The COVID-19 disaster in Mexico City: Exploring risk drivers at the local scale

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ABSTRACT

The COVID-19 pandemic had a significant impact on the inhabitants of Mexico City. With over 9 million people living in 16 districts, infections and mortality rates varied greatly. In this article, demographic and socio-economic factors were analyzed to determine vulnerability and exposure to COVID-19 during the crisis from 27 February 2020 to 10 May 2021. The study revealed that mortality and infections were distributed differently across the districts of Mexico City. The districts with the most confirmed cases did not necessarily have the highest death rates. Many deaths were linked to age and comorbidities, such as hypertension, diabetes, and obesity. Poverty, overcrowding, the lack of space, and basic services contributed to vulnerability and exposure to the disease. Inequalities in the city's development over time resulted in varying degrees of vulnerability and exposure to COVID-19, leading to different patterns of infections and deaths across the districts. The prevalence of infections in the city´s southwestern districts can be attributed to the combination of marginalization, poverty, and inadequate services. Conversely, the northwest areas of the city, with a higher concentration of elderly residents, experienced a greater number of fatalities.

KEYWORDS

Covid-19; disaster; disaster risk drivers; Mexico City

Received: 20 June 2023
Accepted: 26 January 2024
Published online: 21 March 2024

Romero-Gaeta, P. L., Alcántara-Ayala, I. (2024): The COVID-19 disaster in Mexico City: Exploring risk drivers at the local scale.
AUC Geographica 59(1), 1–17
https://doi.org/10.14712/23361980.2024.1

1. Introduction

Since its emergence in early 2020, the pandemic resulting from the transmission of the SARS-CoV-2 virus, which causes COVID-19, has had a profound social, economic, and health impact worldwide. It is a unique disaster in modern history that has transcended borders and disrupted societies at various scales, from individual, family, national and global levels (Lavell and Lavell 2020; Alcántara-Ayala 2021).

The impacts, beyond material damage, translate into human and economic losses worldwide, where, as of 10 March 2023, around 676,6 million confirmed cases and 6,881,955 deaths associated with the disease were counted (Johns Hopkins University 2023). In Mexico, infections and deaths exceed 7,483,444 and 333,188, respectively. Mexico City had the highest percentage of damage within the territory, accounting for 27% of positive cases and 15% of deaths of the national total (DGE 2021).

As with other types of disasters, those linked to COVID-19 highlight the repercussions derived from the intense and extensive intervention of human activities on nature, often related to incipient and ill-informed development that prioritizes unequal economic growth over social well-being and environmental care, and which, over time, contributes to the generation of risk conditions that have a differentiated impact on diverse populations (Alcántara-Ayala et al. 2021; Oliver-Smith et al. 2016).

The increase in zoonotic infectious diseases in humans, such as COVID-19, is due to various environmental and social factors (Morse 2004). On the one hand, due to climate change, pathogens have undergone genetic changes and adaptations that result in variations in their dispersal, infection, and lethality characteristics (Morens and Fauci 2013; Alcántara-Ayala 2021). On the other hand, increasing human interventionism in nature, together with the increase in mobility on a global scale and the concentration of the population in large cities, play an important role in the dispersion of pathogens and, therefore, in the generation of scenarios of high exposure to different diseases (Lavell and Lavell 2020; Alpuche-Aranda 2020).

In such circumstances, human groups face such diseases from a situation of inherent susceptibility due to the absence of an immunity to new infectious forms (Alpuche-Aranda 2020), as well as from a series of socioeconomic, political, and cultural characteristics, which are reflected among other things in the existence of marginalized social groups or those with some degree of poverty, which makes them more vulnerable to this type of hazard (Alcántara-Ayala et al. 2021).

This highlights the importance of approaching the COVID-19 disaster from an integral and disaster risk perspective, which allows the understanding, beyond the characteristics of the virus, of the social dimension in the construction of risk and the resulting disaster (Oliver-Smith et al. 2016; Alcántara-Ayala et al. 2021).

