Science of the Total Environment 739 (2020) 140033

Contents lists available at ScienceDirect

Science of the Total Environment

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

Spatial analysis and GIS in the study of COVID-19. A review

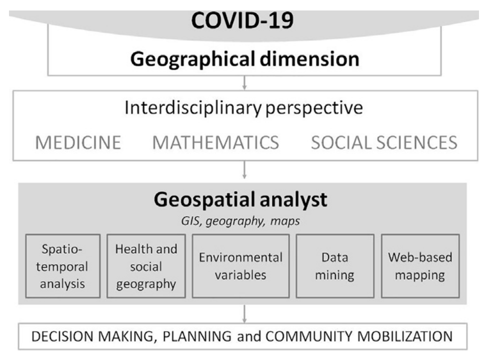
Ivan Franch-Pardo [a,*], Brian M. Napoletano [b,*], Fernando Rosete-Verges [a], Lawal Billa [c]

[a] Universidad Nacional Autónoma de México, Escuela Nacional de Estudios Superiores, Morelia 58190, Michoacan, Mexico
[b] Universidad Nacional Autónoma de México, Centro de Investigaciones en Geografía Ambiental, Morelia 58190, Michoacan, Mexico
[c] University of Nottingham Malaysia Campus, Faculty of Science and Engineering, Semenyih 43500, Selangor Darul Ehsan, Malaysia

HIGHLIGHTS

- Data processed with GIS and spatial statistics are important to study COVID-19.
- Decision making is the principle objective of COVID-19 studies with GIS.
- Geographical aspects of the study of COVID-19 can be grouped into five categories.
- COVID-19 requires an interdisciplinary approach with a global perspective.
- Health geography has a critical perspective that can help vulnerable populations.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 May 2020
Received in revised form 4 June 2020
Accepted 4 June 2020
Available online 8 June 2020

Editor: Jay Gan

Keywords:
COVID-19
Geographical dimensions
Spatiotemporal analyst
Health geography
Interdisciplinary correlation
Data mining and web-base

ABSTRACT

This study entailed a review of 63 scientific articles on geospatial and spatial-statistical analysis of the geographical dimension of the 2019 coronavirus disease (COVID-19) pandemic. The diversity of themes identified in this paper can be grouped into the following categories of disease mapping: spatiotemporal analysis, health and social geography, environmental variables, data mining, and web-based mapping. Understanding the spatiotemporal dynamics of COVID-19 is essential for its mitigation, as it helps to clarify the extent and impact of the pandemic and can aid decision making, planning and community action. Health geography highlights the interaction of public health officials, affected actors and first responders to improve estimations of disease propagation and likelihoods of new outbreaks. Attempts at interdisciplinary correlation examine health policy interventions for the siting of health/sanitary services and controls, mapping/tracking of human movement, formulation of appropriate scientific and political responses and projection of spatial diffusion and temporal trends. This review concludes that, to fight COVID-19, it is important to face the challenges from an interdisciplinary perspective, with proactive planning, international solidarity and a global perspective. This review provides useful information and insight that can support future bibliographic queries, and also serves as a resource for understanding the evolution of tools used in the management of this major global pandemic of the 21 Century. It is hoped that its findings will inspire new reflections on the COVID-19 pandemic by readers.

1. Introduction

Six months have passed since Chinese authorities identified a deadly new coronavirus strain, SARS-CoV-2 (January 7, 2020); four months since the WHO declared a pandemic (March 11, 2020). During this time, scientific papers on the 2019 coronavirus disease (COVID-19)

* Corresponding authors at: UNAM, Morelia Campus, Antigua Carretera a Patzcuaro 8701, Morelia 58190, Michoacán, Mexico.
E-mail addresses: ifranch@enesmorelia.unam.mx (I. Franch-Pardo), brian@ciga.unam.mx (B.M. Napoletano).

https://doi.org/10.1016/j.scitotenv.2020.140033

have been numerous, addressing global awareness (primarily at national levels) and covering a significant range of disciplines including medicine, mathematics and social sciences. Among these disciplines, this paper focuses on the geographical dimensions of the disease.

This thematic aspect of COVID-19 requires analysis that adopts an interdisciplinary approach, and geography is one of the few disciplines that purports to offer a synthetic approach to the interplay between the biophysical and human variables (Turner, 2002), by approaching the environment from a holistic perspective with a focus on the forms and processes that concur in a geographical space (Sauer, 1925). Other disciplines define the physical, historical and social characteristics and processes, but geography situates these in a spatial, territorial, locational and landscape perspective (Pattison, 1964). The complex reality of the environment-society dialectic (sensu Schnaiberg and Gould, 1994) must be understood in the context of the integrative approach of geography.

Medical geography specializes in the application of concepts, methods and quantitative techniques to address spatial issues in disease and medicine (Meade, 2014). Within this, health geography focuses geographical concepts and categories on the population and demographic aspects concerning health. According to Kearns and Moon (2002), health geography has a predominantly utilitarian perspective and analyses the territory technically, although it incorporates structuralist approaches, such as cultural and sociological vision of social welfare, a sense of 'place' for people, and a critical stance.

The COVID-19 pandemic is full of unknowns, and many of them have a spatial dimension that lead to understanding the phenomenon as geographical and potentially mappable. Thus from health science, the research needs include the ability to cross variables of different kinds to interpret the COVID-19 phenomenon, its spatial analysis and spatiotemporal dimensions, its geographical impact on decision-making and everyday life, and predictive modelling of the evolution of the disease. For these reasons, the use of geospatial and statistical tools has become particularly relevant with the declaration of COVID-19 as a global pandemic.

The aim of this study is to review the implementation of geographical and geo-spatial analysis in understanding locations and the distribution patterns of COVID-19. The study seeks to highlight current geospatial-analytical methods in the interpretation of the environmental effects and consequences of COVID-19, to understand its sociodemographic implications and role of big data mining and web based spatial analysis and representation. The review summarizes studies and research on COVID-19 phenomena in the context of geography. It can also be a useful resource in understanding the geographical consequences and effectiveness of the containment of the disease. There are already various reviews on COVID-19, but they have not approached the issue from a geographical perspective. Tobaiqy et al. (2020) discussed the different therapies used in COVID-19 patients, while the use of artificial intelligence and big data to study and mitigate effects of the virus was discussed by Pham et al., 2020, and systematisation of ongoing data science activities in this area was done by Latif et al. (2020). The review here of different works dealing with geographical phenomena of COVID-19 should inspire new reflections for the readers, and help connect between themes and tools.

2. Thematic groups of geospatial analysis

We have reviewed 63 scientific articles found in the Google Scholar, Scopus, ScienceDirect and PubMed search engines, and by following the references in the works we read. The keywords we used to find these articles were 'COVID-19', 'coronavirus' (limited to 2020) or 'SARS-CoV-2', together with different conjugations of the words 'GIS', 'spatiotemporal', 'spatial analysis', 'geospatial', 'geography', 'map' and 'mapping'. The time interval dates from 27 January 2020 (first identified spatial study) to 1 May 2020 (date of the last study reviewed prior to writing and sending this paper for review). Based on the authors' experience and understanding of geographical phenomena and processes, the articles were evaluated in terms of their depth of analysis, leaving aside those that only provided a simple representation of certain details in the form of a map and did not offer relevant contributions in the field of spatial analysis. The review does not include works that take on the spatial dimension abstractly and whose spatial analysis are conceptual. In this, Wallace's (2020) lead is followed in avoiding empiricism while emphasizing a degree of analytical and empirical vigour- Thus it is important to recognise that not all the vital information necessary to address the outbreak can be readily quantified and mapped. The temporal variable, although not always central, was also present in most of the work reviewed.

Research papers were categorized into five general groups and summarized in terms of the most substantial works on themes developed, significant methodologies, and the most relevant results. The first group, of spatiotemporal analysis and disease mapping, refers to studies of the temporal pattern of the COVID-19 phenomenon together with its geographical expansion. After discussing this, we describe the other categories we posited based on the major themes covered: health and social geography, environmental variables, data mining, and web-based mapping. This grouping, derived from the main themes of the papers that we reviewed, integrates all the different studies and adequately summarizes the topics covered, although some works fall into more than one category (Table 1).

