The challenges of the COVID-19 pandemic in geographic science

Os desafios da pandemia COVID-19 na ciência geográfica

Los desafíos de la pandemia de COVID-19 en la ciencia geográfica

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ABSTRACT
The COVID-19 pandemic has impacted geographers and specialists of other areas, driving them to generate knowledge aimed to explain and find solutions to the health crisis that emerged in March 2020. Within the field of geography, quantitative methods, and geotechnologies have been employed to collect measurable data which prove useful explanation and the logical relationship between variables, verifying hypotheses related to COVID-19 contagion and mortality cases. Health geography, as a disciplinary branch, has investigated the spatial-temporal distribution and dynamics of diseases, seeking to understand the processes explaining the spatial structure of them during a pandemic. In this context, a case of study, Mexico City, seeks to address questions from a health geography perspective, such as: What were the causes behind the high levels of pandemic contagion? Which environmental, social, and health factors in time and space relate and contribute to a greater impact of the pandemic? How do these factors interact with each other, and how have they influenced the increase or decrease in contagion and mortality cases? What are the short, medium, and long-term scenarios of COVID-19? To address these inquiries, spatial analysis methods and geotechnological techniques, approached holistically and have efficiently supported the identification of COVID-19 contagion risk zones and their specific characteristics. These insights prove invaluable information for spatial decision-making in comprehensive planning and territorial management.

Keywords: health geography, spatial-temporal dynamics, COVID-19, Geo Artificial Intelligence, Geographic Information Systems (GIS).

RESUMO
A pandemia da COVID-19 impactou geógrafos e especialistas de outras áreas, impulsionando-os a gerar conhecimentos voltados para explicar e encontrar soluções para a crise sanitária surgida em março de 2020. No campo da geografia, métodos quantitativos e geotecnologias têm sido empregados para coletar dados mensuráveis que comprovem a explicação útil e a

relação lógica entre as variáveis, verificando hipóteses relacionadas aos casos de contágio e mortalidade por COVID-19. A geografia da saúde, como ramo disciplinar, tem investigado a distribuição e dinâmica espaço-temporal das doenças, buscando compreender os processos que explicam a estrutura espacial delas durante uma pandemia. Neste contexto, um estudo de caso, a Cidade do México, procura abordar questões do ponto de vista da geografia da saúde, tais como: Quais foram as causas dos elevados níveis de contágio pandémico? Que factores ambientais, sociais e de saúde no tempo e no espaço influenciam e contribuem para um maior impacto da pandemia? Como interagem estes factores entre si e como têm influenciado o aumento ou diminuição dos casos de contágio e mortalidade? Quais são os cenários de curto, médio e longo prazo da COVID-19?. Para responder a estas questões, métodos de análise espacial e técnicas geotecnológicas, abordados de forma holística, têm apoiado de forma eficiente a identificação de zonas de risco de contágio da COVID-19 e das suas características específicas. Estas informações fornecem informações valiosas para a tomada de decisões espaciais no planeamento abrangente e na gestão territorial.

Palavras-chave: geografia da saúde, dinâmica espaço-temporal, COVID-19, Geo Inteligência Artificial, Sistemas de Informação Geográfica (SIG).

RESUMEN
La pandemia por COVID-19 ha incidido en que diversos especialistas como los geógrafos, estén generando conocimientos para dar una explicación, solución a la crisis sanitaria que se ha presentado en marzo de 2020. Desde la geografía se han implementado métodos cuantitativos y geotecnologías para recopilar datos medibles que sean útiles para explicar la relación lógica entre variables, comprobar y verificar hipótesis de los casos de contagio y defunciones derivadas de la pandemia por coronavirus. La geografía de la salud por su enfoque disciplinario ha estudiado la distribución y la dinámica espacio temporal de las enfermedades, comprende los procesos que explican la estructura espacial de las enfermedades en tiempos de pandemia. En este sentido, para el caso de la Ciudad de México, se debe responder bajo dicho enfoque ¿cuáles fueron las causas de los altos niveles de contagios de la pandemia?, ¿cuáles son los factores ambientales, sociales y de salud en tiempo y en espacio que están relacionados y que contribuyeron a un mayor impacto de la pandemia? ¿cómo se relacionan estos factores entre sí?, ¿cómo han incrementado o disminuido los casos de contagio y defunciones?. ¿Cuáles son los escenarios a corto, mediano y largo plazo de la COVID-19?. Para ello los métodos de análisis espacial y técnicas geotecnológicas desde un enfoque integral han apoyado en forma eficiente en la identificación de zonas de riesgo de contagio de COVID-19 y sus características para la toma de decisiones espaciales en los ámbitos de la planeación integral y ordenación territorial.