Mexico City, the capital of the country, is in the center of the national territory, between 19°03′ and 19°36′ north latitude and 98°57′ and 99°22′ west longitude. It is politically and administratively divided into 16 districts with 9,209,944 inhabitants, making it Mexico's second most populated entity (INEGI 2020).

On the other hand, in terms of health, Mexico is one of the countries with the largest population over 20 years of age suffering from obesity (36.1%) and overweight (39.1%). According to data collected in the National Health and Nutrition Survey, Mexico City is home to around one million people with diabetes and just over three million with hypertension, representing 12.7% and 20.2% of the national total, respectively (INEGI and INSP 2018).

Although this area in Mexico had the highest infection rate among its inhabitants (7,138 infections per 100,000 people) and the highest mortality rate in the country (383 deaths per 100,000 inhabitants), the impact of COVID-19 was not evenly distributed throughout the region (DGE 2021). Therefore, it is crucial to study and comprehend the epidemic in Mexico City to identify the underlying reasons behind the varying effects of the virus. Accordingly, this study aims to analyze the driving factors of disaster risk of COVID-19 in Mexico City, focusing on the varying levels of vulnerability and exposure among the population.

2. Theoretical framework

2.1 COVID-19, a global disaster: understanding disaster risk associated with biological hazards

The study and understanding of disasters have undergone several epistemological transformations in recent decades. Research increasingly shows a series of complex socio-natural relationships articulated in the configuration of disasters, refuting the physicalist conception that disasters are the product of nature (Blaikie et al. 1994; Wisner et al. 2004; Oliver-Smith et al. 2016; 2017).

Disasters have become a critical issue in contemporary society. A disaster is a severe disruption of the functioning of a community or society resulting from diverse types of hazards that interact with conditions of exposure, vulnerability, and capacity. The aftermath of such an event can lead to a range of losses and impacts, including those that are human, material, economic, and environmental. The effects of a disaster can be immediate and confined to a specific area, or they can be far-reaching and long-lasting, surpassing the ability of a community or society to manage the situation with its resources. External resources, such as neighboring jurisdictions, national agencies, or international organizations, may be called upon to aid (UN General Assembly 2016).

In recent decades, disasters caused by geological, geophysical, and hydrometeorological hazards have been extensively studied and discussed. However, since 2020, the world has witnessed the enormous impact of biological hazards. A hazard is any process, phenomenon, or human activity that can cause harm to human life, health, property, or the environment or disrupt social and economic stability. Hazards can be natural or human-induced and may occur individually, combined, or in a cascade, with their classification based on specific attributes. Each hazard is characterized by location, intensity or magnitude, frequency, and probability. Organic sources or biological agents can give rise to biological hazards. Such hazards encompass pathogenic microorganisms, toxins, other bioactive substances, venomous wildlife and insects, poisonous plants, and mosquitoes that can carry disease-causing agents. These hazards are distinguished by their infectiousness, toxicity, and other pathogen-related qualities (UN General Assembly 2016).

Disasters were once seen as unpredictable events caused by nature or fate, but since the 1980s, they have been recognized as socially constructed processes often linked to misguided development policies (Blaikie et al. 1994; Lavell and Maskrey 2014). Economic growth often takes priority over social and environmental considerations, creating diverse conditions of vulnerability and exposure, and thus, disaster risk and ultimately leading to the occurrence of disasters (Blaikie et al. 1994; Oliver-Smith et al. 2016; Alcántara-Ayala et al. 2021; 2023). The pandemic is an example of a disaster arising from underlying risk conditions and systemic environmental hazards (Lavell et al. 2020; Alcántara-Ayala et al. 2021).