2.1. Spatiotemporal analysis

One of the most important properties of epidemics is their spatial spread, "a characteristic which mainly depends on the epidemic mechanism, human mobility and control strategy" (Gross et al., 2020: 2). We can use GIS and spatial statistics to respond to this, and also to help mitigate the epidemic through scientific information, find spatial correlations with other variables, and identify transmission dynamics (Xiong et al., 2020). One of the first works, as well as one of the most cited, that makes use of GIS for the spatial analysis of COVID-19 is that of Guan et al. (2020). They extracted data on 1099 patients with laboratory-confirmed COVID-19 cases from Chinese hospitals until January 29, 2020, and proceeded to characterize the profile of the average patient: mean age, gender, symptoms and their spatiotemporal characteristics—i.e., identification of the rapid spread of the disease throughout mainland China, distribution of patients by province, characteristics between residents of Wuhan and non-residents, history of direct contact with wildlife and non-residents of Wuhan who visited the city or who had contact with citizens there (72.3%). The work is important because the early date of its publication (February 28) allowed the clinical characteristics of the affected patients to be more precisely defined. Also in China, around the same time, Chen et al. (2020b), using a Bayesian spatial-temporal model, determined the distribution of COVID-19 cases and their correlation with the migration of the Wuhan population in the early stages of the epidemic, which is of great importance for early warning and prevention of future outbreaks. Huang et al. (2020), weeks later (COVID-19 moves very fast, while the onset of symptoms are delayed by an average of two weeks, allowing many things happen in a short time), analysed the epidemiological characteristics of COVID-19, the control measures taken, their effects with respect to the pandemic, and its spatiotemporal distribution. One enotable result was the identification of a significant number of people who entered Wenzhou from Hubei Province, which explains why this city was the first outside the epicentre where confinement was adopted.

These first geographic analyses also mapped the information to more precise administrative levels (counties, provinces), something that was to be reproduced in other countries such as the USA (Dong et al., 2020), Iran (Arab-Mazar et al., 2020), later South Korea (Rezaei et al., 2020), Brazil (Dagnino et al., 2020), Israel (Rossman et al., 2020), Italy (Giuliani et al., 2020), Spain (Orea and Álvarez, 2020),

Table 1
Grouping of reviewed studies by geospatial theme, date of first publication, country or region studied, provenance of the information used and brief description.

Spatial subject	Study	Date (m/d)	Region or country of study	Data used	Particular subject
Spatiotemporal analysis	Guan et al. (2020)	2/28	China	Confirmed cases of COVID-19	Geographical characteristics of those infected by COVID-19
	Chen et al. (2020a) and Chen et al. (2020b)	2/28	China	Confirmed cases	Distribution of the contagion cases and their correlation with the emigration of the Wuhan population in the initial stage of the epidemic
	Huang et al. (2020)	3/10	China	Confirmed cases	Spatiotemporal analysis of COVID-19 and its relationship with epidemiological characteristics, control of measures taken and their effects.
	Arab-Mazar et al. (2020)	3/14	Iran	Confirmed cases	Spatiotemporal analysis of COVID-19 at the national and provincial levels
	Giuliani et al. (2020)	3/20	Italy	Confirmed cases	Spatiotemporal analysis of COVID-19 at the national and provincial levels
	Zhou et al. (2020)	3/20	China	Data mining and confirmed cases	Reflections on the use of GIS with big data and spatiotemporal analysis of COVID-19
	Rezaei et al. (2020)	3/24	South Korea	Confirmed cases	Spatiotemporal analysis of COVID-19 at the national and provincial levels
	Zhang et al. (2020)	3/26	China	Confirmed cases	Comparison of spatiotemporal evolution between COVID-19 and SARS 2003
	Dagnino et al. (2020)	3/27	Brasil	Confirmed cases	Spatiotemporal analysis of COVID-19 in Rio Grande do Sul
	Ahmadi et al. (2020a) and Ahmadi et al. (2020b)	3/31	Iran	Confirmed cases	Spatiotemporal analysis and call for the need to do more GIS studies locally
	Xiong et al. (2020)	4/5	China	Confirmed cases	Pearson's correlation methods for spatiotemporal analysis
	Gross et al. (2020)	4/5	China	Confirmed cases	Levy's flight to explain the spatiotemporal dynamics of the pandemic
	Desjardins et al. (2020)	4/8	USA	Confirmed cases	Prospective space-time statistics to identify active and emerging COVID-19 groups at the county level
	Rossman et al. (2020)	4/9	Israel	Polls and confirmed cases	Online questionnaire aimed at the geographical identification of possible symptomatics
	De Ángel Solá et al. (2020)	4/10	Caribe basin	Confirmed cases	Predicting the global spread of COVID-19 based on geographic and climatic data
	Team CC-R (2020)	4/10	USA	Confirmed cases	Geographical characteristics and spatiotemporal analysis of infections
	Orea and Álvarez (2020)	4/13	Spain	Confirmed cases	Analysis by provinces of the effectiveness of quarantine on the spread of the pandemic
	Murugesan et al. (2020)	4/14	India	Confirmed cases	Spatiotemporal analysis of COVID-19 at the national and provincial levels
	Tang et al. (2020)	4/15	China	Confirmed cases	Poisson segmented model for the analysis of changing patterns in different geographic areas
	Silva et al. (2020)	4/16	Brasil	Confirmed cases	Spatiotemporal analysis of COVID-19 in Estado da Bahia
	Buzai (2020)	4/17	Argentina	Confirmed cases	Spatiotemporal analysis and reflections on health geography
	Santana Juárez (2020)	4/17	Mexico	Confirmed cases	Spatiotemporal analysis of COVID-19 at the national and provincial levels
	Saha et al. (2020)	4/26	World	Confirmed cases	Spatiotemporal analysis and reflections on usefulness of GIS in the pandemic
Health and social geography	De Kadt et al. (2020)	3/20	South Africa	Socio-economic characteristics and urban structure	For Gauteng city, 2 risk maps: to maintain social distance and preventive hygiene, and health and social vulnerability during the outbreak
	Ahmadi et al. (2020a) and Ahmadi et al. (2020b)	3/31	Iran	Confirmed cases	Emphasises the need for more GIS studies at local scales
	Gibson and Rush (2020)	4/6	South Africa	Socio-economic characteristics and urban structure	Analysis of the feasibility of social distancing in the slums of Cape Town.
	Kuchler et al. (2020)	4/6	USA, Italy	Data mining and confirmed cases	Identification of Facebook friendships in Westchester (NY) and Lodi (Lombardia) and correlations with the pandemic
	Allcott et al. (2020)	4/7	USA	Data mining and polls	Correlation between the ruling party in each county, social behaviour and confirmed COVID-19 cases
	Lakhani (2020a) and Lakhani (2020b)	4/8	Australia	Socio-economic characteristics and urban structure	Analysis of the spatial distribution of health services and the population over 65 years of age in Melbourne
	Padula and Davidson (2020)	4/9	World	Confirmed cases	Correlation between number of nurses per country and COVID-19 mortality
	Lakhani (2020a) and Lakhani (2020b)	4/11	Australia	Socio-economic characteristics and urban structure	Characteristics of rural areas and their ageing population with respect to health services to face the pandemic
	Minetto et al. (2020)	4/16	North Korea, Russia, Germany, USA, China	Remote sensing	Changes in population and economic dynamics through the comparison of satellite images prior to and during the pandemic
	Kuupiel et al. (2020)	4/16	Ghana	Socio-economic characteristics and urban structure	Geographical accessibility analysis of Upper East Region inhabitants to point of care tests
	Samuelsson et al. (2020)	4/18	World	Polls	Discussion on the characteristics of current cities and post-pandemic urban strategies
	Coccia (2020)	4/20	Italy	Confirmed cases	Correlation between geoenvironmental and demographic characteristics of 55 cities and their relationship with the dynamics of COVID-19
	Mollalo et al. (2020)	4/22	USA	Confirmed cases	Correlation between socioeconomic, environmental, topographic and demographic themes using a family of spatial regression and autoregressive models
	Oto-Peralías (2020)	4/24	Spain	Confirmed cases	Correlation between geographic and socioeconomic variables to explain the great disparity of those infected between the provinces

(continued on next page)

Table 1 (*continued*)

