INTERNATIONAL JOURNAL OF HEALTH & MEDICAL RESEARCH

ISSN(print): 2833-213X, ISSN(online): 2833-2148

Volume 02 Issue 08 August 2023

DOI : 10.58806/ijhmr.2023.v2i8n01

Page No. 206-213

The Crucial Roles of Geospatial Techniques in the COVID-19 Fight: A Systematic Review

Thi-Quynh Nguyen[1], Huong-Giang Nguyen[2], Thi-Tuyet-Mai Nguyen[3]

[1,2,3] Faculty of Pharmacy and Nursing, East Asia University of Technology, Hanoi, Vietnam

ORCID: https://orcid.org/0009-0001-9868-4695[1]

ABSTRACT: The Corona Virus Disease 2019 (COVID-19) appeared in Wuhan, China, at the end of 2019, spreading from there across China and the whole world. Such advanced technologies as geospatial techniques have been applied to fight the rapid spread of SARS-CoV-2. This paper aims to review and synthesize the types of applications offered through geospatial techniques to help address different issues related to the fight of the COVID-19 pandemic. The content is presented under four sub-sections; namely the roles of GIS, Remote Sensing, Global Positioning System and Internet Mapping Technologies in the fight of the COVID-19 pandemic. It was found from summarising 73 scientific papers, geospatial techniques have been proven their effectiveness not only in the study of COVID-19 in general, but also in the fight of the pandemic in particular. The wide range of applications offered by geospatial techniques affirms the value of this technique to the COVID-19 fight.

KEYWORDS: Applications, Geospatial techniques, GIS, Remote Sensing, GPS, COVID-19, Review.

1. INTRODUCTION

In 2019 a respiratory disease caused by the Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) led to a pandemic that had a profound impact on global society (1,2). The COVID-19 pandemic has been described as a social, human, and economic crisis. As of 01 July 2023, a total of 768,560,728 confirmed cases of COVID-19 including 6,952,522 deaths were reported to World Health Organization (3). It is, therefore, attempts on the use of such advanced technologies as geospatial techniques are needed in fight the COVID-19 pandemic.Geospatial technologies is a term used to describe the range of modern tools contributing to the geographic mapping and analysis of the Earth and human societies (4). There are now a variety of types of geospatial technologies potentially applicable to human rights, including Geographic Information Systems (GIS), remote sensing, Global Positioning System (GPS) and Internet Mapping Technologies (5). These geospatial technologies have been widely applied in the field of management of natural resources (6), environment (7) and climate change (8). Particularly in recent years, geospatial technologies have been successfully used in studies of epidemiology (9–11) and disease (12–14).This paper aims to give an overview of four types of applications offered by geospatial technologies to help address different issues related to the COVID-19 fight. The content is presented under four sub-sections; namely the roles of GIS, Remote Sensing, Global Positioning System and Internet Mapping Technologies in the fight of the COVID-19 pandemic.

2. MATERIALS AND METHODS

2.1. Materials

In this study, a total of 73 scientific papers colected from Web of Science, SCOPUS, and Google scholar databases was used. These were mostly high impact and were mainly published in recent years after the COVID-19 outbreak.

2.2. Methods

We firstly queried Web of Science, Google Scholar, and SCOPUS databases with different combinations of keywords including ‘applications’, ‘Geospatial techniques’, ‘GIS’ or ‘Geographic Information System’, ‘remote sensing’, ‘GPS’ or ‘GNSS’, ‘COVID-19’ or ‘SARS-CoV-2’, ‘the COVID-19 pandemic’, ‘Internet mapping technologies’ or ‘WebGIS’, and ‘review’ or ‘overview’. Four different sub-topics was then identified based on applications of geospatial techniques including GIS, remote sensing, GPS and Internet mapping technologies in the study of the COVID-19 pandemic. Finally, different types of applications of geospatial techniques in the study of COVID-19 were summarised and discussed.

