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Applications of Remote Sensing in the Study of COVID-19 Pandemic - A Review

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ABSTRACT: The global outbreak of the COVID-19 pandemic has spread worldwide, affecting almost all countries and territories. Various social-economic and environmental factors influence the outbreak and spread of the epidemic. Many modern techniques have been widely employed to study the COVID-19 pandemic. This paper aims to give an overview of applications offered by remote sensing techniques to study the COVID-19 pandemic through summarising a total of 55 scientific papers. Three different issues related to the COVID-19 pandemic is presented under three sub-sections; namely (1) applications of remotely sensed images on monitoring environmental changes and (2) the analysis of social and economic impacts caused by the COVID-19 pandemic, and (3) the use of remote sensing in studies of the epidemiology of SARS-CoV-2. The findings of this study provide important insights into how to apply such an advanced techniques as remote sensing in the fight against the COVID-19 pandemic. The varied applications of remote sensing affirms the value of this advanced technique to the study of small-to-large scale disasters in general and of the COVID-19 pandemic in particular.

KEYWORDS: Applications, Remote Sensing, Landsat Images, the COVID-19 Pandemic, Review.

1. INTRODUCTION

In December 2019, an outbreak of pneumonia epidemiologically linked to the Huanan Seafood Wholesale Market was reported in Wuhan, Hubei Province, China (1). Based on phylogeny, taxonomy, and established practice, the Coronavirus Study Group of the International Committee on Taxonomy of Viruses named this type of pneumonia as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (2). The global spread of SARS-CoV-2 and the thousands of deaths caused by the 2019 coronavirus disease (COVID-19) led the World Health Organization (WHO) to declare a global pandemic on 12 March 2020 (1). Later, on January 30, 2020, the WHO declared the COVID-19 outbreak as the sixth public health emergency of international concern; therefore, this outbreak constitutes a public health risk through the international spread of disease and requires a coordinated international response (2). The global pandemic of COVID-19 has been reported as a social, human, and economic crisis (3). To date, the world has paid a high toll in this pandemic in terms of human lives lost, economic repercussions and increased poverty (1). Globally, as of 28 June 2023, data from the WHO revealed that there have been 767,518,723 confirmed cases of COVID-19, including 6,947,192 deaths (4). It is, therefore, an advanced technique as remote sensing in the study of COVID-19 pandemic plays an important role in the fight against the COVID-19 pandemic.Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Remote sensing allows acquiring information about the Earth's surface without actually being in contact with it (5). Satellite remote sensing data was used widely by government, humanitarian, and private bodies during the pandemic (6). The information derived from remote sensing imagery has been widely utilized in contexts like sustainable development (7–9), disaster management (10,11), environmental degradation (12–14), natural resource management (15–18) , and climage change studies (19–21). It is also commonly used in the development processes like soil (22,23), forestry (24,25), geology (26,27), and agriculture (28,29). Recent years, the applications of remote sensing data to studies of human health (30,31), especially in infectious disease research have been also reviewed (31). A recent study has revealed that a small number of investigators in the health community have explored remotely sensed environmental factors that might be associated with disease-vector habitats and human transmission risk (30). However, most human health studies using remote sensing data have focused on data from Landsat's Multispectral Scanner (MSS) and Thematic Mapper (TM), the National Oceanic and Atmospheric Administration (NOAA)'s Advanced Very High Resolution Radiometer (AVHRR) (30). The applications of collection 1 imagery from the Operational Land Imager (OLI) and Thermal InfraRed Sensor (TIRS) on board Landsat 8 and 9 remain limited.This article aims to give an overview of applications offered by remote sensing techniques on the study of COVID-19 pandemic. The content is presented under three sub-sections; namely (1) applications of remotely sensed images on monitoring environmental changes and (2) the analysis of social and economic impacts caused by the COVID-19 pandemic, and (3) the use of remote sensing in studies of the epidemiology of SARS-CoV-2.

2. MATERIALS AND METHODS

2.1. Materials

A total of 55 scientific papers colected mainly from Web of Science, SCOPUS, and Google scholar databases was used in this study. These papers were mainly published in recent years and selected based on their high number of citations.