Spatial subject	Study	Date (m/d)	Region or country of study	Data used	Particular subject
	Kost (2020)	Apr	World	Confirmed cases	Discussion of the importance of point-of-care testing in pandemics and the need for geospatial analysis for its optimal location
	Jella et al. (2020)	Apr	USA	Confirmed cases	Analysis of the geographical distribution of orthopaedic surgeons over 65 years of age to compare with COVID-19 infections in New York, New Jersey, California and Florida
	Sarwar et al. (2020)	5/1	Pakistan	Confirmed cases	Development of an open and practical GIS to detect, collect and analyse outbreak data. Discussion on the usefulness of GIS in Pakistan
Environmental variables	Luo et al. (2020)	2/17	China	Confirmed cases	Correlation between the number of contact cases and absolute humidity of the geographical location
	Sajadi et al. (2020)	3/9	World	Confirmed cases	Analysis of the temperature, humidity and latitude of 8 cities with high infections and extrapolation to the rest of the world
	Wang et al. (2020)	3/10	World	Confirmed cases	Analysis of temperature and humidity in Chinese cities with more than 40 infections and extrapolation to the rest of the world
	Ma et al. (2020)	3/18	China	Confirmed cases	Correlation between deaths from COVID-19 in Wuhan and climate data and environmental pollution
	Tosepu et al. (2020)	4/3	Indonesia	Confirmed cases	Correlation between climate and COVID-19 in Jakarta
	Liu et al. (2020)	4/5	China	Confirmed cases	Correlation between climate and COVID-19 in 30 Chinese cities
	Keshavarzi (2020)	4/6	World	Confirmed cases	Search for climatic and geographic evidence to explain the pandemic
	Baker et al. (2020)	4/7	World	Confirmed cases	Climate-dependent epidemic model to simulate the COVID-19 pandemic in different scenarios
	Hasan and Mahfujul Haque (2020)	4/7	World	Confirmed cases	Correlation between climate and COVID-19 in temperate and tropical countries
	Bariotakis et al. (2020)	4/9	World	Confirmed cases	Predicting the global spread of COVID-19 based on climate data.
	De Ángel Solá et al. (2020)	4/10	Caribe basin	Confirmed cases	Predicting the global spread of COVID-19 based on geographic and climatic data
	Ahmadi et al. (2020a) and Ahmadi et al. (2020b)	4/13	Iran	Confirmed cases	Correlation between demographic and climatic characteristics and the spread of COVID-19
	Qi et al. (2020)	4/16	China	Confirmed cases	Analysis of average daily temperature and relative humidity against cases of contagion
	Bashir et al. (2020)	4/18	USA	Confirmed cases	Correlation between climatic characteristics and the spread of the virus in New York
	Gupta et al. (2020)	4/19	USA, India	Confirmed cases	Correlation between climatic characteristics and the spread of the virus in the USA, and extrapolation of the method to India
Data mining	Zhou et al. (2020)	3/20	China	Data mining and confirmed cases	Reflections on the use of GIS with big data and spatiotemporal analysis of COVID-19
	Bogoch et al. (2020)	1/27	World	Data mining	International flights from Wuhan, number of passengers, potential distribution of the disease
	Iacus et al. (2020)	3/10	World	Data mining	Flow of domestic and international flights from China, Oct-19 to Mar-20
	Warren and Skillman (2020)	3/31	USA	Data mining	Geolocation data from mobile devices to measure the mobility of the population per day
	Kuchler et al. (2020)	4/6	USA, Italy	Data mining and confirmed cases	Identification of Facebook friendships in Westchester (NY) and Lodi (Lombardia) and correlation with the pandemic
	Chen et al. (2020a) and Chen et al. (2020b)	4/7	USA	Data mining and confirmed cases	Correlation between infections by state with the entrances and exits of interstate travellers
	Allcott et al. (2020)	4/7	USA	Data mining and polls	Correlation between the ruling party in each county, social behaviour and confirmed COVID-19 cases
	Gao et al. (2020)	4/9	USA	Data mining	Mobility pattern analysis using mobile data at the county level. Web cartographic viewer
	Su et al. (2020)	4/15	China	Data mining and confirmed cases	Number of infections and daily travel intensity index to assess the level of restrictions and measures to adopt
	Chan et al. (2020)	Apr	World	Data mining	Analysis with mobility data from Google users
Web-based mapping	Dong et al. (2020)	2/19	World	Confirmed cases	Presentation of the John Hopkins University web cartographic viewer
	Cicalò and Valentino (2019)	Feb	World	Confirmed cases	Geohistorical context of the maps for the study of epidemics and design of the web maps on COVID-19
	Boulos and Geraghty (2020)	3/11	USA, China, UK	Data mining and confirmed cases	Review of cartographic web viewers and Chinese mobile applications to slow contagion
	Rossman et al. (2020)	4/9	Israel	Polls and confirmed cases	Online questionnaire aimed at the geographical identification of possible symptoms
	Gao et al. (2020)	4/9	USA	Data mining	Mobility pattern analysis using mobile data at the county level. Web cartographic viewer

Argentina (Buzai, 2020), Mexico (Santana Juárez, 2020), India (Saha et al., 2020) and Pakistan (Sarwar et al., 2020).

Returning to the spatiotemporal analyses carried out in China, Gross et al. (2020) agree that the spread of the disease originated in the Hubei migration prior to confinements. With more information on the dynamics of the virus, in this work they drew imaginary lines connecting vertices representing the epicentres of the virus, specific provinces, cities and locations scattered around the world. The distances and the intensities of the epicentres are very irregular; the virus propagation adopts the flight of Levy, a tendency to fractal movement typical of human mobility. With pertinent mathematics, future scenarios could be modelled. In the work of Zhang et al. (2020), an attempt was made to determine whether the pattern of spatial-temporal behaviour is related to SARS 2003, and came up with negative results owing to changes in social and demographic factors, local government containment strategies, and differences in the dynamics of transmission between these two coronaviruses.

Later, Tang et al. (2020) analysed the changing patterns in the different geographical areas of the country, with the temporal evolution of the COVID-19 epidemic. They used Poisson's segmented model and attempt to provide further explanations for what is happening in real time. Su et al. (2020) combined efforts to understand the transmission dynamics, focusing on the main Chinese metropolitan areas. They used the reported data of infected people in a time interval, plus the daily travel intensity index with Baidu Maps data for those dates, in order to calibrate the level of restrictions and estimate the proportion of the population in quarantine. It is a study based on the Chinese experience, but its purpose is to help large urban agglomerations in other regions of the world that have to go through the same thing.

In Israel, an online questionnaire was carried out to identify possible symptoms and, with this, to follow up with infected persons over time (Rossman et al., 2020: 3). In the interpretation of the data, differences in the proportion of reported symptoms in participants from different cities and different neighbourhoods that are geographically close to each other are revealed, which could suggest the ability to detect changes at a high geographical resolution.

The GIS analyses carried out in the USA, where containment efforts have been belated and relatively lax (in comparison with China, South Korea, and Taiwan), have very diverse themes, as we will see throughout the other sections. Desjardins et al. (2020) used prospective space-time statistics to identify active and emerging COVID-19 groups at the county level. The prospective approach is an important surveillance tool for controlling disease outbreaks as they develop (Kulldorff and Kleinman, 2015 cited in Desjardins et al., 2020) and its main strength is the ability to add updated COVID-19 counts and re-execute the statistics to identify new emerging groups. It also tracks previously detected groups to determine whether they are growing or shrinking in magnitude. Doing so can help determine whether current mitigation and isolation techniques are effective in slowing the spread of COVID-19, and suggests that they could be used more widely in public health departments. In other works, such as that of Gao et al. (2020), the daily evolution of human mobility in US counties was mapped, allowing monitoring of changes in population trends based on the different measures adopted by respective governments. Likewise, in the web map viewer of Dong et al. (2020), the figures for the number of people infected and killed by COVID-19 are shown at a national level, but for the USA the information is available at a county level.

In Spain, one month after the declaration of a national emergency and mandatory confinement, Orea and Álvarez (2020) analysed by province the effectiveness of these measures with respect to the spread of the pandemic. The result is favourable, with the emphasis on those provinces that are closest to the main epicentres of the COVID-19, where the state of emergency seems to have allowed the vicious circle of contagion to be broken.

Also at the provincial level, but in Italy, Giuliani et al. (2020) modelled the spatial-temporal dynamics of COVID-19 contagion and victims. As in Spain, the local distribution is very heterogeneous. Its main foci are in the north, but it has been progressively infiltrating the southern provinces. There is strong evidence that the strict control measures implemented in some provinces effectively break the cycles of infection and limit the spread to nearby areas. They also mention that planning to contain the spread of COVID-19 must take into account the peculiarities of local territories, but there must also be control measures at the national level to avoid delaying or losing control of the disease's spread as a whole.

For Pakistan, Sarwar et al. (2020) are developing an open and user-friendly GIS to detect, collect and analyse outbreak data in the country. In addition to the uses mentioned in the other papers referred to, GIS Pakistan can be useful for accurate spatial segmentation (larger scale of detail) of areas at epidemic risk and appropriate level of prevention, assessment of population flow and distribution, concerns about the adequacy of health services and constant monitoring of information. They encourage public authorities to use this tool to locate the most affected regions and take appropriate action.

2.2. Health and social geography

2.2.1. Specific health geography issues

The works of De Kadt et al. (2020) and Gibson and Rush (2020) in South Africa explore the challenges of establishing health control measures in developing countries where there are entire neighbourhoods in extreme poverty. De Kadt et al. (2020) produced two maps for the city of Gauteng. One is the risk factor index for maintaining social distance and preventive hygiene, which is not as feasible for all people in all communities (Gibson and Rush, 2020). Thus, they compile six risk factors that can be considered impediments to achieving basic hygiene and social distancing: crowded living conditions; sharing of water and sanitation services; dependence on public health services; limited access to communication tools; and dependence on public transport. The second map is the index of risk factors that increase social and health vulnerability during an outbreak or wider quarantine. This map responds to the concern about how the social distancing measures taken by the South African government and its reaction to an outbreak will impact poorer communities. Gibson and Rush (2020), following their GIS study, state that social distancing is unfeasible (apart from enclosure) in certain informal settlements of the more than 146,000 households located in Cape Town, which are densely populated, with houses in close proximity to each other, and with a severe lack of sanitation infrastructure. Here the intrinsic link between widespread poverty and disease susceptibility faced by communities in the Global South, and thus the need to address the structural drivers of this poverty in the global political-economy, becomes apparent (Davis, 2020; Zeilig and Cross, 2020).