3. RESULTS AND DISCUSSIONS

3.1. Roles of Geographic Information Systems in the COVID-19 fight

Geographic Information Systems (GIS) is a suite of software tools for mapping and analyzing data which is georeferenced (assigned a specific location on the surface of the Earth, otherwise known as geospatial data). GIS can be used to detect geographic patterns in other data, such as disease clusters resulting from toxins, sub-optimal water access, etc. GIS tools can map and visualize the relationship between location coordinates and COVID-19 pandemic cases to map hot spots (15). For instance, to identify the spatio-temporal clustering of COVID-19 hot spots and cold spots in Vietnam using spatial statistics. The local Getis-Ord's G_i^* statistic was successfully applied to detect hotspots and coldspots of COVID-19 cases in four waves in Vietnam. The results showed that seven hotspots of COVID-19 cases in provinces were detected in areas of high population density in the north-eastern region of Vietnam (Figure 1). Also in Vietnam, the local Moran's I spatial statistic and Moran scatterplot were successfully employed to identify high-high and low-low clusters and low-high and high-low outliers of COVID-19 cases from a dataset of 10,742 locally transmitted cases in four COVID-19 waves in 63 prefecture-level cities/provinces in Vietnam (16). A Moran's I autocorrelation and spatial cluster analysis for identifying Coronavirus disease COVID-19 using GIS approach was also successfully carried out in Iraq (17). With the advantage of mapping spatial data, GIS has been widely employed to map the COVID-19 vulnerability. For instance, in Palestine, the COVID-19 vulnerability map for the West Bank was successfully developed using the combination of Analytic Hierarchy Process, GIS, multi-criteria decision analysis and some selected potential criteria including population, population density, elderly population, accommodation and food service activities, school students, chronic diseases, hospital beds, health insurance, and pharmacy (18). In India, , through geographic information system, attempts were also made to model the COVID-19 vulnerability using an integrated fuzzy multi-criteria decision-making approach, namely fuzzy-analytical hierarchy process and fuzzy-technique for order preference by similarity to ideal solution for West Bengal (19). Also with the help of GIS, the analysis of vulnerability to COVID-19 occurrence was also successfully carried out other contries such as in the United States (20), Ethiopia (21), Algeria (22), and México (23). A part from vulnerability assessment, a GIS-based spatial modeling approach was adopted to identify of risk factors contributing to COVID-19 incidence rates in Bangladesh (24), India (25) and other severely COVID-19 affected countries (25–27).

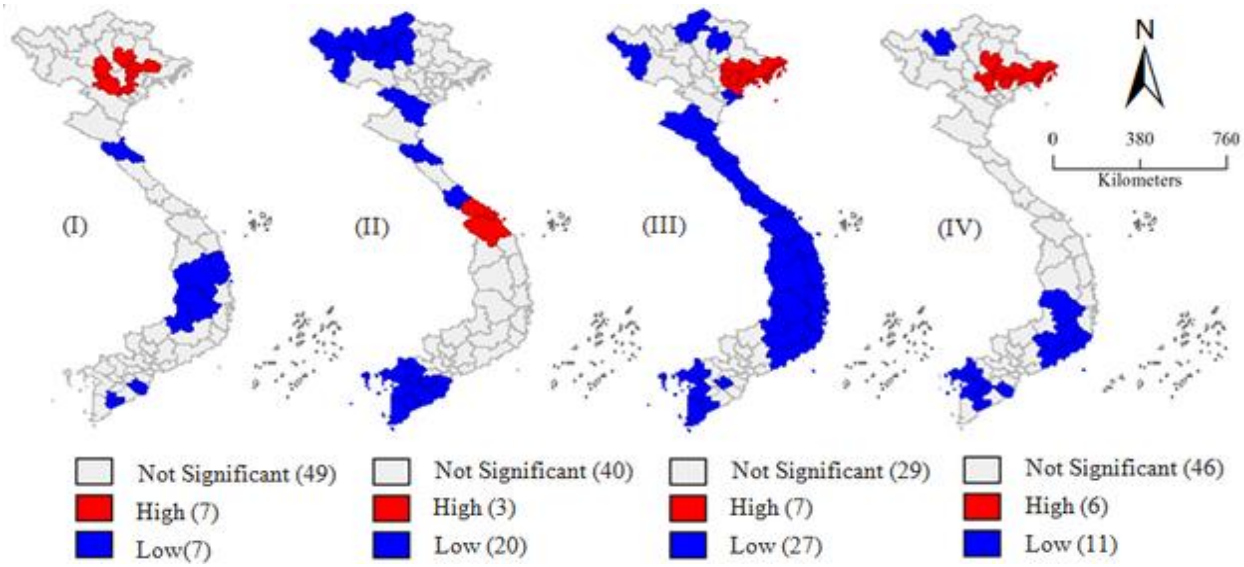

Figure 1. Hotspots and coldspots of locally transmitted cases in four COVID-19 waves in Vietnam (16).

