha, E., 2020. Impact of Air Pollution Hazards on Human Development Health Impacts of Developmental Exposure to Environmental Chemicals. Springer, pp. 223–245.
Levin, R., Vieira, C.L.Z., Mordarski, D.C., Rosenbaum, M.H., 2020. Lead seasonality in humans, animals, and the natural environment. Environ. Res. 180, 108797.
McKibbin, W.J., Fernando, R., 2020. The Global Macroeconomic Impacts of COVID-19: Seven Scenarios. CAMA Working Paper No. 19/2020.
Organization, W.H., 2019. Global Action Plan on Physical Activity 2018-2030: More Active People for a Healthier World. World Health Organization.
Parodi, S.M., Liu, V.X., 2020. From containment to mitigation of COVID-19 in the US. J. Am. Med. Assoc. 323 (15), 1441–1442.
Piazzalunga-Expert, A., 2020. Evaluation of the Potential Relationship between Particulate Matter (PM) Pollution and COVID-19 Infection Spread in Italy.
Piguillem, F., Shi, L., 2020. The Optimal Covid-19 Quarantine and Testing Policies. EIEF Working Papers Series 2004. Einaudi Institute for Economics and Finance (EIEF) revised Apr 2020.
Ramadan, N., Shaib, H., 2019. Middle East respiratory syndrome coronavirus (MERS-CoV): a review. Germs 9 (1), 35.
Sankhla, M.S., Sharma, K., Kumar, R., 2017. Heavy metal causing neurotoxicity in human health. Int. J. Innov. Res. Sci. Eng. Technol. 6 (5).
Shereen, M.A., Khan, S., Kazmi, A., Bashir, N., Siddique, R., 2020. COVID-19 infection: origin, transmission, and characteristics of human coronaviruses. J. Adv. Res.
Wang, P., Chen, K., Zhu, S., Wang, P., Zhang, H., 2020. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resour. Conserv. Recycl. 158, 104814.
Wu, X., Nethery, R.C., Sabath, B.M., Braun, D., Dominici, F., 2020. Exposure to Air Pollution and COVID-19 Mortality in the United States. medRxiv.
Wu, Y., Li, R., Cui, L., Meng, Y., Cheng, H., Fu, H., 2020. The high-resolution estimation of sulfur dioxide (SO2) concentration, health effect and monetary costs in Beijing. Chemosphere 241, 125031.
Xue, R., Wang, S., Li, D., Zou, Z., Chan, K.L., Valks, P., Saiz-Lopez, A., Zhou, B., 2020. Spatio-temporal variations in NO2 and SO2 over Shanghai and chongming eco-island measured by Ozone monitoring instrument (OMI) during 2008–2017. J. Clean. Prod. 258, 120563.
Yao, Y., Pan, J., Wang, W., Liu, Z., Kan, H., Meng, X., Wang, W., 2020. Spatial Correlation of Particulate Matter Pollution and Death Rate of COVID-19. medRxiv.
Zhong, N.S., Zheng, B.J., Li, Y.M., Poon, L.L.M., Xie, Z.H., Chan, K.H., Li, P.H., Tan, S.Y., Chang, Q., Xie, J.P., Liu, X.Q., Xu, J., Li, D.X., Yuen, K.Y., Peiris, J.S.M., Xie, J., 2003. Epidemiology and cause of severe acute respiratory syndrome (SARS) in Guangdong, People's Republic of China, in February, 2003. Lancet 362 (9393), 1353–1358.