In Ghana, a malaria-endemic country, Kuupiel et al. (2020) tested the geographical accessibility of inhabitants to Point of Care (POC) tests for Glucose-6-Phosphate Dehydrogenase (G6PD) deficiency. Specifically in their upper east region, they identify 100 Rural Primary Health and the health centres where G6PD tests are provided. Considering the spatial distribution of the population and other means of public transport, plus topographic determining factors (relief, road network, rivers), they used near function analysis tools to measure which areas and how much of the population have good geographic access to these services and which ones have shortcomings. According to the authors, this information is very relevant for the treatment of COVID-19 because there are a number of antimalarial drugs that, reportedly, are useful in its treatment (Gao et al. 2020, cited in Kuupiel et al., 2020).

On a global scale, Padula and Davidson (2020) related the concentration of nurses (more than half the world's healthcare workers) to the mortality of COVID-19 by country. The paper shows an association between high numbers of nurses and reduced mortality rates of COVID-19. The key to addressing current and future outbreaks of COVID-19, or for that matter, any infectious disease outbreak of this magnitude, is to prepare a versatile and highly skilled nursing workforce.

In the USA, Jella et al. (2020) identified the geographical distribution of orthopaedic surgeons aged 65 years or more (age-group considered more vulnerable to the disease) to compare their distribution with other specialties and with those diagnosed with COVID-19. The objective was to determine the potential risk of orthopaedic surgeons during the pandemic of COVID-19. From their results, they highlight that the highest numbers occur in the states most severely affected by COVID-19: New York, New Jersey, California and Florida.

Lakhani (2020a) carried out a spatial analysis of the Australian city of Melbourne, at a time of extraordinary vigilance over older people The city was spatially analysed to identify the areas that offer the greatest difficulties in accessing health services, where populations over 65 years of age are concentrated and which require medical assistance at home and, finally, the location of hospitals and pharmacies. This type of study is proposed for other issues related to COVID-19, such as studying how rural areas in different countries are being managed (Lakhani, 2020b), especially when they are located in remote conditions (Bocco, 2016).

2.2.2. Interdisciplinary correlations

Allcott et al. (2020) analysed the relationship between the governing political party in each US county, social behaviour with respect to containment measures, and confirmed cases of COVID-19. Large partisan gaps in social distancing behaviour were revealed. There is a strong correlation between counties with weaker social distancing responses and those with higher percentages of Republican voters. Stronger social distancing responses are also observed in counties with more COVID-19 confirmed cases. From the discussion, it appears that messages from political leaders and the media about the severity of COVID-19 could substantially affect North Americans' responses to the pandemic.

Also in the USA, Kuchler et al. (2020) studied the correlation between Facebook friendships and COVID-19 cases in two administrative entities heavily hit by COVID-19: an American county (Westchester County, NY) and an Italian municipality (Lodi, Lombardy). They were looking to see if the Facebook friendship links of these two points with other cities have a correlation with COVID-19 infections, assuming that such friendship indicates a higher probability of physical interaction. The results indicate that a social connectivity index can help epidemiologists predict the spread of communicable diseases.

Remote sensing tools are very useful for the spatial study of diseases. In addition to the atmospheric information obtained by satellites (as we see in the next section), vegetation, sea surface characteristics and changes in land cover can influence the spread of diseases. Recently, Minetto et al. (2020) measured changes in economic activity since containment measures were adopted in different parts of the world (Munich, Phoenix, Moscow, Wuhan, North Korea). They used recent and pre-COVID-19 satellite images to identify the change in vehicle volume at regular points, ship traffic at ports, and aircraft at gates.

2.3. Environmental variables

2.3.1. Environment, geography and socioeconomic correlations

Coccia (2020) analysed the geo-environmental and demographic characteristics of 55 Italian cities and their relationships with the dynamics of COVID-19. The study identified, for each city, its distance from the sea, latitude, population density, air pollution levels (PM10 or ozone), climatic variables of these months (average temperature, relative humidity, predominant wind speed, rainy and foggy days), and spatial-temporal characteristics of COVID-19 and of infected people. The work found a probable association between the accelerated diffusion of COVID-19 and high air pollution, specific meteorological conditions (e.g. low wind speed) and the cities farthest from the sea. The author appeals to environmental and sustainability sciences to prevent future epidemics.

Oto-Peralías (2020), in Spanish provinces, used geographical variables (latitude, longitude, average temperature and rainfall for the months under study, average altitude and amplitude, insularity, coastal province, distance from Madrid—the Spanish epicentre) and socioeconomic variables (GDP, population and age groups, density, urban agglomerations, labour sector, flights, pollution) to explain the large disparity of infected people (by number of inhabitants) between the provinces and tried to determine if there is an indicator that could be correlated. He found interesting correlations with temperature and distance from Madrid. The observed temperature correlation contradicts hopes that the summer heat will stop the coronavirus, even if it minimizes its transmission efficiency.

Mollalo et al. (2020), for the USA, used 35 explanatory factors, of socio-economic (average income, inequality, unemployment, insurance, etc.), behavioural (smoking), environmental (road density, pollutants, air quality, temperature, precipitation), topographical (altitude, altitudinal range, slope) and demographic (over 65 years, race, sex, number of doctors and nurses, hospitals) attributes. These variables were processed using a family of spatial regression and autoregressive models. The authors conclude that environmental factors are not shown to have a substantial influence on the incidence of COVID-19, as is the case in other studies (e.g. Ma et al., 2020). However, a combination of four variables—average household income, income inequality, percentage of nurse practitioners, and percentage of black women—could explain a relatively high variability in disease incidence in the continental United States.

2.3.2. Studies of the relationship between climate and COVID-19 to project the virus's spread

The first projection of the global dispersion of COVID-19 was proposed by Bogoch et al. (2020) in January 2020 from air passenger transport, who identified Thailand, Taiwan, Japan and South Korea as the main sources of dispersion. Additionally, taking into account previous studies conducted to predict the spread of influenza (Viboud et al., 2006; Lowen et al., 2007; Tamerius et al., 2011; Lowen et al., 2018) and SARS-CoV (Tan et al., 2005; Casanova et al., 2010; Chan et al., 2011) from climate variables, two publications attempting to predict the potential spread of COVID-19 appeared in early March 2020. One of them, with a global scope, considered the temperature at two meters above the surface, relative humidity, specific humidity and absolute humidity (Sajadi et al., 2020), and the other, with a national scope, using data from the 100 Chinese cities with more than 40 cases recorded in January, used air temperature and humidity (Wang et al., 2020).

Sajadi et al. found very different results to those reported by Bogoch et al. (2020), since they identified that between March and April the main areas at risk of virus dispersion were Manchuria, Central Asia, the Caucasus, Eastern Europe, Central Europe, the British Isles, the northeast and middle east of the USA, and British Columbia (Sajadi et al., 2020), a result that agrees somewhat with the main areas of expansion of the virus at an international level.

Wang et al. found that high temperatures and high relative humidity seemed to reduce the transmission of the virus, consistent with similar behaviour reported for influenza transmission (Wang et al., 2020).

In late March, another paper appeared that explored the association between deaths from COVID-19 and daytime temperature ranges and relative humidity in Wuhan, the epicentre of the pandemic (Ma et al., 2020). This paper was the first to link recorded deaths to climate factors.

These three articles have marked different geographical approaches to investigate the potential for distribution or affectation of the virus using climatic factors at the global, regional/national and local levels.

During the month of April, several works appeared analysing this relationship between climatic factors and the virus's dispersion potential, which can be grouped into three geographical approaches: global (Hasan and Mahfujul Haque, 2020; Bariotakis et al., 2020), regional/national (Liu et al., 2020; De Ángel Solá et al., 2020; Ahmadi et al., 2020a; Ahmadi et al., 2020b; Qi et al., 2020; Gupta et al., 2020) and local (Bashir et al., 2020; Tosepu et al., 2020).

2.4. Data mining

Geospatial big data refers to spatial data sets exceeding the capacity of current computing systems (Lee and Kang, 2015). Having information on human mobility patterns from mobile phones, or the registration of global flight networks, is fundamental to epidemiological modelling (Chen et al., 2020a; Chen et al., 2020b; Buckee et al., 2020). Using big data, researchers can attempt to quantify the scale of an event before it has occurred, thereby facilitating appropriate and timely policies, at least for authorities willing to act on the data provided. Such studies could help us to understand a pandemic's behaviour in terms of outbreak tracking, disease treatment and future vaccine manufacture and distribution (Pham et al., 2020).