3.2. Roles of Remote Sensing in the COVID-19 fight

Imagery and data collected from space- or airborne camera and sensor platforms. Some commercial satellite image providers now offer images showing details of one-meter or smaller, making these images appropriate for monitoring humanitarian needs and human rights abuses (5), particularly for monitoring natural resources, environment and climate change . Since the COVID-19 outbreak in Wuhan, Hubei Province, China, remote sensing techniques have been widely used to aid governments and other stakeholders in their campaigns against the COVID-19 pandemic by supplying real-time data of on-the-ground conditions to decision makers (28). A recent study of (28) has summarised the roles of remote sensing during the COVID-19 pandemic. This study revealed that remote sensing techniques have been successfully used for (i) real-time decision-making and strategic planning during the pandemic, (ii) investigating it's impacts on social-economics and environment, and (iii) the study of the epidemiology of SARS-CoV-2 (28). One of the first use of remote sensing for real-time decision-making and strategic planning is the assessment of the risk of artisanal fishers to the COVID-19 pandemic in coastal Ghana using an unmanned aerial vehicle (UAV) (29). Also using UAV, rery high-resolution images obtained from two cameras were employed to monitor to monitor social distancing and trace

COVID-19 infected suspects (30). Remote sensing provides information to support activities affected by the COVID-19 pandemic such as the use of Sentinel-2 and Sentinel-3 imagery in substituting in-situ surveys for harmful algal blooms in the ocean off the coast in Chile (31). Similar to those reported in a study (28) that remote sensing techniques have been proven their effectiveness in aiding government, private companies, humanitarian, and research organizations in their various activities during the COVID-pandemic. After the COVID-19 outbreak, remote sensing techniques have been also widely applied to assess the impacts of the COVID-19 pandemic on social-economics and environment. For instances, air pollution was successfully monitored from the space. Recent studies using remotely sensed images have shown that there was a decline in air pollutants from major cities of East Asia, Europe, and the USA (32,33). In India, when measuring the change in PM_{10} level in the Kolkata metropolitan area, it was found that the level of particulate matter (PM_{10}) has decreased during the COVID-19 induced lockdown (34). In China, PM_{10} and NO_2 obtained from remotely sensed images were also decreased rapidly from the pre-lockdown stage to the lockdown periods (Figure 2) (35). Similar findings of the improvement of environment quality during the COVID-19 induced lockdown in other contries have been also reported such as lake and surface water quality (36,37), air quality (38,39) and surface urban heat island (40).In the propagation of COVID-19, many studies revealed meteorological variables affect the spread of SARS-CoV-2 (41,42). Data on these meteorological raiables can be obtained by remote sensing techniques. It is therefore, remote sensing such as ground-based, radar, and weather satellite data has been successfully employed in epidemiological studies of COVID-19. For instance, remotely sensed data products was used to investigate the spatial variation in disease transmission rates with local air temperatures, humidity, and air pressure in the United States from NLDAS (43) and ERA5 (44) images, respectively. Also using ERA5, a study of has successfully discovered that low temperature and humidity both correlated to increased disease spread of COVID-19 (45). A part from meteorological variables, nitrogen dioxide (NO2) was proven to have effects on the respiratory system, by increasing the risk for respiratory tract infections (28). A study of (46) has 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. Additionally, a positive association between levels of NO_2 levels and subsequent prevalence of SARS-CoV-2 was also detected in northern Italy (47). These above-discussed studies has confirmed the effectiveness of remote sensing in the study of the epidemiology of SARS-CoV-2.

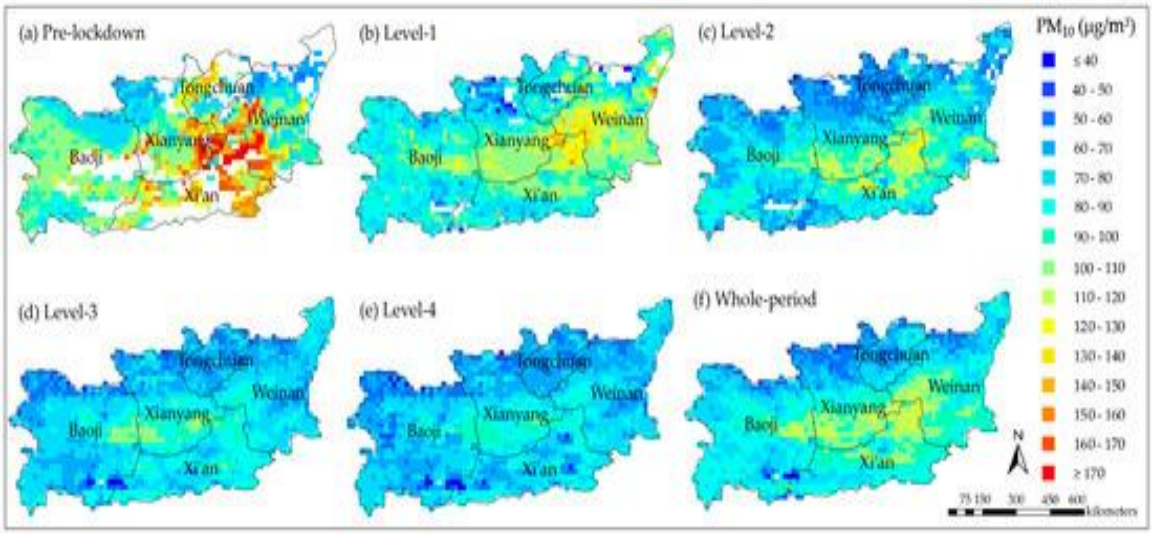

Figure 2. PM_{10} concentrations in the Guanzhong Basin before and after the COVID-19 outbreak (35).