2.2. Methods

We firstly queried Web of Science, Google Scholar, and SCOPUS databases with different combinations of keywords including ‘applications’, ‘remote sensing’, ‘Landsat images’, ‘satellite imagery’, ‘the COVID-19 pandemic’ and ‘review’ or ‘overview’. Four different sub-topics was then identified based on applications of remote sensing in the study of the COVID-19 pandemic. Based on search results, search terms were refined to get more specific results for each topic, e.g., ‘environmental changes’, ‘social and economic impacts caused by the COVID-19 pandemic’, and ‘remote sensing in the epidemiology of SARS-CoV-2’. Finally, different types of remote sensing methods and their applications in the COVID-19 studies were summarised and discussed.

3. RESULTS AND DISCUSSIONS

3.1. Monitoring environmental changes and impacts of the COVID-19 pandemic

During the COVID-19 pandemic the sudden halt of transport networks and people's activity suddenly halted led to a reduction in the various types of pollution and environmental impacts that are associated with anthropogenic activities (6). Remote sensing has been widely applied to monitoring these changes in the atmosphere, biosphere, and hydrosphere during the pandemic. When analyzing data from the Sentinel-5P and the Himawari-8 satellites to examine concentrations of NO_2, HCHO, SO_2, and CO, and the aerosol optical depth (AOD) over the BTH, Wuhan, Seoul, and Tokyo regions in February 2019 and February 2020 to investigate the impact of the coronavirus outbreak and the resulting lockdown of public venues on air pollution levels in East Asia, it was found that in many regions of East China, particularly in Wuhan, ozone production in February 2020 is less NO_X saturated during the daytime than it was in February 2019 and significant increases in surface ozone in East China from February 2019 to February 2020 are likely the result of less reaction of NO and O_3 caused by significantly reduced NO_X concentrations and less NO_X saturation in East China during the daytime (32). Using the MCD19A2v006 data product, a study has shown that lockdown events have reduced the population-weighted concentration of nitrogen dioxide and particulate matter levels by about 60% and 31% in 34 countries (33).

With the help of time-series remote sensing images, when assessing the lockdown effects on total suspended solids concentrations in the Lower Min River (China) during COVID-19, it was revealed that the decline of TSS in the lockdown period was due largely to the substantially-reduced discharges from industrial estates, densely-populated city center, and river’s shipping (34). With the aim of determining the COVID-19 pandemic consequences on the Tangier coastal environment in northern Morocco, WST sentinel-3 data has been successfully used to reveal that there was a positive impact of the COVID-19 pandemic consequences on the coastal environment quality in the study area and a decreasing the industrial discharge on the west coast of Tangier (35). Recently, using two remote sensing techniques: spectral reflectance and chromaticity analysis, an indicative analysis is adopted to understand the effect of lockdown on the changes in the water quality parameters for Lake Hussain Sagar (36). When quantifying COVID-19 enforced global changes in atmospheric pollutants using cloud computing based remote sensing, the study results showed that statistically significant reductions are observed over megacities with mean reduction by 19.74%, 7.38% and 49.9% in nitrogen dioxide (NO_2), aerosol optical depth (AOD) and $PM_{2.5}$ concentrations (37). Most recently, when assessing the effect of covid-19 lockdown on surface urban heat island for different land use /cover types using Landsat 8 OLI/TIRS images, it was found that for New Delhi, Hyderabad, and Mumbai, the mean land surface temperature decreases by 5°C, 1.9°C, and 0.26°C, respectively, in April 2020 (after lockdown) in comparison with April 2019 (38). In addition, environmental changes and impacts of the COVID-19 pandemic using remote sensing has been also successfully monitored and assessed in many COVID-19 badly-affected countries such as China (39,40), Italy (41), and India (42) etc