In the case of COVID-19, the disease is characterized by a long incubation period, high infectivity, and difficulty in detection, which has contributed to the rapid outbreak and development of the epidemic. This situation has led to calls for GIS and big data technology to enable rapid responses and analysis, rapid provision of information on the dynamics of the epidemic and an understanding of the rules of its development to provide timely support for prevention and control decisions and interventions (Zhou et al., 2020). In the case of China, Zhou et al. (2020) point out that GIS has played a key role by rapidly aggregating big data from multiple sources, quickly visualizing epidemic information, spatially tracking confirmed cases, predicting regional transmission, spatially segregating epidemic risk and level of prevention, balancing and managing supply and demand for material resources and socio-emotional guidance and elimination of panic, which provided strong spatial information support for decision making, formulating measures and evaluating the effectiveness of prevention and control of COVID-19 cases.

In relation to applied cases for COVID-19, Chan et al. (2020) used the worldwide data that Google provided with (anonymous) mobility reports of its users describing the changes in mobility for various geographies in different types of locations, including shopping and recreation, supermarkets, shops and pharmacies, parks, transit stations, workplaces and private residences. They propose to offer this information to the scientific community for future research.

Zhou et al. (2020), using data from Chinese public institutions, analysed the spatial representation of the disease, material, population and social psychology on three scales: individual (spatial monitoring of the epidemic and spatial-temporal mobility of those infected), group (population flow and spatial distribution) and regional (spatial risk segmentation, geographical supply and demand for medical resources). The article highlights its innovative process for data acquisition through big data technology feeding into GIS.

For the USA, Warren and Skillman (2020) and Gao et al. (2020) used anonymous data on mobile device locations to measure population mobility by day. The resulting geospatial statistics were used to predict levels of disease spread and evaluate the effectiveness of health policy strategies for containment. Chen et al. (2020a) and Chen et al. (2020b), on the other hand, developed a mathematical model that characterizes infections by state and incorporates interstate traveller inputs and outputs. The modelling reveals that stopping interstate travel when the disease is already widespread makes little difference—it is akin, to use an old English proverb, to closing the stable door after the horse has bolted. This model could also be used to determine the resources needed before state policies on social distancing can be safely lifted.

Allcott et al. (2020), as mentioned in Section 2.3, analysed the relationship between the governing party in each U.S. county, social behaviour with respect to containment measures, and confirmed cases of COVID-19. This paper used GPS data from SafeGraph, adding GPS pings from numerous mobile applications to measure pedestrian traffic patterns at a collection of points of interest: retail stores, restaurants, cinemas, hospitals, and other locations. For each point, SafeGraph reports its geographic location and the total number of visitors.

Social network data is also being used to measure and understand the geographic structure of social networks (Bailey et al., 2018). Particularly in the work of Kuchler et al. (2020), mentioned in 2.3, the authors claim that measuring the geographic structure of social networks can be useful for epidemiologists in predicting the spread of communicable diseases, as they presented in their study in Westchester County (NY, USA), and the Lodi municipality (Lombardy, Italy).

2.5. Web-based mapping

Web map viewers are playing a very important role in the dissemination and provision of (official) information on COVID-19. They are very effective for the spatial representation of the pandemic and its evolution, both for specialised and non-specialised Internet users. Boulos and Geraghty (2020) reviewed the different web mapping applications on COVID-19 available in January and February. Since then, more viewers have been created; each country has its own viewer, often with detailed information at the provincial or local level. Themes have also become more diversified, as in three cases: a map of changes in population mobility in US counties,[1] a map of information from Israeli population surveys,[2] and a map of New York City sidewalks indicating their suitability for social distancing.[3]

However, the most widely referenced viewer, the one with the most international information compiled, and the first to go online out is that of Dong et al. (2020), from John Hopkins University.[4] Numerous papers reviewed here have used their information or cited them (Ahmadi et al., 2020a; Ahmadi et al., 2020b; Buzai, 2020; Desjardins et al., 2020; Kuchler et al., 2020; Mollalo et al., 2020; Padula and Davidson, 2020; Sajadi et al., 2020a). Several media outlets around the world also refer to this platform. Numerous subsequent national viewers, generated for their respective territorial domains, have been based on Dong et al. (2020), following their web design and the ArcGIS online platform and its map bases. Regarding this last point, in relation to the web mapping platforms available for the visualization of geographic information, it is worth mentioning that other works used free platforms such as openstreetmap (Iacus et al., 2020; Rossman et al., 2020; Minetto et al., 2020).

The news media also are constantly using maps to present COVID-19 information to their audiences. International, national and local news organizations are developing their own personalized maps with international information, plus information corresponding to their country. Powerful media outlets mapping their information include *The New York Times*,[5] *South China Morning Post*,[6] *El Pais*,[7] *Yomiuri shimbun*,[8] *Le Monde*,[9] and the *BBC*,[10] all of which have their sections highlighted with eloquent interactive maps and graphics, and receive large numbers of daily visits.

3. Discussion

These days, a geographical axiom has been alluded to which, paradoxically, does not apply to the COVID-19 pandemic: "all objects (on the earth's surface) are related to each other, but the relationships are more intense with the closer objects than with the more distant ones" (Tobler, 1970: 236). The falsification of this axiom indicates the need to adapt it to today's interconnected world. Already in 2015 Escolano modified the axiom as follows: "all objects (on the earth's surface) are related to each other, but the relationships are more intense among the better connected objects regardless of their proximity" (Escolano, 2015: 51). For the current case of COVID-19, Kost (2020) states that "everything is related to everything else, and mobility compresses spatial things" (Kost, 2020: 9), or, in the words of Giuliani, "the phenomenon external to an area of interest affects what goes on inside" (Giuliani et al., 2020: 3). Tobler's (1970) premise, although effective in its message and true in some senses, does not conform to the geography of the 21st century.

1 https://geods.geography.wisc.edu/covid19/physical-distancing/
2 https://coronaisrael.org/
3 https://www.sidewalkwidths.nyc/
4 https://coronavirus.jhu.edu/map.html
5 https://www.nytimes.com/interactive/2020/world/coronavirus-maps.html
6 https://multimedia.scmp.com/infographics/news/china/article/3047038/wuhan-virus/index.html?src=article-launcher
7 https://elpais.com/sociedad/2020/04/13/actualidad/1586788600_290634.html
8 https://www.yomiuri.co.jp/topics/covid19/
9 https://www.lemonde.fr/les-decodeurs/article/2020/02/27/en-carte-visualisez-la-propagation-mondiale-de-l-epidemie-de-coronavirus_6031092_4355770.html
10 https://www.bbc.com/mundo/noticias-51705060

From the reflections in this review, we posit that, in order to face COVID-19, it is necessary to approach the issues from an interdisciplinary perspective, with proactive measures, international solidarity and collaboration, and a global perspective (from De Ángel Solá et al., 2020 ; Coccia, 2020; Holmes et al., 2020; Segal et al., 2020). Unfortunately, at the political level, contradictions have emerged and been reported in the media, particularly where pundits and analysts acritically accept the inherent conflict between economic interests and public health. For example, in an international case, US companies are demanding Mexico exercise greater laxity in its preventive measures so that the commodity chains of US companies dependent on workers in Mexico's maquiladoras are not disrupted (Hernández Navarro, 2020; Corchado and Olivares, 2020).

The generation of information is one of the keys to confronting COVID-19. There are proposals worth mentioning, such as the international consortium Coronavirus Census Collective[11] (Segal et al., 2020) where they are integrating information from multiple sources, including surveys, diagnostic laboratory test results, geospatial statistics, and real-time data. These efforts will likely be referenced in future events, just as we are currently building on previous pandemic work.

COVID-19 as an object of study is a thematic polyhedron where geographical variables are present in several of its facets. An important part of the study of the COVID-19 pandemic is based on geographical data, which are then processed through GIS and spatial statistical tools. But the most pressing issue is that these studies contribute to better social mobilization, decision-making, and planning, especially by helping to:

- provide a large number of methods on the dynamics of spatial transmission that enable effective feedback to public health officials, decision makers, and affected communities (Desjardins et al., 2020);
- improve estimations of the number of infections, detection of possible new outbreaks, and thus facilitate more successful interventions in public health (Coccia, 2020);
- improve the locations of health services and controls, points of care, and facilitate access, which translates into an improvement in patient outcomes, time, and material resources (Kuupiel et al., 2020);
- understand and map human movement, and formulate appropriate scientific, policy, and social measures (Chan et al., 2020; Mollalo et al., 2020); and
- predict the spatial spread and temporal trends of the outbreak, which is essential for health services (Giuliani et al., 2020).