3.3. Roles of Global Positioning System in the COVID-19 fight

Global Positioning System (GPS) is a network of U.S. Department of Defense satellites which can give precise coordinate locations to civilian and military users with proper receiving equipment. A similar European system called Galileo will be operational within the next several years while a Russian system is functioning but restricted. GPS and GIS applications can provide real-time mapping, tracking and combating COVID-19 pandemic (15). Particularly, GPS data provided by users' smartphones can be analyzed to obtain a verifiable record of individuals' human mobility patterns and help predict the future disease trajectory of COVID-19 such as the identification of hotspots and the social and environmental factors that contribute to the further spread of COVID-19 (15). One key data source has been human mobility which can be collected from geospatial global positioning system data on smartphones that can be used to support efforts to understand the transmission patterns of COVID-19 and to control the effectiveness of public health interventions like contact tracing (48–50). Specifically, GPS location data in mobile phones has been usedto inform analysis of COVID-19 pandemic epidemiology (48). GPS location-based social network data can be used to study mobility during crises during the first wave of Covid-19 outbreak and lockdown in Italy (49). GPS data collected via mobile phone apps was used for capture non-pharmaceutical interventions (50). Additionally, a GPS can be used for for contact tracing of infection chains to enhance response to the COVID-19 pandemic (51). Recently, GPS has been used to track the location and also display grid. It is used to

display to share the location of bus to the nearby hospitals and fire-services through the control room (52). GPS tracking was proposed to monitor the health conditions of the Covid-19 patients and track their real-time location via mobile application (53). Whereas, information on symptom onset and exposure history of the patients was collected by global positioning system (GPS) tracking to investigate possible points of contact or spread of COVID-19 (54). In Korea, the government used GPS records from their cellular phone or credit card records to generate a movement map which was displayed on the Web or notifications and sent to inhabitants in the relevant neighborhoods so they could take additional precaution (55). The cell phone associated with the GPS location data is collected from the COVID-19 subjects to identify COVID-19 infectious and hazardous sites and to detect disease outbreaks (56). Additionally, GPS has been also proven its effectiveness in the COVID-19 fight in other studies (57–60).

3.4. Roles of Internet Mapping Technologies in the COVID-19 fight

Internet Mapping Technologies (IMTs) are software programs like WebGIS, Google Earth Engine (GEE) platform, Google map, Baidu map and web features. These technologies are changing the way geospatial data is viewed and shared. One of the main advantages is that IMTs allow deliver up to date information on the COVID-19 pandemic. It is therefore, IMTs have been widely used in the COVID-19 fight. For instance, in response to this ongoing public health emergency, an online interactive dashboard, hosted by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University, Baltimore, MD, USA, was developed to visualise and track reported cases of coronavirus disease 2019 (COVID-19) in real time (Figure 3) (61). Web-GIS maps have been widely used for delivering public information on this fast-moving, epidemiologically complex, and geographically unbounded process (62). A WebGIS for small-scale detection and analysis of COVID-19 (SARS-CoV-2) cases based on volunteered geographic information was developed for the city of Cologne, Germany (63). When investigating geographical tracking and mapping of coronavirus disease COVID-19/SARS-CoV-2 epidemic and associated events around the world, different types of WebGIS-based mapping such as practical online/mobile GIS and mapping dashboards have been successfully used for tracking the 2019/2020 coronavirus epidemic (7). Also based on WebGIS, a visualization system for COVID-19 simulation has also been designed and developed (64). In Gemany, a Web GIS was developed for small-scale detection and analysis of COVID-19 (SARS-CoV-2) cases based on volunteered geographic information for the city of Cologne (63). In Italy, the construction of a digital cartography tool as a WebGIS to allow local communities understanding of epidemiological spread is presented (65). In India, a user interractive webgis webpage was designed for decision making and resource allocation during COVID in the Solapur City, Maharashtra, India (66).