3.2. Assessing social and economic impacts of the COVID-19 pandemic

Since the pandemic spread globally, the economies of almost all countries were affected (43). Accordingly, attempts have been made on the study of changes and impacts of the COVID-19 pandemic on social and economic activities like changed distribution of people between urban and rural areas, loss of people's livelihoods, and changes to food supply and employment (44). For example, the economic activities can be directly obtained from high-resolution imagery such as WorldView-3 images (45). When analyzing spatial temporal traffic patterns during the COVID-19 epidemic, it was found that, vehicles during the COVID-19 epidemic could be dectected from Planet remote-sensing satellite images (46). In this study, high temporal Planet multispectral images (from November 2019 to September 2020, on average 7.1 days of frequency) were successfully utilized to detect traffic density in multiple cities. With the aim of support city-scale decision-making during COVID-19 pandemic, another study has shown that human and economic activities could be measured from satellite imagery to support city-scale decision-making during COVID-19 pandemic using a deep learning approach (44). This study also revealed that satellite imagery can support the decision-making of analysts and policymakers by providing a different kind of visibility into the unfolding economic changes during the COVID-19 pandemic (44). Using flying airplanes, economic activities for a wide range of spatial areas were successfully measured from space. This study found that drops in the number of flying aircraft over Europe could be detected from Sentinel 2 imagery (47). These social and economic activity-related data can benefit studies on the spatial variation and timing of economic impacts caused by the pandemic (6). A recent study in Western India has investigated the impact of COVID-19 lockdown on the fisheries sector (48). In (48), high-resolution PlanetScope data for monitoring and comparison of "area under fishing boats" during the pre-lockdown, lockdown, and post-lockdown phases was utilized. It was also found that during the peak of the lockdown, it was found that the "area under fishing boats" near the docks and those parked on the land area increased by 483%, 189%, and 826% at Mangrol, Veraval, and Vanakbara harbor, respectively (48). In addition, examining the economic and environmental impacts of COVID-19 using earth observation data was also carried out in Los Angeles, California; Chicago, Illinois; Washington DC from February to April 2020 (49). The preliminary analysis revealed that the reduction in mobility involved reduced economic activity (a decrease in energy consumption as measured by the radiance from the DNB data) that impacted on gross domestic product, poverty levels, and the unemployment rate (49). Although, remote sensing does not replace conventional sources like economic surveys, satellite imagery still offers the advantage of being able to measure a variety of indicators from the same data source, bypassing the complexity of integrating information from heterogeneous sources that have differing formats, spatial and temporal resolutions, and are compiled and stored by different stakeholders in different locations (6). Remote sensing has proved the effectiveness in the assessment of social and economic impacts of the COVID-19 pandemic.

3.3. Studying the epidemiology of SARS-CoV-2

Remote sensing is recognized as a tool to aid the study of the spread, distribution, and causes of diseases and other health conditions by giving spatial information about determinants of diseases, like disease vector habitats (in the case of vector-borne diseases), or meteorological conditions associated with the spread of the disease (50). It is, therefore, remotely sensed data was widely employed in the epidemiology of SARS-CoV-2 in many studies. A lots of attemps have been made on the study of propagation of COVID-19. One of the first study on the impacts of meteorological variables on the propagation of COVID-19 has discovered that the distribution of significant community outbreaks along restricted latitude, temperature, and humidity are consistent with the behavior of a seasonal respiratory virus (51). Later, when investigating the role of meteorological factors in the transmission of SARS-CoV-2 in the United States using ground-based, radar, and weather satellite data, it was indicated that cold and dry weather and low levels of ultraviolet radiation are moderately associated with increased SARS-CoV-2 transmissibility, with humidity playing the largest role. Using ERA5 hourly data (52). Another study in US cities was successfully carried out to evaluate the association between COVID-19 cases and meteorological parameters (local air temperatures, humidity, and air pressure). It was suggested that weather should be considered in infectious disease modeling efforts (53). Remotely sensed data allowed researchers to study the association of temperature and humidity and the COVID-19 transmission in Mainland China (54). The study results of (54) showed that every 1°C increase in the average temperature led to a decrease in the daily confirmed cases by 36% to 57% when average relative humidity was in the range from 67% to 85.5%. Every 1% increase in average relative humidity led to a decrease in the daily confirmed cases by 11% to 22% when average temperature was in the range from 5.04°C to 8.2°C (54). Apart from meteorological variables, the impacts of environmental variables on the propagation of COVID-19 have been also attracted much of attention. Nitrogen dioxide (NO_2) is one of the important environmental variables that mainly affects the respiratory system by increasing the risk for respiratory tract infections (6). Recent studies using remotely sensed data also revealed that exposure to NO_2 may be one of the most important environmental determinants for the spread and fatality caused by the COVID-19 disease (55). It can be seen that remote sensing techniques are was particularly useful in epidemiological studies of SARS-CoV-2.