Palabras clave: geografía de la salud, dinámica espacio temporal, COVID-19, Geo Inteligencia Artificial, Sistemas de Información Geográfica.

1 INTRODUCTION

Throughout history, various epidemiological outbreaks have emerged, posing significant threats to the lives of entire nations, consequently resulting in a profound economic and social repercussions on a global scale. Geographical science has been an instrument in conducting studies to analyse spatial-temporal distribution patterns of diseases, as well as identifying high-risk sites, spatial effects, geographical impact and their association with public health.

Geography, particularly in the field of territorial planning and urban development, investigates COVID-19 as an extraordinary evolutionary phenomenon that has significantly impacted urban populations. The pandemic has unveiled a multitude of spatial variations within cities, arising from diverse factors such as environmental, geographical, social, demographic, epidemiological, ethnic, economic, and infrastructural aspects.

In the context of the COVID-19 pandemic, geographical science has employed spatial models for the localization, distribution, causality, correlation, and evolution of changes in the epidemiological outbreak. Furthermore, it has harnessed geoinformatics tools such as Geographic Information Systems (GIS), programming, statistical models, and Artificial Intelligence algorithms to facilitate the mapping of areas demanding heightened public health attention.

2 OBJECTIVE

The present study is objective to present theoretical and conceptual aspects for investigating the dynamics of the COVID-19 pandemic through the lens of geography, utilizing spatial analysis methods and Artificial Intelligence models in the context of Mexico City. This forms the foundation for developing a comprehensive prototype that incorporates geographical, environmental, epidemiological, and socio-economic characteristics.

3 BACKGROUND

As a result of the global health crisis, there has been an urgent need for swift and informed decision-making. However, scientific research on the theoretical-conceptual integration of the COVID-19 pandemic, grounded in socio-economic, environmental, and epidemiological conditions within densely populated cities, is limited. Few studies focus on quantifying the impact of each condition on the spread and impact of the pandemic, as well as predicting the future spatial-temporal dynamics, which are crucial for enhancing population resilience against similar future events.

Various fields of knowledge have conducted research to provide objective and timely solutions for the SARS-CoV-2 virus. Numerous publications have demonstrated the necessity for interdisciplinary and cross-cutting approaches to understanding, controlling, mitigating, and preventing respiratory diseases during epidemic times. In the context of geography, studies should focus on the stages of health promotion and prevention.

International studies have employed Geospatial Artificial Intelligence tools for tracking the spread of the SARS-CoV-2 virus (Das & Bebortta, 2022), identifying outbreak trends (Kamel Boulos, 2004; Mohammad Ayyoubzadeh et al., 2020), predicting potential epidemiological waves (Yang et al., 2020), mapping the spatial distribution of infected cases in the short term (Moneer Yahya et al., 2021), assessing vulnerability in areas with older adult populations (Razavi-Termeh et al., 2022), and providing early warning of COVID-19 outbreaks (Wang et al., 2022). In addition, the social vulnerability to COVID-19 in cities includes populations engaged in informal economic activities, among others.

From social conditions and a Multilayer Perceptron Artificial Neural Network model, it has been discovered that unemployment is one of the factors that has most affected the population in situations of respiratory disease risk (Kianfar et al., 2022) around the world. Besides, it has been confirmed that high mortality variations in the southern hemisphere are associated with socioeconomic factors and demographic structure (Mansour et al., 2022). Using machine learning algorithms and spatial analysis, social and urban factors have been examined with the purpose of identifying and evacuating areas with high infection risk (Pourghasemi et al., 2020). The development of this type of investigation whether with correlated or isolated data, allows the construction of adequate and timely systems for local and regional health authorities (Caldas Barros e Sá et al., 2020; Silva et al., 2021).