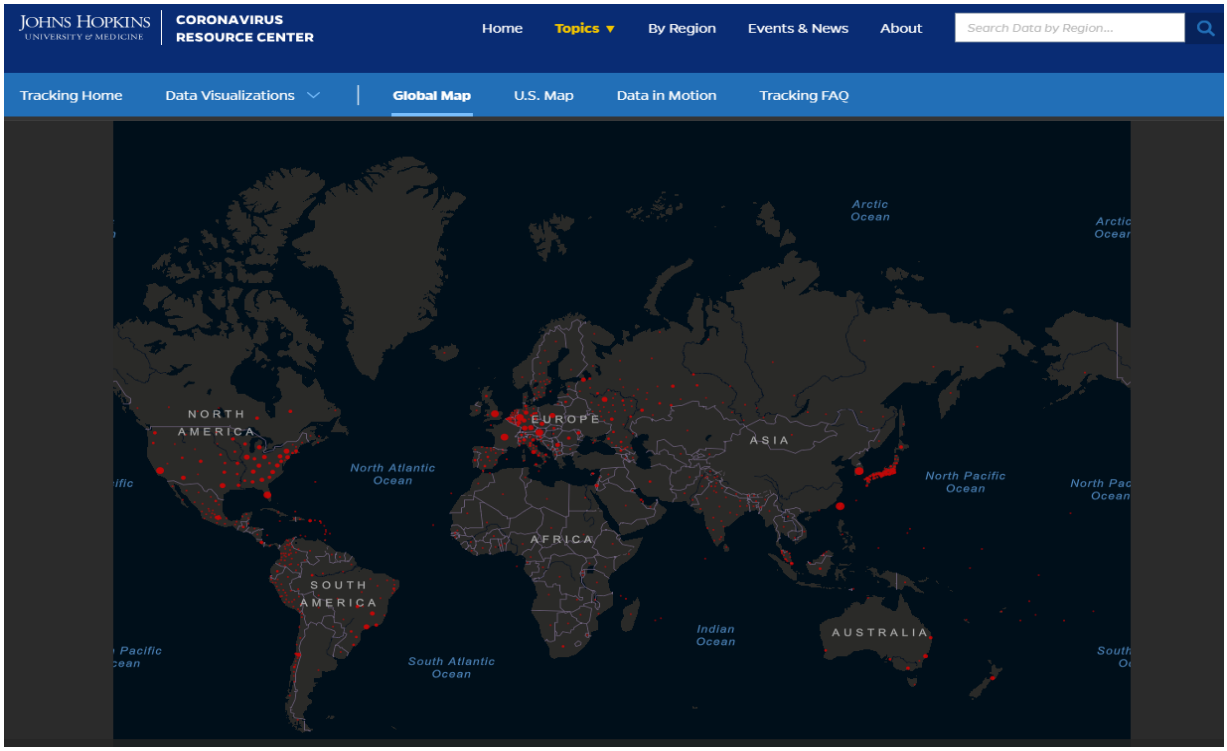

Figure 3. Johns Hopkins' coronavirus-tracking map.

A part from WebGIS, other IMTs have been also widely in the COVID-19 fight such as Google Earth Engine platform, Google map and Baidu Map. For instances, Google Earth Engine, a web-based platform to resolve big data problems to enhance the processing of satellite images for large-scale applications (67), has been used for spatio-temporal analysis of air pollutants before and during the first wave COVID-19 outbreak over Turkey (68). In recent years, with the increasing availability of open-source data, more and

more researchers have used Application Programming Interface (API) of online mapping services, such as the Google Map API and Baidu map API, to acquire the estimated travel distance and time for detecting service areas of various travel modes (69). In Poland, Google map weas employed to investigate changes in regional and local mobility patterns during COVID-19 lockdown (70). Baidu Map was also successfully used for mapping the accessibility of medical facilities of Wuhan during the COVID-19 pandemic (71). These IMTs have been also widely used for the COVID-19 fight in other studies (69,72,73).

4. CONCLUSIONS

This paper summarised and synthesized a wide range of applications offered through geospatial techniques to help address different issues related to the fight of the COVID-19 pandemic. A total of 73 scientific papers have been reviewed. The crucial roles of GIS, Remote Sensing, Global Positioning System and Internet Mapping Technologies in the fight of the COVID-19 pandemic were discussed. This study confirms the effectiveness of geospatial techniques not only in the study of COVID-19 in general, but also in the fight of the pandemic in particular. The value of geospatial technique should increase over time, particularly in the study of such a global pandemic as COVID-19.

DECLARATION BY AUTHORS

Ethical Approval: Approved

Acknowledgement: The authors thank editors and anonymous reviewers for their constructive comments and suggestions on this paper that have helped to greatly improve the quality of the paper.