4. CONCLUSIONS

This paper summarised applications of remote sensing techniques in the study of the COVID-19 pandemic. A total of 55 scientific papers has been discussed. Three different issues related to the COVID-19 pandemic is presented under three sub-sections including applications of remotely sensed images on monitoring environmental changes, the analysis of social and economic impacts caused by the COVID-19 pandemic, and the use of remote sensing in studies of the epidemiology of SARS-CoV-2. The results of this review indicate that remote sensing techniques have proved their effectiveness not only in monitoring environmental changes and in the assessment of social-economic and environmental impacts of the COVID-19 pandemic, but also in the study of the epidemiology of SARS-CoV-2. The findings of this study provide important insights into how to apply such advanced techniques as remote sensing in the fight against the COVID-19 pandemic. It can be concluded that remote sensing is a very useful tool in its various applications, especially in such disaster situations as the COVID-19 pandemic.

Declaration By Authors

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REFERENCES

1) Ciotti M, Ciccozzi M, Terrinoni A, Jiang W-C, Wang C-B, Bernardini S. The COVID-19 pandemic. Crit Rev Clin Lab Sci. 2020;57(6):365–88.
2) Lai C-C, Liu YH, Wang C-Y, Wang Y-H, Hsueh S-C, Yen M-Y, et al. Asymptomatic carrier state, acute respiratory disease, and pneumonia due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): Facts and myths. J Microbiol Immunol Infect. 2020;53(3):404–12.
3) Nations U. The Social Impact of COVID-19 [Internet]. 2020 [cited 2007 Mar 20]. Available from: https://www.un.org/development/desa/dspd/2020/04/social-impact-of-covid-19/
4) WHO. WHO Coronavirus (COVID-19) Dashboard [Internet]. 2023. Available from: https://covid19.who.int/
5) Kieu Q-L, Nguyen T-T, Hoang A-H. GIS and remote sensing: a review of applications to the study of the COVID-19 pandemic. Geogr Environ Sustain. 2021;14(4).
6) Louw AS, Fu J, Raut A, Zulhilmi A, Yao S, McAlinn M, et al. The role of remote sensing during a global disaster: COVID-19 pandemic as case study. Remote Sens Appl Soc Environ. 2022;27:100789.
7) Estoque RC. A review of the sustainability concept and the state of SDG monitoring using remote sensing. Remote Sens. 2020;12(11):1770.
8) Martos V, Ahmad A, Cartujo P, Ordoñez J. Ensuring agricultural sustainability through remote sensing in the era of agriculture 5.0. Appl Sci. 2021;11(13):5911.
9) Shao Z, Sumari NS, Portnov A, Ujoh F, Musakwa W, Mandela PJ. Urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data. Geo-Spatial Inf Sci. 2021;24(2):241–55.
10) Kaku K. Satellite remote sensing for disaster management support: A holistic and staged approach based on case studies in Sentinel Asia. Int J Disaster Risk Reduct. 2019;33:417–32.
11) Kucharczyk M, Hugenholtz CH. Remote sensing of natural hazard-related disasters with small drones: Global trends, biases, and research opportunities. Remote Sens Environ. 2021;264:112577.
12) Halder B, Bandyopadhyay J, Banik P. Monitoring the effect of urban development on urban heat island based on remote sensing and geo-spatial approach in Kolkata and adjacent areas, India. Sustain Cities Soc. 2021;74:103186.
13) Li J, Pei Y, Zhao S, Xiao R, Sang X, Zhang C. A review of remote sensing for environmental monitoring in China. Remote Sens. 2020;12(7):1130.
14) Shen G, Yang X, Jin Y, Xu B, Zhou Q. Remote sensing and evaluation of the wetland ecological degradation process of the Zoige Plateau Wetland in China. Ecol Indic. 2019;104:48–58.
15) Suthar MVP, Bhoite MRR, Mane MAB, Jayram MA, Mandhare P, Salvi SS. Watershed Management of Purandar Taluka by Remote Sensing and GIS: A Review. Int J Res Appl Sci Eng Technol. 2022;10(1):835–8.
16) Morales-Barquero L, Lyons MB, Phinn SR, Roelfsema CM. Trends in remote sensing accuracy assessment approaches in the context of natural resources. Remote Sens. 2019;11(19):2305.
17) Rajan Girija R, Mayappan S. Mapping of mineral resources and lithological units: A review of remote sensing techniques. Int J Image Data Fusion. 2019;10(2):79–106.
18) Tadese M, Kumar L, Koech R, Kogo BK. Mapping of land-use/land-cover changes and its dynamics in Awash River Basin using remote sensing and GIS. Remote Sens Appl Soc Environ. 2020;19:100352.
19) Hussain S, Lu L, Mubeen M, Nasim W, Karuppannan S, Fahad S, et al. Spatiotemporal variation in land use land cover in the response to local climate change using multispectral remote sensing data. Land. 2022;11(5):595.
20) Zhao J, Xie H, Ma J, Wang K. Integrated remote sensing and model approach for impact assessment of future climate change on the carbon budget of global forest ecosystems. Glob Planet Change. 2021;203:103542.
21) Avand M, Moradi H. Using machine learning models, remote sensing, and GIS to investigate the effects of changing climates and land uses on flood probability. J Hydrol. 2021;595:125663.
22) Dari J, Quintana-Seguí P, Escorihuela MJ, Stefan V, Brocca L, Morbidelli R. Detecting and mapping irrigated areas in a Mediterranean environment by using remote sensing soil moisture and a land surface model. J Hydrol. 2021;596:126129.
23) Ford TW, Quiring SM. Comparison of contemporary in situ, model, and satellite remote sensing soil moisture with a focus on drought monitoring. Water Resour Res. 2019;55(2):1565–82.
24) Li X, Chen WY, Sanesi G, Lafortezza R. Remote sensing in urban forestry: Recent applications and future directions.