Research based on Geographic Information Systems has indicated that geographical and environmental factors, such as climate (Chen et al., 2021; Su et al., 2020), temperature (Bashir et al., 2020; Bedford et al., 2015), relative humidity (Dalziel et al., 2018; Thai et al., 2015), air quality (Fattorini & Regoli, 2020; Bert & Stephen, 2002), and socio-spatial health conditions, including income (Patel et al., 2020), family members (Truong & Asare, 2021), economic activity (Bank of Mexico, 2020), education level (Faghri et al., 2021), population density (Teller, 2021), sex (Nielsen et al., 2021), and vulnerable populations (Decoster et al., 2021), are factors that influence with the increase in COVID-19 infection cases and fatalities.

In the case of Mexico, Geographic Information Systems have been implemented as a spatial strategy to conduct spatial epidemiological analyses of COVID-19 infection outbreaks (Ramírez-Aldana et al., 2021; Vílchez et al., 2022). Artificial Intelligence models have been compared to predict morality dynamics (Conde-Gutiérrez et al., 2021a), and regression models have been employed to identify structural and health determinants that increase susceptibility to the pandemic (Bello-Chavolla et al., 2021). Moreover, Sierra-Alcocer et al. (2022) have developed COVID-19 vulnerability indices in the entire nation.

4 THEORETICAL ASPECTS

Since the incorporation of the neopositivist paradigm in geographical science in the mid-20th century, this one has worked as a foundation for the development of research with epistemological and methodological approaches based on logic and the measurement of social and environmental data. Since then, research has emphasized the use of quantitative analysis techniques, such as statistics, automated cartography, predictive algorithms, and explanatory models of geographical phenomena (Pillet Capdepón, 2004). This paradigm seeks scientific rigor, objectivity, precision, and spatial measurement to eliminate subjective interpretations (Delgado Mahecha, 2003).

The emergence of the new geography has integrated statistical tools to measure spatial relationships (Sánchez, 2010) and has focused on analysing spatial patterns of social phenomena and their interaction with the environment from a geometric, measurable, and quantifiable perspective (Ortega Valcárcel, 2000). In response to research demands, a geotechnological paradigm with a digital vision has been required to explain spatial reality through Geographic Information Technologies, employing spatial analysis models, Geographic Information Systems (GIS), photogrammetry, and GeoArtificial Intelligence (Buzai, 2001).

To comprehend the phenomenon of COVID-19 infections and fatalities, a great number of branches of geography, primarily health geography, play a central role in understanding morbidity, comorbidity, and deaths in a temporal space dimension based on historical data.

According to Barcellos et al. (2018), health geography, from a macroscopic perspective, encompasses the context and spatial dynamics in which health-disease and disease-care issues occur, functioning as a strategy of intervention in the territory. In other words, its scope of action revolves around understanding disease surveillance processes, healthcare provision, health promotion, and the provision of health services to the population.

4.1 FUNDAMENTAL CONCEPTS OF SPATIAL ANALYSIS

Localization: This concept refers to the specific place and location in the understanding of geographical phenomena and processes. It is crucial for comprehending the spatiotemporal relationship between humans and society in the geographical space. The geographer must accurately determine where the studied phenomenon occurs (Berry, 1964). The key to this principle is the concepts of site and situation, as well as the topology or position of objects.

Causality or Association: This principle suggests that phenomena and processes in geographical space are not isolated; it examines the causes that originate, aggravate or increase a phenomenon in space.

Correlation or Connection: Correlation stems from the relationships and interactions between humans and their environment. It allows for a broader understanding of space to conduct detailed studies (Buzai & Baxendale, 2013).

Comparison or Generalization: This principle emphasizes the importance of contrasting areas, regions, social, economic, and environmental processes, enabling the identification of similarities or differences in human-space relationships (Lipp, 2016).

Evolution: This principle relates the process of increment or decrement of a phenomenon, requiring a historical analysis that works as a starting point for understanding the spatiotemporal dynamics and transformative agents. Temporal studies explain how, where, and when a phenomenon occurred (Buzai & Baxendale, 2013).

4.2 HEALTH GEOGRAPHY

Health geography is a discipline that focuses on the temporary space dynamics of diseases by identifying patterns of geographical distribution and their relationship with social and environmental conditions that impact the population's health status. Since the 1960s, it has been characterized by its emphasis on population health and well-being (Ortega Valcárcel, 2000).

One of the main challenges of health geography is to understand the socio-spatial, economic, environmental, geographical, and epidemiological conditions that influence the spread and fatality rates of COVID-19 through the basic principles of geography (Buzai & Santana Juárez, 2018).