The COVID-19 virus becomes a biological hazard for exposed and vulnerable populations, and global economic structures heavily influence its spread. Although it does not cause physical destruction like disasters associated with other hazards, for instance, earthquakes or floods, the pandemic has significantly impacted the world, leading it to be classified as a global disaster. Its effects have disrupted societies and caused negative consequences in various domains, including social, economic, cultural, political, and institutional. This is mainly due to the challenges of the virus's high susceptibility and rapid spread, combined with pre-existing societal vulnerabilities and exposure conditions. The global economy played a significant role in shaping exposure to COVID-19, mainly through economic integration and social inequalities. Factors such as international travel, displacement, and urbanization increased the risk of exposure (Lavell et al. 2020; Alcántara-Ayala 2021; Alcántara-Ayala et al. 2021).

The expansion of urban areas, including suburbanization, post-suburbanization, and peri-urbanization, can have negative consequences on public health by increasing the transmission of infectious diseases. Factors such as demographic changes, infrastructure, and governance play a significant role in determining the susceptibility of peri-urban and suburban regions to such diseases. The socio-ecological changes that occur on the outskirts of cities may further exacerbate the risk of infection. As urbanization continues to extend, the conditions for the spread of infectious diseases are amplified (Connolly et al. 2021).

The COVID-19 pandemic has profoundly impacted countries worldwide, resulting in widespread illness, loss of life, and societal upheaval. The pandemic has overwhelmed healthcare systems and exposed global public health infrastructure fragilities (Jovanović et al. 2020). Like other disasters, its humanitarian impact has affected millions directly or indirectly. The pandemic has also triggered economic downturns, job losses, and business disruptions on a global scale, further exacerbating existing inequalities (Maital and Barzani 2020). Measures such as lockdowns, social distancing, and quarantine protocols disrupted daily life, with significant consequences for mental health, education, and social well-being (Nurunnabi et al. 2020). These effects are typical of disasters, often resulting in social dislocation and community-level impacts. As with disasters triggered by geo-hazards or climate-related hazards, the COVID-19 pandemic will have long-term consequences beyond the immediate crisis, necessitating ongoing efforts to recover and rebuild (Fakhruddin et al. 2020). The global response to the pandemic has required collaboration between governments, international organizations, and non-governmental entities, reflecting the characteristics of disaster response (Pawar 2020).

A growing body of literature has examined diverse spheres of the COVID-19 pandemic from a disaster risk perspective. The pandemic was recognized as a disaster in several countries from the early stages of its outbreak. In Indonesia, for example, the significance of disaster risk communication emerged as a major concern due to the exacerbation of communication breakdowns, which impeded both government and public efforts to curb the spread of the virus (Rudianto and Hendra 2021).

Mostafanezhad (2020) affirms that the pandemic reframed as a disaster creates new debates at the intersection of tourism geographies and political ecologies of hope, which can provide a better understanding of the impact of the pandemic on society and the environment. Cvetković et al. (2020) conducted an online survey in Serbia to assess citizens' readiness for the COVID-19 disaster. Their study revealed differences in risk perception, suggesting the need for targeted strategies to improve decision-making and preparedness.

As disaster management systems continue to evolve, they now encompass human-induced hazards and emerging crises associated with biological hazards like epidemics and pandemics. Kim and Ashihara

(2020) pointed out that individuals look to their governments for guidance and assistance during times of crisis. Therefore, the recent outbreak of COVID-19 in South Korea underscored the need for a more proactive and organized national approach to disaster management.

A full discussion of analyzing the COVID-19 pandemic as a disaster lies beyond the scope of this study. However, it is important to acknowledge its profound impact on a global scale and the uncertainty surrounding the direction of disaster risk reduction policymaking at both the national and local levels. This involves understanding the vulnerability and exposure of individuals to biological hazards and implementing measures to reduce disaster risk and improve disaster risk governance.

Consequently, to understand the pattern of damage resulting from the pandemic in Mexico City, it is necessary to analyze it from the paradigm of the social construction of risk in order to identify the disaster risk drivers that are linked to the vulnerability and exposure of the city's population (Oliver-Smith et al. 2016; Alcántara-Ayala et al. 2021). Against this background, disaster risk refers to the possibility of adverse impacts in economic, social, environmental, material, or human losses triggered by one or more hazards under specific conditions of vulnerability and exposure in communities, livelihoods, and environmental systems (UN General Assembly 2016).