Source of Funding: None

Conflict of Interest: The authors declare no conflict of interest

REFERENCES

1) Malik S, Pal SC, Arabameri A, Chowdhuri I, Saha A, Chakrabortty R, et al. GIS-based statistical model for the prediction of flood hazard susceptibility. Environ Dev Sustain. 2021;23:16713–43.
2) Zheng J. SARS-CoV-2: an emerging coronavirus that causes a global threat. Int J Biol Sci. 2020;16(10):1678.
3) WHO. WHO Coronavirus (COVID-19) Dashboard [Internet]. 2023. Available from: https://covid19.who.int/
4) McCoy MD. Defining the geospatial revolution in archaeology. J Archaeol Sci Reports. 2021;37:102988.
5) Kamraju M. Overview of Geospatial Science and Technology. In: Temporal and Spatial Environmental Impact of the COVID-19 Pandemic. Springer; 2023. p. 1–6.
6) Wright DJ, Duncan SL, Lach D. Social power and GIS technology: a review and assessment of approaches for natural resource management. Ann Assoc Am Geogr. 2009;99(2):254–72.
7) Kamel Boulos MN, Geraghty EM. Geographical tracking and mapping of coronavirus disease COVID-19/severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) epidemic and associated events around the world: how 21st century GIS technologies are supporting the global fight against outbr. Vol. 19, International journal of health geographics. Springer; 2020. p. 1–12.
8) Politi E, Rowan JS, Cutler MEJ. Assessing the utility of geospatial technologies to investigate environmental change within lake systems. Sci Total Environ. 2016;543:791–806.
9) VoPham T, Hart JE, Laden F, Chiang Y-Y. Emerging trends in geospatial artificial intelligence (geoAI): potential applications for environmental epidemiology. Environ Heal. 2018;17(1):1–6.
10) Cringoli G, Rinaldi L, Albonico M, Bergquist R, Utzinger J. Geospatial (s) tools: integration of advanced epidemiological sampling and novel diagnostics. Geospat Health. 2013;7(2):399–404.
11) Singh H, Fortington L V, Thompson H, Finch CF. An overview of geospatial methods used in unintentional injury epidemiology. Inj Epidemiol. 2016;3:1–12.
12) Saran S, Singh P, Kumar V, Chauhan P. Review of geospatial technology for infectious disease surveillance: use case on COVID-19. J Indian Soc Remote Sens. 2020;48:1121–38.
13) Roberts DP, Short NM, Sill J, Lakshman DK, Hu X, Buser M. Precision agriculture and geospatial techniques for sustainable disease control. Indian Phytopathol. 2021;74:287–305.
14) Jing F, Li Z, Qiao S, Zhang J, Olatosi B, Li X. Using geospatial social media data for infectious disease studies: a systematic review. Int J Digit Earth. 2023;16(1):130–57.
15) Hswen Y, Nguemdjo U, Yom-Tov E, Marcus GM, Ventelou B. Individuals' willingness to provide geospatial global positioning system (GPS) data from their smartphone during the COVID-19 pandemic. Humanit Soc Sci Commun. 2022;9(1):1–8.
16) Hoang A, Nguyen T. Identifying Spatio-Temporal Clustering of the COVID-19 Patterns Using Spatial Statistics: Case Studies of Four Waves in Vietnam. Int J Appl Geospatial Res. 2022;13(1):1–15.
17) Jaber AS, Hussein AK, Kadhim NA, Bojassim AA. A Moran's I autocorrelation and spatial cluster analysis for identifying