By applying the principles of geography, it becomes possible to address the following questions arising from the COVID-19 pandemic: What are the spatial characteristics in areas with the highest infection rates? What are the social, environmental, and epidemiological causes influencing the spread of the virus? How does COVID-19 relate to comorbidities in the most affected population? Which regions are at the highest risk of contagion in the short, medium, and long term? Addressing these questions allows the identification of health demands specific to different spatial scales of analysis and the development of highly targeted public policies that align with the unique characteristics of the population.

During the high-risk period of the COVID-19 pandemic, socio-economic, epidemiological, and geographical-environmental factors played a significant role in exponentially increasing infection cases worldwide. In the initial months of the pandemic (March, April, and May 2020), there were 6,036,798 reported cases and 412,023 fatalities globally (World Health Organization, 2020). In Mexico, there were 125,202 confirmed cases and 20,837 deaths, in the entire nation, Mexico City registering 33,174 infected individuals and 5,245 fatalities (CONACYT et al., 2023).

These figures highlight how the COVID-19 pandemic resulted from various social, educational, environmental, lifestyle, housing conditions, healthcare, mobility (Sarra & Mülfarth, 2021), cultural, ethnic, and factors such as continental dimensions (Leite, 2020), and other challenges experienced on a global and national scale. The situation tragically claimed the lives of millions of people, especially those vulnerable to the SARS-CoV-2 virus.

4.3 SOCIO-SPATIAL HEALTH CONDITIONS IN THE COVID-19

Currently, it is crucial to understand the Socio-spatial Health Conditions to define the social characteristics as a strategy for analyzing the health of the population residing in densely populated urban areas, such as Mexico City (Buzai, 2021). This approach allows for the identification of priority areas for healthcare intervention. For instance, in industrialized regions like the Mexican capital, poor health, nutrition, employment, housing conditions, and heavy reliance on vehicles have led to a state of high exposure to atmospheric pollutants from various sources, including industries and public transportation. This exposure increases the risk of respiratory diseases, strokes, and lung cancer (Pan American Health Organization, 2023). In the worst cases, it can exacerbate the risk of COVID-19 infection and fatality among the most vulnerable populations. Through the Socio-spatial Health Conditions, it becomes possible to identify zones requiring much more healthcare attention.

Although the COVID-19 pandemic is not purely a physical phenomenon like an earthquake or a volcanic eruption, it is a social and epidemiological phenomenon that is interconnected with geographical and environmental factors such as weather conditions, and air pollution. These factors have resulted from a long process of imbalance and distress in the population due to high exposure to a mixture of atmospheric pollutants over long time periods, leading to respiratory illnesses in urban areas like Mexico City. Health geography explains the social conditions such as transportation, mobility, education, and employment, also their relationship with COVID-19 infection and fatality cases.

To achieve this, health geography draws upon various branches, including population geography, economic geography, urban geography, trade and services geography, industrial geography, cultural geography, regional geography, environmental geography, and risk geography. Furthermore, it collaborates with disciplines such as climatology, meteorology, and territorial planning, among others.

Given the interdisciplinary nature of health geography, it relies on geotechnological tools and disease tracking instruments, as seen in the case of the COVID-19 pandemic. It utilizes Geographic Information Systems (GIS), spatial analysis models, and Artificial Intelligence algorithms to effectively visualize and communicate the spread of the virus in a targeted and efficient manner.

4.4 GEOTECHNOLOGIES IN HEALTH

Geographic Information Systems (GIS) in health geography have played a significant role in understanding spatial relationships between location and health. Historically, one of the earliest works in health cartography dates to 1854 during the cholera epidemic in the city of London, England, where Dr. Snow demonstrated that cartographic tools are a valuable resource for addressing and identifying spatial health issues (Khashoggi & Murad, 2020).

Currently, geotechnological tools have allowed for the integration of various spatial data sources, such as population and housing censuses, surveys, sensor data, social networks, satellital, and drone imagery, into a single system for analysis, visualization, and dissemination. GIS technology has evolved to the point where it works not only as a processing and analysis tool for spatial data but also plays a vital role in times of pandemics by providing valuable information through virus spread mapping, locating vulnerable populations, assessing hospital capacity, and forecasting propagation patterns (Dangermond et al., 2020).