COVID-19 is a socio-biological hazard since it is a natural element – the SARS-coV-2 virus (of zoonotic origin) – whose transmission derives from human interventionism in natural spaces, which responds to current economic processes (Morens and Fauci 2013; Karesh et al. 2004; Alcántara-Ayala 2021; Li et al. 2020). In addition, this virus is positioned as a hazard as conditions of exposure and vulnerability favor the spread of this virus in society (Alcántara-Ayala 2021; Lavell et al. 2020).

According to Oliver-Smith et al. (2016), exposure plays a crucial role in determining the level of risk. Exposure refers to the physical presence of people, infrastructure, housing, production capacities, and other human assets in areas susceptible to hazards, as defined by the UN General Assembly (2016).

Transmission of COVID-19 occurs from person to person or through direct contact with a surface on which the virus is present and subsequent contact with the mucous membranes of the face (Li et al. 2020; Lavell and Lavell 2020). In general terms, human exposure to the virus is directly linked to the global economic structure, which conditions the mobility patterns of individuals, the integration of societies in densely populated cities, and the organization of territory and urban space (Lavell et al. 2020; Alcántara-Ayala et al. 2021).

The COVID-19 pandemic posed significant challenges for informal and poor residential settlements in the Global South, including Mexico City. These communities face a shortage of essential resources, including water, sanitation facilities, secure housing, and waste management systems, making them ill-equipped to deal with the crisis. Additionally, the dense population, lack of space, and prevalence of violence make it difficult for residents to practice physical distancing or self-isolation, exacerbating the risk of COVID-19 transmission (Corburn et al. 2020).

Various situations, ranging from utilizing mass public transportation in urban regions to residing in densely populated areas or overcrowded living quarters, can heighten an individual's exposure to biological hazards, such as COVID-19. Moreover, specific professions, such as informal labor or occupations that necessitate direct interaction with others, can also increase the likelihood of contracting diseases (Lavell et al. 2020; Alcántara-Ayala et al. 2021).

In the context of the pandemic, all of humanity is vulnerable to the virus – since, until vaccination, the necessary antibodies to combat it were unavailable (Alpuche-Aranda 2020). However, the form and degree of susceptibility of individuals are marked by intrinsic or endogenous factors, such as genetics, age or the existence of or susceptibility to chronic degenerative diseases and can be enhanced by conditions of poverty or malnutrition that are linked to processes of inequality, corruption and lack of access to basic education and health services (Lavell and Lavell 2020; Alcántara-Ayala 2021; Alcántara-Ayala et al. 2021).

In other words, once an individual is exposed to the virus and therefore infected, the harm they present – in terms of health and/or livelihoods – will be directly related to intrinsic susceptibility and vulnerability (Lavell and Lavell 2020).

Among the population considered most susceptible to acute symptomatology or death worldwide are adults over 60 years of age and/or with pre-existing chronic degenerative or autoimmune diseases, such as hypertension, diabetes, asthma, chronic obstructive pulmonary disease (COPD) or cardiovascular problems and obesity (Porcel-Gálvez et al. 2020; Luna-Nemecio 2020; Martínez-Martínez et al. 2020; Villerías and Juárez 2020). This results in higher levels of vulnerability in those countries or cities where the population is older than in societies with younger populations, even with the same degree of hazard and exposure (Lavell et al. 2020).

Studies have revealed a connection between the density of urban areas and the number of COVID-19 cases in Latin America. Urban areas have reported more cases and deaths compared to their rural counterparts. The reasons for this include factors such as cramped living conditions, poor sanitation, high population density, and inadequate public services. These factors increase the risk of getting infected and developing complications from the disease (Luna-Nemecio 2020; Ortega et al. 2020).

Different individuals and societies may not be affected similarly when exposed to a hazard. This is because their susceptibility or vulnerability to the hazard will play a significant role. In this context, vulnerability arises from various dynamic processes and underlying causes (Oliver-Smith et al. 2016). Such underlying causes often result from physical, social, economic, and environmental factors or processes, which increase the vulnerability of an individual, community, assets, or systems to the effects of hazards (UN General Assembly 2016).