Regarding the last point, we expect that the future will bring a greater volume of information, with geospatial data increasing at least 20% each year (Lee and Kang, 2015), and hopefully increased accessibility. GIS developers must work towards opening up their online applications, and designing software applications that operate with big data in a user-friendly way while responding to privacy and other social concerns, more than is currently the case. For data integration, historical data tracking and dynamic mapping of spatial-temporal variables at multiple scales would be invaluable (Zhou et al., 2020).

Predictive modelling is becoming one of the vocations of spatial-temporal analysis, mainly referring to climate analysis and its effects on the expansion of COVID-19. As the pandemic has developed, more complex and refined predictive models of virus spread have also been generated. At a global level, there is a very important jump from the work of Wang et al. (2020), which used two variables—air temperature and relative humidity—to the work presented by Bariotakis et al. (2020) in which 19 bioclimatic parameters were analysed. Sophisticated works with more accumulated variables (Mollalo et al., 2020; Baker et al., 2020) conclude that, although the climate and geography are factors that can modulate the transmission of SARS-CoV-2, these are not determining factors in the trajectory of the pandemic.

[11] https://coronaviruscensuscollective.org

In terms of nation-states, both as objects of study and the places of origin of the authors, China and the USA have carried out the most analysis on their territorial domains, especially in relation to big data—almost all the papers come from there. In the rest of the categories, many Chinese papers have been oriented towards spatial-temporal analysis under different statistical models, and those from the USA, on the other hand, have a greater emphasis on inter-disciplinary analyses. The intervention of other countries in GIS studies of COVID-19 has been extended as it has evolved chronologically. Iran, Israel, South Africa, Australia, Brazil, South Korea, Italy, Spain and India could represent this second grouping, with more than one work.

Although valuable work has been done in Africa (Gibson and Rush, 2020; Kuupiel et al., 2020), Latin America and the Caribbean (De Ángel Solá et al., 2020; Buzai, 2020) and in South Asian countries (Sarwar et al., 2020), work here is clearly insufficient. COVID-19 is full of many unknowns, and in these regions of the world intersecting social issues could multiply the effects of the pandemic. Health geography that uses GIS to respond to needs at the local, neighbourhood and village level, is shown to have a very strong applicability. We believe that research in health geography should be expanded in terms of topics and areas of study, for its ability to map health infrastructures and their accessibility, and for territorial planning in terms of location and allocation of health services (Cicalò and Valentino, 2019). We suggest that research in health geography and COVID-19 has the potential to be applied in more subjects and in more regions of the world that need studies of this type. In short, more experiences are needed in this regard.

The management of public space in cities after the pandemic is another of the great challenges that we will face in the near future (Honey-Roses et al., 2020). In addition to the spatial analysis applications summarized in this work, participatory GIS is seen as a very useful application in post-coronavirus urban planning, through the inclusive participation of the population that inhabits these places. Such an application is helpful in identifying which spaces are social priorities, context-sensitive place-based information, social sustainability and social, economic and environmental dynamics that affect a specific community (Samuelsson et al., 2020).

With regard to access to information, the availability of information from the WHO, public institutions in different countries, the JHU and large platforms such as Google, Baidu or Facebook, who have made their information available to the public, is proving to be fundamental to the proliferation of academic work and efforts to coordinate responses to the outbreak. It is important to note that 76% of the works consulted have used official data on SARS-CoV-2 infections. In addition, 20% have used information data mining obtained from cell phones (geolocation, payments, points of connection), flights or social networks. To a lesser extent, 10% of the works have been based on the socio-economic characteristics of the population and its urban structure, and some specific cases that have worked through polls, participatory GIS and satellite images (Table 1).

Regarding software, for GIS more than half of the works that refer to the software used mention ArcGIS, followed by R, QGIS, Kosmo and GeoJSON. For statistics, those referred to are R, SPSS, ERA5, WinBUGS, Geomathematics and SaTScan. We expect that GIS development will increase, both for private platforms and free ones.

The web map viewers appear to have been successful at disseminating information to the public and specialists, becoming a tool that improves data transparency and helps authorities to communicate important information and generates greater sensitivity in public opinion (Cicalò and Valentino, 2019; Boulos and Geraghty, 2020). Many countries have their own viewers within their official websites. As a criticism, we could comment that some are unnecessarily complex and not very intuitive, and in others it takes too long to load the cartography, which causes the tool to lose effectiveness. Behind this comment lies the observation that web map viewers are becoming a fad that, in some cases, is unnecessary where a static image at an appropriate resolution could work perfectly well to communicate spatial information.

Regarding cartographic design, as already noted in February (Field, 2020), we continue to identify cases with inadequate use of COVID-19 information in their maps, due to the incorrect use of choropleth thematic mapping technique, conformal projections where the area is a datum considered in the interpretation of the information, or the dispensable use of 3D tools. Ultimately, a map is only as helpful as the data, assumptions, representations and interpretations that go into it.

4. Conclusions

This work is an addition to recent reviews on COVID-19 that offers a geographical perspective. It is a compendium that identifies the themes and analyses that are being carried out with GIS and spatial-statistical tools. We believe that compiling this information can streamline efforts for future, more effective bibliographic inquiries. It can also serve as support for the evolution in the use of these tools in the following months and inspire new reflections for the readers, connecting between themes and tools. We have delimit a state of the art five months after the start of the phenomenon, where each week seems like a year on a human scale.

To date, spatiotemporal analysis and disease mapping, health and social geography, environmental variables, data mining, and web-based mapping have been the most recurrent topics.

COVID-19 studies with GIS could be valuable tools in decision-making and, more importantly, social mobilization and community responses. Health geography also has a critical social perspective that is highly relevant, so that political decisions can be accountable to all sectors of society, hopefully minimising the regularity with which marginalised populations are sacrificed or left unprotected.

Understanding the spatial-temporal dynamics of COVID-19 is critical to its mitigation, which is why such work is being done in all regions of the world. This is due in large part to the opening up of large volumes of information by public institutions, international organizations and private companies with geospatial information.

CRediT authorship contribution statement

Ivan Franch-Pardo: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration.**Brian M. Napoletano:** Methodology, Writing - review & editing, Visualization, Supervision. **Fernando Rosete-Verges:**Formal analysis, Investigation, Writing - original draft.**Lawal Billa:**Conceptualization, Writing - review & editing, Visualization, Supervision.

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.

References

Ahmadi, A., Fadai, Y., Shirani, M., Rahmani, F., 2020a. Modeling and forecasting trend of COVID-19 epidemic in Iran until May 13, 2020. Medical Journal of The Islamic Republic of Iran (MJIRI) 34 (1), 183–195.

Ahmadi, M., Sharifi, A., Dorosti, S., Ghoushchi, S.J., Ghanbari, N., 2020b. Investigation of effective climatology parameters on COVID-19 outbreak in Iran. Sci. Total Environ. 729, 138705 10 August 2020.

Allcott, H., Boxell, L., Conway, J., Gentzkow, M., Thaler, M., Yang, D.Y., 2020. Polarization and public health: partisan differences in social distancing during the coronavirus pandemic. NBER Working Paper (w26946).

Arab-Mazar, Z., Sah, R., Rabaan, A.A., Dhama, K., Rodriguez-Morales, A.J., 2020. Mapping the incidence of the COVID-19 hotspot in Iran – implications for travellers. Travel Med. Infect. Dis. https://doi.org/10.1016/j.tmaid.2020.101630.

Bailey, M., Cao, R., Kuchler, T., Stroebel, J., Wong, A., 2018. Social connectedness: measurements, determinants, and effects. J. Econ. Perspect. 32 (3), 259–280.

Baker, R.E., Yang, W., Vecchi, G.A., Metcalf, C.J.E., Grenfell, B.T., 2020. Susceptible supply limits the role of climate in the early SARS-CoV-2 pandemic. Science, eabc2535.

Bariotakis, M., Sourvinos, G., Castanas, E., Pirintsos, S.A., 2020. Climatic influences on the worldwide spread of SARS-CoV-2. medRxiv https://doi.org/10.1101/2020.03.19.20038158 preprint.

Bashir, M.F., Ma, B., 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. 138835.

Bocco, G., 2016. Remoteness and remote places. A geographic perspective. Geoforum 77, 178–181.

Bogoch, I.I., Watts, A., Thomas-Bachli, A., Huber, C., Kraemer, M.U., Khan, K., 2020. Potential for global spread of a novel coronavirus from China. Journal of Travel Medicine 27 (2) (taaa011).

Boulos, M.N.K., Geraghty, E.M., 2020. 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 outbreaks and epidemics. Int. J. Health Geogr. 19, 8.

Buckee, C.O., Balsari, S., Chan, J., Crosas, M., Dominici, F., Gasser, U., Lipsitch, M., 2020. Aggregated mobility data could help fight COVID-19 Science (New York, NY). 368 (6487) pp. 145–146.