Mapping the distribution of communicable and non-communicable diseases has been a task by geographers and planners to spatial model pandemics and epidemics. They have employed various spatial analysis methods that allow the identification of spatial patterns of morbidity, regions with high transmission incidence rates, areas of high vulnerability and the prediction of epidemiological outbreaks.

The methods and techniques utilized during the COVID-19 pandemic include regression analysis, spatial correlation analysis, hotspot analysis, Local and Global Moran's Index, Geographically Weighted Regression (GWR), and proximity analysis, such as standard distance, directional distribution, or standard deviational ellipse (SDE). The most used software includes ESRI ArcMap, RStudio, QGIS, GeoDa, and, to a lesser extent, Stata.

The trends in solutions based on GIS primarily focus on spatial-temporal analysis studies, Location-Based Services (LBS), Volunteered Geographic Information (VGI), which involves volunteers disseminating spatial data, web-based mapping, Spatial Decision Support Systems (SDSS), satellite imagery, geobusiness, and the Internet of Things (IoT) (Samany et al., 2022).

Given the need to generate almost real-time information during the coronavirus pandemic, the geographical community has been tasked to incorporate more Artificial Intelligence (AI) models into Geographic Information Systems to enhance the accuracy and scope of predictive models. In this context, GIS provides spatial and non-spatial data, while AI analyzes vast datasets to identify intricate patterns and relationships. Together, Geospatial Artificial Intelligence technologies enable a comprehensive understanding of the factors and conditions that influence a phenomenon or process in space.

4.5 ARTIFICIAL INTELLIGENCE (AI)

Since the inception of Geographic Information Systems, Machine Learning (ML) and Deep Learning (DL), models and algorithms have been implemented for the processing and analysis of spatial data. However, with the rise of social media, terms like Big Data, Data Science, and Artificial Intelligence gained popularity due to the increasing use of internet, resulting in a generation of large volumes of real-time data. These data include geotagged information from social media platforms like Twitter, Facebook, and mobile sensors that monitor real-time air quality.

Geo Artificial Intelligence (GeoAI) is a high-performance science with the capability to apply machine learning models to predict spatial phenomena and deploy algorithms capable of performing tasks without explicit programming. Deep learning imitates the brain's capacity; and spatial science, analyzes large, complex, georeferenced datasets for classification and correlation, identifying nonlinear relationships in geospatial data.

GeoAI develops computer programs to mimic processes of human perception, spatial reasoning, discovery of atypical phenomena and spatiotemporal dynamics. It requires specialists with skills in computing, programming, and geographical knowledge (Gao, 2021). To create more accurate maps, Geo Artificial Intelligence relies on spatial data mining techniques (Janowicz et al., 2020). There are several Geospatial Artificial Intelligence techniques that can be applied in predicting COVID-19 cases and deaths. Some of the most common techniques are described below:

Linear Regression Models: This is one of the most widely used techniques in data mining, applied to predict daily infection cases (Mohammad Ayyoubzadeh et al., 2020; Moneer Yahya et al., 2021), and COVID-19 deaths. It also finds applications in multiple prediction problems using multiple linear regression based on factors like population density, mobility, and employment.

Neural Networks: It is a technique that learns from hierarchical structures, levels of abstraction, and representation to understand patterns in large sets of textual or audiovisual data (Torres, 2020). During the pandemic, these were implemented to predict vulnerable areas of contagion (Razavi-Termeh et al., 2022).

The algorithms employed in Geo Artificial Intelligence have been a key element for analyzing large, complex datasets related to social, economic, cultural, and geographical-environmental aspects. Their use has enabled forecasting and localization of future epidemiological outbreaks in regions with high vulnerability. Additionally, they have been helpful in tracking confirmed COVID-19 cases and implementing public policy strategies for prevention and mitigation of future epidemiological events. The combination of GIS and AI technologies allows a more comprehensive understanding of factors influencing an event and this facilitates in short time the decision-making and planning.

Several studies have confirmed that it is possible to analyze and verify the principles of geography using techniques and methods of Geographic Information Systems and Artificial Intelligence in the context of the COVID-19 pandemic, as shown in Table 1.

Table 1. Principles of geography, methods, and techniques of GeoAI applied to health and COVID-19.