The susceptibility of a population to a virus like SARS-CoV-2 is not solely determined by intrinsic factors such as age and gender. Socio-economic factors, such as access to healthcare and public services, insecure employment, inadequate housing leading to overcrowding, and marginalization and discrimination of specific social groups, also play a crucial role. Therefore, the degree of exposure varies according to each population's mobility structures, territorial organization, and cultural practices, resulting in different impacts on infections and deaths across countries or regions (Lavell et al. 2020).

The Latin American region is facing high vulnerability due to marginalization, poverty, social inequality, labor informality, and weak health systems, which have caused various social groups to be vulnerable to COVID-19 disease. ECLAC (2020) reports that the most vulnerable groups include indigenous and Afro-descendant populations, with limited access to social protection and communication and labor market difficulties. In Mexico, COVID-19 has affected the indigenous population with a higher lethality rate (18.8%) compared to the general population (11%), which could be attributed to delayed prevention measures and a lack of culturally and linguistically appropriate information on COVID-19 (Cortéz-Gómez et al. 2020).

3. Mexico City in the Context of the COVID-19 Pandemic

3.1 Mexico City's socio-demographic characteristics: Shaping vulnerability and exposure

Internally, the socioeconomic and demographic characteristics of Mexico City (Fig. 1) maintain a heterogeneous distribution in space based on a center-periphery model in which there are clear differences