Remote Sens. 2019;11(10):1144.

25) Lechner AM, Foody GM, Boyd DS. Applications in remote sensing to forest ecology and management. One Earth. 2020;2(5):405–12.
26) Peyghambari S, Zhang Y. Hyperspectral remote sensing in lithological mapping, mineral exploration, and environmental geology: an updated review. J Appl Remote Sens. 2021;15(3):31501.
27) Ahmadi H, Pekkan E. Fault-based geological lineaments extraction using remote sensing and GIS—a review. Geosciences. 2021;11(5):183.
28) Sishodia RP, Ray RL, Singh SK. Applications of remote sensing in precision agriculture: A review. Remote Sens. 2020;12(19):3136.
29) Khanal S, Kc K, Fulton JP, Shearer S, Ozkan E. Remote sensing in agriculture—accomplishments, limitations, and opportunities. Remote Sens. 2020;12(22):3783.
30) Beck LR, Lobitz BM, Wood BL. Remote sensing and human health: new sensors and new opportunities. Emerg Infect Dis. 2000;6(3):217.
31) Viana J, Santos JV, Neiva RM, Souza J, Duarte L, Teodoro AC, et al. Remote sensing in human health: A 10-year bibliometric analysis. Remote Sens. 2017;9(12):1225.
32) Ghahremanloo M, Lops Y, Choi Y, Mousavinezhad S. Impact of the COVID-19 outbreak on air pollution levels in East Asia. Sci Total Environ. 2021;754:142226.
33) Venter ZS, Aunan K, Chowdhury S, Lelieveld J. COVID-19 lockdowns cause global air pollution declines. Proc Natl Acad Sci. 2020;117(32):18984–90.
34) Xu H, Xu G, Wen X, Hu X, Wang Y. Lockdown effects on total suspended solids concentrations in the Lower Min River (China) during COVID-19 using time-series remote sensing images. Int J Appl Earth Obs Geoinf. 2021;98:102301.
35) Cherif EK, Vodopivec M, Mejjad N, Esteves da Silva JCG, Simonovič S, Boulaassal H. COVID-19 pandemic consequences on coastal water quality using WST Sentinel-3 data: case of Tangier, Morocco. Water. 2020;12(9):2638.
36) Wagh P, Sojan JM, Babu SJ, Valsala R, Bhatia S, Srivastav R. Indicative lake water quality assessment using remote sensing images-effect of COVID-19 lockdown. Water. 2021;13(1):73.
37) Singh M, Singh BB, Singh R, Upendra B, Kaur R, Gill SS, et al. Quantifying COVID-19 enforced global changes in atmospheric pollutants using cloud computing based remote sensing. Remote Sens Appl Soc Environ. 2021;22:100489.
38) Jallu SB, Shaik RU, Srivastav R, Pignatta G. Assessing the effect of COVID-19 lockdown on surface urban heat island for different land use/cover types using remote sensing. Energy Nexus. 2022;5:100056.
39) Pei Z, Han G, Ma X, Su H, Gong W. Response of major air pollutants to COVID-19 lockdowns in China. Sci Total Environ. 2020;743:140879.
40) Aral N, Bakır H. Spatiotemporal pattern of Covid-19 outbreak in Turkey. GeoJournal. 2023;88(2):1305–16.
41) Sannino A, D'Emilio M, Castellano P, Amoruso S, Boselli A. Analysis of air quality during the COVID-19 pandemic lockdown in Naples (Italy). Aerosol Air Qual Res. 2021;21(1):200381.