Buzai, G.D., 2020. De Wuhan a Luján. Evolución espacial del COVID-19. Posición 3, 2683–8915.

Casanova, L.M., Jeon, S., Rutala, W.A., Weber, D.J., Sobsey, M.D., 2010. Effects of air temperature and relative humidity on coronavirus survival on surfaces. Appl. Environ. Microbiol. 76 (9), 2712–2717.

Chan, H.F., Skali, A., Torgler, B., 2020. A Global Dataset of Human Mobility. Center for Research in Economics, Management and the Arts (CREMA) (2020-04).

Chan, K.H., et al., 2011. The effects of temperature and relative humidity on the viability of the SARS coronavirus. Adv. Virol. 734690–734696.

Chen, S., Li, Q., Gao, S., Kang, Y., Shi, X., 2020a. Mitigating COVID-19 outbreak via high testing capacity and strong transmission-intervention in the United States. medRxiv 2020.04.03.20052720.

Chen, Z.L., Zhang, Q., Lu, Y., Guo, Z.M., Zhang, X., Zhang, W.J., ... Lu, J.H., 2020b. Distribution of the COVID-19 epidemic and correlation with population emigration from wuhan, China. Chinese medical journal https://doi.org/10.1097/CM9.0000000000000782.

Cicalò, E., Valentino, M., 2019. Mapping and visualisation on of health data. The contribution on of the graphic sciences to medical research from New York yellow fever to China coronavirus. Disegnarecon 12 (23), 12–21.

Coccia, M., 2020. Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. Sci. Total Environ. 138474.

Corchado, A., Olivares, V., 2020. U.S. companies join call for reopening of border factories despite rising deaths. The Dallas Morning News https://www.dallasnews.com/news/public-health/2020/04/23/us-companies-join-call-for-re-opening-of-border-factories-despite-rising-deaths/ (23 April 2020).

Dagnino, R., Weber, E.J., Panitz, L.M., 2020. Monitoramento do Coronavírus (Covid-19) nos municípios do Rio Grande do Sul, Brasil. SocArXiv https://doi.org/10.31235/osf.io/3uqn5 (March, 28).

Davis, M., 2020. The monster is finally at the door. MR Online https://mronline.org/2020/03/19/mike-davis-on-covid-19-the-monster-is-finally-at-the-door/ (19 March 2020).

De Ángel Solá, D.E., Wang, L., Vázquez, M., Méndez Lázaro, P.A., 2020. Weathering the pandemic: how the Caribbean Basin can use viral and environmental patterns to predict, prepare and respond to COVID-19. J. Med. Virol. 1–9.

De Kadt, J., Gotz, G., Hamann, C., Maree, G., Parker, A., 2020. Mapping Vulnerability to COVID-19 in Gauteng. GCRO Map of the Month. Gauteng City-Region Observatory.

Desjardins, M.R., Hohl, A., Delmelle, E.M., 2020. Rapid surveillance of COVID-19 in the United States using a prospective space-time scan statistic: detecting and evaluating emerging clusters. Appl. Geogr. 102202.

Dong, E., Du, H., Gardner, L., 2020. An interactive web-based dashboard to track COVID-19 in real time. Lancet Infect. Dis. 20, 533–534.

Escolano, S., 2015. Sistemas de información geográfica: una introducción para estudiantes de geografía. Prensas de la Universidad de Zaragoza, p. 251 (978-84-16515-12-7).

Field, K., 2020. Mapping coronavirus, responsibly. ArGIS blog. https://www.esri.com/arcgis-blog/products/product/mapping/mapping-coronavirus-responsibly/.

Gao, S., Rao, J., Kang, Y., Liang, Y., Kruse, J., 2020. Mapping County-Level Mobility Pattern Changes in the United States in Response to COVID-19 (SSRN 3570145).

Gibson, L., Rush, D., 2020. Novel coronavirus in Cape Town informal settlements: feasibility of using informal dwelling outlines to identify high risk areas for COVID-19 transmission from a social distancing perspective. JMIR Public Health Surveill. 6 (2), e18844. https://doi.org/10.2196/18844.

Giuliani, D., Dickson, M.M., Espa, G., Santi, F., 2020. Modelling and Predicting the Spatio-Temporal Spread of Coronavirus Disease 2019 (COVID-19) in Italy (3/20/2020). SSRN. https://doi.org/10.2139/ssrn.3559569.

Gross, B., Zheng, Z., Liu, S., Chen, X., Sela, A., Li, J., ... Havlin, S., 2020. Spatio-temporal propagation of COVID-19 pandemics. medRxiv 2020.03.23.20041517.

Guan, W.J., Ni, Z.Y., Hu, Y., Liang, W.H., Ou, C.Q., He, J.X., ... Du, B., 2020. Clinical characteristics of coronavirus disease 2019 in China. New England Journal of Medicine 382 (18), 1708–1720.

Gupta, S., Raghuwanshi, G.S., Chanda, A., 2020. Effect of weather on COVID-19 spread in the US: a prediction model for India in 2020. Sci. Total Environ. 138860.

Hasan, N.A., Mahfujul Haque, M., 2020. Predict the next moves of COVID-19: reveal the temperate and tropical countries scenario. medRxiv https://doi.org/10.1101/2020.04.04.20052928.

Hernández Navarro, L., 2020. Maquiladoras y coronavirus. La Jornada. https://www.jornada.com.mx/2020/04/28/opinion/016a2pol (28 April 2020).