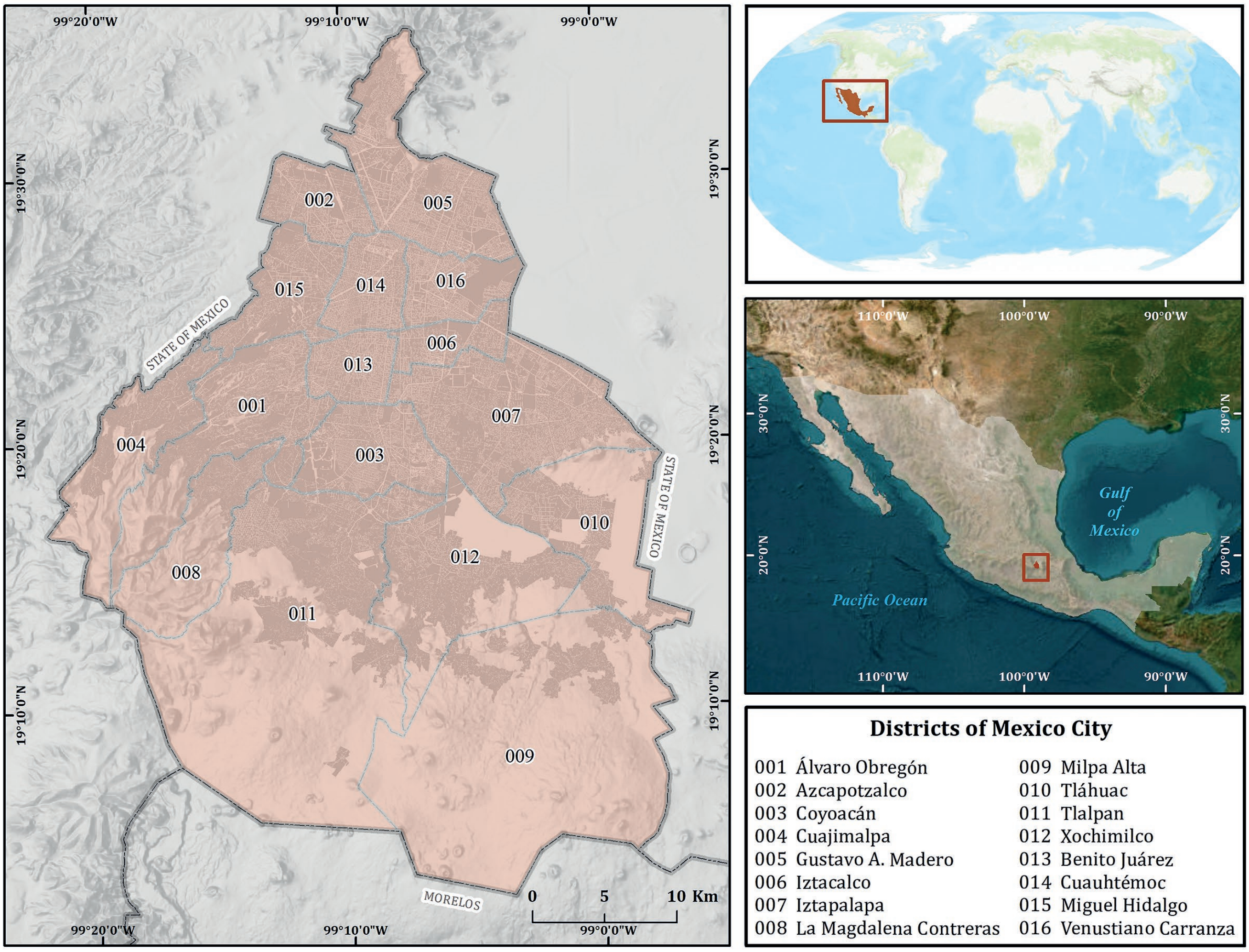

Fig. 1 Location of Mexico City and its districts.

between the central and northern districts and those in the south.

In the first group, the districts of Benito Juárez, Miguel Hidalgo, Azcapotzalco, Coyoacán, Álvaro Obregón, Venustiano Carranza, and Cuauhtémoc have the highest population density in the city (more than 8,000 inhabitants/km^2), the highest percentages of the population over 60 years of age (between 17% and 20.3%), the highest median ages (between 36 and 39 years) as well as the highest levels of schooling (more than ten years of formal education). In contrast, these districts had the lowest percentages in terms of illiteracy, poverty, overcrowding, lack of quality of housing spaces and services, lack of health services, and lack of basic housing services in this region (INEGI 2020; CONAPO 2020; CONEVAL 2020).

They are also the districts with the lowest percentage of indigenous population (less than 1.15%, except for Coyoacán with 1.29%) and, at the same time, the highest concentration of Afro-descendant population (between 2% and 2.8%, except for Coyoacán with 1.8%) (INEGI 2020). In other words, in the central and north-central districts, there is a high population density associated with inhabitants over 37 years of age, with significant percentages of older adults, high levels of schooling, adequate access to services and quality of housing spaces, and health services.

Despite their location, Iztapalapa, Iztacalco, and Gustavo A. Madero do not share the same particularities as the rest of the central-northern districts; on the contrary, the former, despite having a high population density (16,219 inhabitants/km^2), also presents high levels of poverty (43.8%), marginalization (59.5%), and lack of health services (31.8%), and, in contrast, low levels of schooling (10.4 years of formal education) and a percentage of the population over 60 years of age (14.2%) (INEGI 2020; CONAPO 2020; CONEVAL 2020) (Tab. 1).

In the case of Iztacalco and Gustavo A. Madero, the population density is high (17,522 inhabitants/km^2 and 13,347 inhabitants/km^2), as is the level of schooling (11.5 and 11.1 years of formal education), and the degree of marginalization (60.4% and 60.1%). However, they present intermediate levels in the percentage of the population aged 60 and over (17.5% and 17.3%, respectively), illiteracy (1.16% and 1.53%,

Tab. 1 Demographic and socioeconomic characteristics by district.