42) Aman MA, Salman MS, Yunus AP. COVID-19 and its impact on environment: improved pollution levels during the lockdown period–a case from Ahmedabad, India. Remote Sens Appl Soc Environ. 2020;20:100382.
43) Maital S, Barzani E. The global economic impact of COVID-19: A summary of research. Samuel Neaman Inst Natl Policy Res. 2020;2020:1–12.
44) Minetto R, Segundo MP, Rotich G, Sarkar S. Measuring human and economic activity from satellite imagery to support city-scale decision-making during covid-19 pandemic. IEEE Trans Big Data. 2020;7(1):56–68.
45) Sobue S, Hirabayashi T, Tadono T, Murakami H, Kuze A, Ishizawa J, et al. Assessment of the Impact of Environmental and Economic Activities Related to the COVID-19 Pandemic Using Earth Observation Satellite Data. J Remote Sens Soc Japan. 2020;40(4).
46) Chen Y, Qin R, Zhang G, Albanwan H. Spatial temporal analysis of traffic patterns during the COVID-19 epidemic by vehicle detection using planet remote-sensing satellite images. Remote Sens. 2021;13(2):208.
47) Segundo MP, Pinto A, Minetto R, da Silva Torres R, Sarkar S. Measuring economic activity from space: a case study using flying Airplanes and COVID-19. IEEE J Sel Top Appl Earth Obs Remote Sens. 2021;14:7213–24.
48) Avtar R, Singh D, Umarhadi DA, Yunus AP, Misra P, Desai PN, et al. Impact of COVID-19 lockdown on the fisheries sector: a case study from three harbors in Western India. Remote Sens. 2021;13(2):183.
49) Straka III W, Kondragunta S, Wei Z, Zhang H, Miller SD, Watts A. Examining the economic and environmental impacts of COVID-19 using earth observation data. Remote Sens. 2020;13(1):5.
50) Polgreen PM, Polgreen EL. Infectious diseases, weather, and climate. Clin Infect Dis. 2018;66(6):815–7.
51) Sajadi MM, Habibzadeh P, Vintzileos A, Shokouhi S, Miralles-Wilhelm F, Amoroso A. Temperature, humidity, and latitude analysis to predict potential spread and seasonality for COVID-19. Soc Sci Res Netw. 2020;
52) Ma Y, Pei S, Shaman J, Dubrow R, Chen K. Role of meteorological factors in the transmission of SARS-CoV-2 in the

United States. Nat Commun. 2021;12(1):3602.

53) Runkle JD, Sugg MM, Leeper RD, Rao Y, Matthews JL, Rennie JJ. Short-term effects of specific humidity and temperature on COVID-19 morbidity in select US cities. Sci Total Environ. 2020;740:140093.
54) Qi H, Xiao S, Shi R, Ward MP, Chen Y, Tu W, et al. COVID-19 transmission in Mainland China is associated with temperature and humidity: A time-series analysis. Sci Total Environ. 2020;728:138778.
55) Copat C, Cristaldi A, Fiore M, Grasso A, Zuccarello P, Santo Signorelli S, et al. The role of air pollution (PM and NO2) in COVID-19 spread and lethality: a systematic review. Environ Res. 2020;191:110129.