Coronavirus disease COVID-19 in Iraq using GIS approach. Casp J Environ Sci. 2022;20(1):55–60.
18) Shadeed S, Alawna S. GIS-based COVID-19 vulnerability mapping in the West Bank, Palestine. Int J Disaster Risk Reduct. 2021;64:102483.
19) Malakar S. Geospatial modelling of COVID-19 vulnerability using an integrated fuzzy MCDM approach: a case study of West Bengal, India. Model Earth Syst Environ. 2022;8(3):3103–16.
20) Ali T, Mortula M, Sadiq R. GIS-based vulnerability analysis of the United States to COVID-19 occurrence. J Risk Res. 2021;24(3–4):416–31.
21) Asfaw H, Karuppannan S, Erduno T, Almohamad H, Dughairi AA Al, Al-Mutiry M, et al. Evaluation of Vulnerability Status of the Infection Risk to COVID-19 Using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA): A Case Study of Addis Ababa City, Ethiopia. Int J Environ Res Public Health. 2022;19(13):7811.
22) Kalla MI, Lahmar B, Geullouh S, Kalla M. Health geo-governance to assess the vulnerability of Batna, Algeria to COVID-19: The role of GIS in the fight against a pandemic. GeoJournal. 2022;87(5):3607–20.
23) Sánchez-Sánchez JA, Chuc VMK, Canché EAR, Uscanga FJL. Vulnerability assessing contagion risk of Covid-19 using geographic information systems and multi-criteria decision analysis: Case study Chetumal, México. In: GIS LATAM: First Conference, GIS LATAM 2020, Mexico City, Mexico, September 28–30, 2020, Proceedings 1. Springer; 2020. p. 1–17.
24) Rahman MH, Zafri NM, Ashik FR, Waliullah M, Khan A. Identification of risk factors contributing to COVID-19 incidence rates in Bangladesh: A GIS-based spatial modeling approach. Heliyon. 2021;7(2).
25) Kanga S, Meraj G, Sudhanshu, Farooq M, Nathawat MS, Singh SK. Analyzing the risk to COVID-19 infection using remote sensing and GIS. Risk Anal. 2021;41(5):801–13.
26) Nath B, Majumder S, Sen J, Rahman MM. Risk analysis of COVID-19 infections in Kolkata Metropolitan city: A GIS-based study and policy implications. GeoHealth. 2021;5(4):e2020GH000368.
27) Kanga S, Meraj G, Farooq M, Nathawat MS, Singh SK. Risk assessment to curb COVID-19 contagion: A preliminary study using remote sensing and GIS. 2020;
28) 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.
29) Okyere I, Chuku EO, Ekumah B, Angnuureng DB, Boakye-Appiah JK, Mills DJ, et al. Physical distancing and risk of COVID-19 in small-scale fisheries: A remote sensing assessment in coastal Ghana. Sci Rep. 2020;10(1):22407.
30) Pandey S, Barik RK, Gupta S, Arthi R. Pandemic drone with thermal imaging and crowd monitoring system (DRISHYA). Tech Adv Mach Learn Healthc. 2021;307–25.
31) Rodríguez-Benito C V, Navarro G, Caballero I. Using Copernicus Sentinel-2 and Sentinel-3 data to monitor harmful algal blooms in Southern Chile during the COVID-19 lockdown. Mar Pollut Bull. 2020;161:111722.
32) 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.
33) 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.
34) Gayen A, Haque SM, Mishra SV. COVID-19 induced lockdown and decreasing particulate matter (PM10): An empirical investigation of an Asian megacity. Urban Clim. 2021;36:100786.
35) Zhang K, de Leeuw G, Yang Z, Chen X, Jiao J. The impacts of the COVID-19 lockdown on air quality in the Guanzhong Basin, China. Remote Sens. 2020;12(18):3042.
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) Yunus AP, Masago Y, Hijioka Y. COVID-19 and surface water quality: Improved lake water quality during the lockdown. Sci Total Environ. 2020;731:139012.
38) Elshorbany YF, Kapper HC, Ziemke JR, Parr SA. The status of air quality in the United States during the COVID-19 pandemic: a remote sensing perspective. Remote Sens. 2021;13(3):369.
39) Metya A, Dagupta P, Halder S, Chakraborty S, Tiwari YK. COVID-19 lockdowns improve air quality in the South-East Asian regions, as seen by the remote sensing satellites. Aerosol Air Qual Res. 2020;20(8):1772–82.
40) 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.
41) Gupta A, Banerjee S, Das S. Significance of geographical factors to the COVID-19 outbreak in India. Model earth Syst Environ. 2020;6:2645–53.
42) 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;
43) 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.