Principles of geography	**Procedures**	**Methods GIS/AI**	**Techniques**
Location	Identifies spatial patterns of death rate	Clustering	Getis -Ord Index
	Identification of regions with high incidence or transmission rates of COVID-19	Spatial analysis	Markov Chain Monte Carlo (MCMC)
Causality	Modeling of mortality rate variations	Artificial neural networks	Poisson model
Correlation or connection	Relationship between COVID-19 and socio-spatial determinants of health	Spatial analysis	Multiscale Geographically Weighted Regression (MGWR)
	Identification of groups of patients with COVID-19 with similar characteristics	Cluster analysis	K- Means
		Spatial data analysis	Density-based spatial clustering of applications

	Relationship of cases of contagion with socioeconomic factors		with density-based noise (DBSCAN)
		Exploratory Spatial Data Analysis	Spatial autocorrelation *Spatial regression
	Analyzes the relationships of contagion cases with social, economic, geographical, and environmental conditions	Spatial analysis	Geographically Weighted Regression (GWR)
Comparison	Spatial distribution of COVID-19 cases in different cities	Spatial autocorrelation	Local Moran Index
			Global Moran's Index
			Spatial concentration index (Simpson)
	Identification of regions with a high contagion rate	Machine learning	cluster analysis
	Detect spatial patterns of propagation	Spatial autocorrelation	Local Indicators of Spatial Association (LISA)
Evolution	Prediction of epidemiological outbreaks	Machine learning	Linear regression
		Recurrent Neural Networks	Long Short- Term Memory (LSTM)
		Diferential calculus	Susceptible (S), Exposed (E), Infected (I) and Recovered (R) Model
		Artificial neural networks	Radial Basis Function (RBF) -Nonlinear _ AutoRegressive models with eXogenous inputs (NARX) -Multilayer Perceptron
	Early warning systems	Recurrent Neural Networks	Bidirectional Long Short-Term Memory (BI-LSTM)
		Combination of fuzzy logic and Neural Networks	Adaptive Fuzzy Inference System (ANFIS)
	Probability of contagion in a region	Grouping	Fuzzy C- Means (FCM)

Source: Own elaboration based on Lai et al., (2004); Gatto et al., (2020); Mukandavire et al., (2020); Murgante et al., (2020); Conde-Gutiérrez et al., (2021b); Moneer Yahya et al., (2021); Kianfar et al., (2022); Ma et al., (2021); Mohammad Ayyoubzadeh et al., (2020); Razavi-Termeh et al., (2022); Wang et al., (2022); Barajas-Carrillo et al., (2022); Yang et al., (2020).

5 FINAL CONSIDERATIONS

The coronavirus pandemic has presented significant opportunities and challenges to the field of geographical science. Now more than ever, maps, statistical dashboards, and real-time monitoring have been employed to visualize and locate high infection and mortality areas due to the analysis of the COVID-19 spatiotemporal dynamics as a communication strategy for this epidemic phenomenon.

The methodological literature reviews published at international level have revealed an organized and replicable panorama applicable in different regions worldwide. In the context of this pandemic in Mexico, the lack of geospatial information has been and continues to be a challenge for researchers. Consequently, national geospatial investigations have provided a general overview of the epidemiological phenomenon. However, it is recognized that the scarcity of epidemiological data at smaller spatial scales creates a knowledge gap that hampers progress in the science and practice related to GIS and geospatial technologies, which are essential for targeting public policies in areas of higher vulnerability. Besides, the findings in Mexico indicate that spatial studies of COVID-19 have primarily focused on national data at state and municipal scales.

Geotechnologies and the application of Artificial Intelligence-based algorithms have played a significant role in identifying contagion outbreak trends and predicting the magnitude of the pandemic and its peaks. The effectiveness of Artificial Intelligence has been assessed for infection prevention and control during different epidemiological waves. Also, it has served as a modelling tool for assessing variations in mortality rates in developing countries and mapping high-vulnerability zones. However, a challenge faced by geospatial Artificial Intelligence is to develop comprehensive algorithms that enable the analysis of health-related factors and their spatial correlation with the spread of COVID-19.

The implementation of spatial predictive models during pandemics has been crucial for decision-making and has presented a significant challenge for geographers and other specialists. The success of prediction models relies on the quality and availability of spatial data infrastructure, which supports the application of Machine Learning or Deep Learning algorithms to ensure effective training and algorithm performance.

One of the challenges encountered in the City of Mexico, being this one the urban areas heavily impacted by COVID-19 due to its large population, high density, and mobility patterns, is the implementation of predictive models at microspatial scales such as neighbourhood, district, or household levels.

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