Holmes, E.A., O'Connor, R.C., Perry, V.H., Tracey, I., Wessely, S., Arseneault, L., ... Ford, T., 2020. Multidisciplinary research priorities for the COVID-19 pandemic: a call for action for mental health science. The Lancet Psychiatry 7 (6), 547–560.
Honey-Roses, J., Anguelovski, I., Bohigas, J., Chireh, V., Daher, C., Konijnendijk, C., Litt, J., Mawani, V., McCall, M., Orellana, A., 2020. The Impact of COVID-19 on Public Space: A Review of the Emerging Questions.
Huang, H., Wang, Y., Wang, Z., Liang, Z., Qu, S., Ma, S., ... Liu, X., 2020. Epidemic Features and Control of 2019 Novel Coronavirus Pneumonia in Wenzhou, China China 3/3/2020).
Iacus, S.M., Natale, F., Vespe, M., 2020. Flight restrictions from China during the COVID-2019 coronavirus outbreak. arXiv 1–9 (preprint arXiv:2003.03686).
Jella, T.K., Acuña, A.J., Samuel, L.T., Jella, T.K., Mroz, T.E., Kamath, A.F., 2020. Geospatial mapping of orthopaedic surgeons age 60 and over and confirmed cases of COVID-19. J. Bone Joint Surg. Am. https://doi.org/10.2106/JBJS.20.00577.
Kearns, R., Moon, G., 2002. From medical to health geography: novelty, place and theory after a decade of change. Prog. Hum. Geogr. 26 (5), 605–625.
Keshavarzi, A., 2020. Coronavirus Infectious Disease (COVID-19) Modeling: Evidence of Geographical Signals. SSRN 3568425.
Kost, G.J., 2020. Geospatial hotspots need point-of-care strategies to stop highly infectious outbreaks: Ebola and coronavirus. Archives of Pathology & Laboratory Medicine https://doi.org/10.5858/arpa.2020-0172-RA (In press).
Kuchler, T., Russel, D., Stroebel, J., 2020. The Geographic Spread of COVID-19 Correlates With Structure of Social Networks as Measured by Facebook (No. w26990). National Bureau of Economic Research.
Kuupiel, D., Adu, K.M., Bawontuo, V., Adogboba, D.A., Drain, P.K., Moshabela, M., Mashamba-Thompson, T.P., 2020. Geographical accessibility to glucose-6-phosphate dioxygenase deficiency point-of-care testing for antenatal care in Ghana. Diagnostics 10 (4), 229.
Lakhani, A., 2020a. Introducing the percent, number, availability, and capacity [PNAC] spatial approach to identify priority rural areas requiring targeted health support in light of COVID-19: a commentary and application. J. Rural. Health 1–4.
Lakhani, A., 2020b. Which Melbourne metropolitan areas are vulnerable to COVID-19 based on age, disability and access to health services? Using spatial analysis to identify service gaps and inform delivery. J. Pain Symptom Manag. (In Press).
Latif, S., Usman, M., Manzoor, S., Iqbal, W., Qadir, J., Tyson, G., ... Crowcroft, J., 2020. Leveraging Data Science To Combat COVID-19: A Comprehensive Review.
Lee, J.G., Kang, M., 2015. Geospatial big data: challenges and opportunities. Big Data Research 2 (2), 74–81.
Liu, J., Zhou, J., Yao, J., Zhang, X., Li, L., ... Zhang, K., 2020. Impact of meteorological factors on the COVID-19 transmission: A multicity study in China. Science of the Total Environment 726, 138513.
Lowen, A., Mubareka, S., Steel, J., Palese, P., 2007. Influenza virus transmission is dependent on relative humidity and temperature. PLoS Pathog. 3 (10), 1470–1476.
Lowen, A., Samira, M., Palese, P., 2018. High temperature (30 °C) blocks aerosol but not contact transmission of influenza virus. J. Virol. 82, 5650–5652.
Luo, W., Majumder, M., Liu, D., Poirier, C., Mandl, K., Lipsitch, M., Santillana, M., 2020. The role of absolute humidity on transmission rates of the COVID-19 outbreak MedRxiv.
Ma, Y., Zhao, Y., Liu, J., He, X., Wang, B., Fu, S., Yan, J., Niu, J., Zhou, J., Luo, B., 2020. Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. Sci. Total Environ. 724, 138226.
Meade, M.S., 2014. Medical geography. The Wiley Blackwell Encyclopedia of Health, Illness, Behavior, and Society, pp. 1375–1381.
Minetto, R., Segundo, M.P., Rotich, G., Sarkar, S., 2020. Measuring human and economic activity from satellite imagery to support city-scale decision-making during COVID-19 pandemic. arXiv, 215786072 (preprint arXiv:2004.07438).
Mollalo, A., Vahedi, B., Rivera, K.M., 2020. GIS-based spatial modeling of COVID-19 incidence rate in the continental United States. Sci. Total Environ. 138884.
Murugesan, B., Karuppannan, S., Mengistie, A.T., Ranganathan, M., Gopalakrishnan, G., 2020. Distribution and TrendAnalysis of COVID-19 in India: geospatial approach. Journal of Geographical Studies 4 (1), 1–9. https://doi.org/10.21523/gcj5.20040101.
Orea, L., Álvarez, I.C., 2020. How Effective Has the Spanish Lockdown Been to Battle COVID-19? A Spatial Analysis of the Coronavirus Propagation across Provinces. Documento de Trabajo, 03.
Oto-Peralías, D., 2020. Regional Correlations of COVID-19 in Spain. OSF Preprints (April, 24).
Padula, W.V., Davidson, P., 2020. Countries with High Registered Nurse (RN) Concentrations Observe Reduced Mortality Rates of Coronavirus Disease 2019 (COVID-19) (Available at SSRN 3566190).
Pattison, W.D., 1964. The four traditions of geography. J. Geogr. 63, 211–216.
Pham, Q.V., Nguyen, D.C., Hwang, W.J., Pathirana, P.N., 2020. Artificial Intelligence (AI) and Big Data for Coronavirus (COVID-19) Pandemic: A Survey on the State-of-the-Arts.
Qi, H., Xiao, S., Shi, R., Ward, M.P., Chen, Y., Tu, W., ... Zhang, Z., 2020. COVID-19 transmission in Mainland China is associated with temperature and humidity: a time-series analysis. Science of The Total Environment 138778.
Rezaei, M., Nouri, A.A., Park, G.S., Kim, D.H., 2020. Application of geographic information system in monitoring and detecting the COVID-19 outbreak. Iran. J. Public Health 49, 114–116.
Rossman, H., Keshet, A., Shilo, S., Gavrieli, A., Bauman, T., Cohen, O., ... Segal, E., 2020. A framework for identifying regional outbreak and spread of COVID-19 from one-minute population-wide surveys. Nature Medicine 1–4.
Saha, A., Gupta, K., Patil, M., 2020. Monitoring and Epidemiological Trends of Coronavirus Disease (COVID-19) around the World. Osfpreprints.
Sajadi, M.M., Habibzadeh, P., Vintzileos, A., Shokouhi, S., Miralles-Wilhelm, F., Amoroso, A., 2020. Temperature, humidity, and latitude analysis to predict potential spread and seasonality for COVID-19. SSRN. https://ssrn.com/abstract=3550308.
Samuelsson, K., Barthel, S., Colding, J., Vetenskapsakademien, K., Giusti, M., 2020. Urban Nature as a Source of Resilience during Social Distancing Amidst the Coronavirus Pandemic. Research Gate Pre-Print. https://doi.org/10.31219/osf.io/3wx5a.
Santana Juárez, M.V., 2020. COVID-19 en México: comportamiento espacio temporal y condicionantes socioespaciales, febrero y marzo de 2020. Posición 3, 2683–8915.
Sarwar, S., Waheedab, R., Sarwar, S., Khand, A., 2020. COVID-19 challenges to Pakistan: is GIS analysis useful to draw solutions? Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139089.
Sauer, C.O., 1925. The Morphology of Landscape. University of California, Oakland, CA, USA, pp. 19–53.
Schnaiberg, A., Gould, K., 1994. Environment and Society: The Enduring Conflict. St. Martin's Press, New York, NY, USA, p. 280.
Segal, E., Zhang, F., Lin, X., King, G., Shalem, O., Shilo, S., ... Anders, S., 2020. Building an international consortium for tracking coronavirus health status. medRxiv https://doi.org/10.1038/s41591-020-0929-x.
Silva, R.J., Silva, K., Mattos, J., 2020. Análise espacial sobre a dispersão da covid-19 no Estado da Bahia Scielo preprints.
Su, L., Hong, N., Zhou, X., He, J., Ma, Y., Jiang, H., Han, L., Chang, F., Shan, G., Zhu, W., Long, Y., 2020. Evaluation of the secondary transmission pattern and epidemic prediction of COVID-19 in the four metropolitan areas of China. medRxiv https://doi.org/10.1101/2020.03.06.20032177.
Tamerius, J., Nelson, M.I., Zhou, S.Z., Viboud, C., Miller, M.A., Alonso, W.J., 2011. Global influenza seasonality: reconciling patterns across temperate and tropical regions. Environ. Health Perspect. 119 (4), 439–445.
Tan, J., Mu, L., Huang, J., Yu, S., Chen, B., Yin, J., 2005. An initial investigation of the association between the SARS outbreak and weather: with the view of the environmental temperature and its variation. J. Epidemiol. Community Health 59 (3), 186–192.
Tang, T., Huipeng, L., Gifty, M., Zaisheng, W., Weibin, C., Dan, W., Rongbin, Y., 2020. The changing patter of COVID-19 in China: a tempo-geographic analysis of the SARS-CoV-2 epidemic. Clin. Infect. Dis., ciaa423 https://doi.org/10.1093/cid/ciaa423.
Team CC-R, 2020. Geographic differences in COVID-19 cases, deaths, and incidence - United States, February 12-April 7, 2020. MMWR Morb. Mortal. Wkly Rep. 69 (15), 465–471.
Tobaiqy, M., Qashqary, M., Al-Dahery, S., Mujallad, A., Hershan, A.A., Kamal, M.A., Helmi, N., 2020. Therapeutic management of COVID-19 patients: a systematic review. Infection Prevention in Practice 100061.
Tobler, W.R., 1970. A computer movie simulating urban growth in the Detroit region. Econ. Geogr. 46 (sup1), 234–240.
Tosepu, R., Gunawan, J., Effendy, D.S., Lestari, H., Bahar, H., Asfian, P., 2020. Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia. Sci. Total Environ. 138436.
Turner, B.L., 2002. Contested identities: human-environment geography and disciplinary implications in a restructuring academy. Ann. Assoc. Am. Geogr. 92 (1), 52–74.
Viboud, C., Alonso, W.J., Simonsen, L., 2006. Influenza in tropical regions. PLoS Med. 3 (4), e89.
Wallace, R., 2020. Notes on a novel coronavirus. MR online. https://mronline.org/2020/01/29/notes-on-a-novel-coronavirus/.
Wang, J., Tang, K., Feng, K., Lv, W., 2020. High Temperature and High Humidity Reduce the Transmission of COVID-19. SSRN. https://doi.org/10.2139/ssrn.3551767.
Warren, M.S., Skillman, S.W., 2020. Mobility changes in response to COVID-19. arXiv (preprint arXiv:2003.14228, abs/2003.14228).
Xiong, Y., Guang, Y., Chen, F., Zhu, F., 2020. Spatial statistics and influencing factors of the novel coronavirus pneumonia 2019 epidemic in Hubei Province, China. ResearchSquare https://doi.org/10.21203/rs.3.rs-16858/v2 Preprint.
Zeilig, L., Cross, H., 2020. Pulverized. Review of African Political Economy http://roape.net/2020/03/31/pulverized-capitalism-africa-and-the-covid-19-crisis/ (31 March 2020).
Zhang, X., Rao, H.X., Wu, Y., Huang, Y., Dai, H., 2020. Comparison of the spatiotemporal characteristics of the COVID-19 and SARS outbreaks in mainland China. medRxiv 2020.03.23.20034058.
Zhou, C., Su, F., Pei, T., Zhang, A., Du, Y., Luo, B., ... Song, C., 2020. COVID-19: challenges to GIS with big data. Geography and Sustainability 1 (1), 77–87.