44) 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.
45) Zhang C, Liao H, Strol E, Li H, Li R, Jensen SS, et al. The Role of Weather Conditions in COVID-19 Transmission: A Study of a Global Panel of 1236 Regions (preprint). 2020;
46) 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.
47) Ogen Y. Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ. 2020;726:138605.
48) Grantz KH, Meredith HR, Cummings DAT, Metcalf CJE, Grenfell BT, Giles JR, et al. The use of mobile phone data to inform analysis of COVID-19 pandemic epidemiology. Nat Commun. 2020;11(1):4961.
49) Beria P, Lunkar V. Presence and mobility of the population during the first wave of Covid-19 outbreak and lockdown in Italy. Sustain Cities Soc. 2021;65:102616.
50) Perra N. Non-pharmaceutical interventions during the COVID-19 pandemic: A review. Phys Rep. 2021;913:1–52.
51) Weizman Y, Tan AM, Fuss FK. Use of wearable technology to enhance response to the Coronavirus (COVID-19) pandemic. Public Health. 2020;185:221.
52) Anandkumar A, Dinakaran K, Mani T. IoT enabled smart bus for COVID-19. Microw Opt Technol Lett. 2022;64(4):639–42.
53) Chin CG, Jian TJ, Ee LI, Leong PW. IoT-based indoor and outdoor self-quarantine system for COVID-19 patients. Int J Technol. 2022;13(6):1231–40.
54) Han T, Park H, Jeong Y, Lee J, Shon E, Park M-S, et al. COVID-19 cluster linked to aerosol transmission of SARS-CoV-2 via floor drains. J Infect Dis. 2022;225(9):1554–60.
55) Her M. How is COVID-19 affecting South Korea? What is our current strategy? Disaster Med Public Health Prep. 2020;14(5):684–6.
56) Ghayvat H, Awais M, Gope P, Pandya S, Majumdar S. Recognizing suspect and predicting the spread of contagion based on mobile phone location data (counteract): a system of identifying covid-19 infectious and hazardous sites, detecting disease outbreaks based on the internet of things, edge computing, and . Sustain Cities Soc. 2021;69:102798.
57) Smith CD, Mennis J. Peer reviewed: incorporating geographic information science and technology in response to the COVID-19 pandemic. Prev Chronic Dis. 2020;17.
58) Herath H, Karunasena G, Herath H. Development of an IoT based systems to mitigate the impact of COVID-19 pandemic in smart cities. In: Machine intelligence and data analytics for sustainable future smart cities. Springer; 2021. p. 287–309.
59) Li J, Guo X. COVID-19 contact-tracing apps: A survey on the global deployment and challenges. arXiv Prepr arXiv200503599. 2020;
60) Jusoh JA, Rose ANM, Aledinat LS, Altrad A, Saany SIA, Aseh K, et al. Track Student Attendance at a Time of the COVID-19 Pandemic Using Location-Finding Technology. In: 2021 2nd International Conference on Smart Computing and Electronic Enterprise (ICSCEE). IEEE; 2021. p. 147–52.
61) Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time. Lancet Infect Dis. 2020;20(5):533–4.
62) Mooney P, Juhász L. Mapping COVID-19: How web-based maps contribute to the infodemic. Dialogues Hum Geogr. 2020;10(2):265–70.
63) Schmidt F, Dröge-Rothaar A, Rienow A. Development of a Web GIS for small-scale detection and analysis of COVID-19 (SARS-CoV-2) cases based on volunteered geographic information for the city of Cologne, Germany, in July/August 2020. Int J Health Geogr. 2021;20(1):1–24.
64) Lipeng J, Xuedong Z, Jianqin Z, Zhijie X, Shaocun D. Design and Development of a Visualization System for COVID-19 Simulation Based on WebGIS. In: 2020 International Conference on Public Health and Data Science (ICPHDS). IEEE; 2020. p. 278–82.
65) Gabellieri N, Geri F, Pranzo AMR, Zatelli P. Bridging research and dissemination in the CoViD-19 era: a WebGIS dashboard for the Autonomous Province of Trento (Italy). In: Proceedings of the ICA. Copernicus Publications Göttingen, Germany; 2021. p. 34.
66) Salunke S. A user interractive webgis webpage for decision making & resource allocation during COVID-19 pandemic–A case study for Solapur City, Maharashtra, India. In: 41st Asian Conference on Remote Sensing, ACRS 2020. 2020.
67) Ghosh S, Kumar D, Kumari R. Google earth engine based computational system for the earth and environment monitoring applications during the COVID-19 pandemic using thresholding technique on SAR datasets. Phys Chem Earth, Parts A/B/C. 2022;127:103163.
68) Ghasempour F, Sekertekin A, Kutoglu SH. Google Earth Engine based spatio-temporal analysis of air pollutants before and during the first wave COVID-19 outbreak over Turkey via remote sensing. J Clean Prod. 2021;319:128599.

69) Tao Z, Cheng Y. Modelling the spatial accessibility of the elderly to healthcare services in Beijing, China. Environ Plan B Urban Anal City Sci. 2019;46(6):1132–47.
70) Tarkowski M, Puzdrakiewicz K, Jaczewska J, Połom M. COVID-19 lockdown in Poland–changes in regional and local mobility patterns based on Google Maps data. Pr Kom Geogr Komun PTG. 2020;23(2):46–55.
71) Zhou Z, Xu Z, Liu A, Zhou S, Mu L, Zhang X. Mapping the accessibility of medical facilities of wuhan during the COVID-19 pandemic. ISPRS Int J Geo-Information. 2021;10(5):318.
72) Sarkar SK. COVID-19 susceptibility mapping using multicriteria evaluation. Disaster Med Public Health Prep. 2020;14(4):521–37.
73) Pradana AR, Madjid SR, Prayitno HJ, Utami RD, Dharmawan Y. Potential applications of big data for managing the COVID-19 pandemic. In: Journal of Physics: Conference Series. IOP Publishing; 2021. p. 12002.