District	Álvaro Obregón	Azcapotzalco	Benito Juárez	Coyoacán	Cuajimalpa	Cuauhtémoc	Gustavo A. Madero	Iztacalco	Iztapalapa	La Magdalena C.	Miguel Hidalgo	Milpa Alta	Tláhuac	Tlalpan	Venustiano Carranza	Xochimilco
PD	7916	12892	16259	11395	3059	16783	13347	17533	16219	3904	8927	512	4569	2225	13102	3874
AA	35	37	39	38	32	36	36	36	33	34	37	30	31	34	36	33
P. >60 years (%)	16.13	18.72	20.12	20.60	11.85	17.18	17.34	17.52	14.28	15.37	17.40	10.76	11.77	15.59	17.81	13.79
IP	9.24	7.53	9.37	8.88	9.65	8.64	6.57	6.84	7.87	9.75	5.01	20.32	14.63	11.85	5.86	12.39
AP	2.10	2.05	2.84	1.80	1.40	2.70	1.85	1.72	1.81	2.20	2.72	1.46	1.86	1.75	2.36	2.22
SGL	11.30	11.90	14.50	12.50	11.40	12.40	11.10	11.50	10.40	10.80	13.10	10.00	10.50	11.50	11.50	10.80
I	1.57	1.02	0.35	1.10	1.50	0.95	1.53	1.16	1.84	1.87	0.75	2.77	1.67	1.61	1.09	1.96
P	37.70	24.20	7.90	27.10	32.50	20.90	33.80	25.20	43.90	42.50	13.50	54.70	42.40	39.70	30.00	48.20
Marg.	60.48	60.63	62.39	60.87	60.44	61.33	60.10	60.44	59.54	59.68	61.22	57.28	59.32	59.56	60.38	58.57
LSQH	5.30	3.50	0.90	3.00	5.80	3.60	3.90	3.40	6.30	6.30	2.20	11.60	6.20	6.70	3.40	10.50
Oc.	0.80	0.80	0.60	0.70	0.80	0.70	0.80	0.80	0.90	0.90	0.70	1.00	0.90	0.80	0.80	0.90
LBHS	3.50	1.00	0.10	1.50	3.10	0.40	1.00	0.30	0.60	8.90	0.40	23.30	4.10	9.10	0.40	13.00
EAP	64.70	63.40	70.40	62.60	65.80	70.20	61.30	64.10	63.50	62.90	68.10	67.00	63.20	64.20	64.80	63.20
PPEPS	0.23	0.05	0.08	0.06	0.30	0.11	0.13	0.18	0.17	0.27	0.09	8.68	1.49	0.89	0.09	2.93
PPESS	14.69	17.40	9.60	11.74	17.82	8.93	17.35	13.72	18.00	14.09	11.62	19.80	18.76	14.62	11.44	15.18
PPES	65.30	59.00	73.90	67.70	63.20	64.40	58.20	62.00	55.10	65.30	68.60	49.30	55.80	65.50	59.70	58.10
PPET	16.11	20.99	14.00	16.19	14.71	23.07	22.30	21.29	24.51	16.03	15.03	21.18	22.11	15.89	25.68	20.03

Population density (PD), Average age (AA), Population over 60 years of age (P. >60 years), Indigenous population (IP), Afro-descendant population (AP), School grade level, (SGL), Illiteracy (I), Poverty (P), Marginalization Index (Marg), Lack of Space and Quality in Housing (LSQH), Overcrowding (Oc), Lack of basic housing service (LBHS), Economically Active Population (EAP), Percentage of the population employed in the primary sector (PPEPS), Percentage of the population employed in the secondary sector (PPESS), Percentage of the population employed in service (PPES), Percentage of the population employed in trade (PPET), Lack of access to basic health service (LABHS).

respectively), overcrowding (13.5% and 16.4%), poverty (25% and 33%) and lack of quality of services and housing spaces (3.4%) (INEGI 2020; CONAPO 2020; CONEVAL 2020) (Tab. 1).

The dissimilarities among these districts can be attributed to unique geo-historical formation processes distinct from those observed in neighboring districts.

The southern districts, on the other hand, corresponding to Milpa Alta, Tláhuac, La Magdalena Contreras, Cuajimalpa, and Xochimilco, have the lowest population densities (less than 4,570 inhabitants/km^2), average ages between 30 and 34, and the lowest percentages of the population aged 60 and over (between 15.3% and 10.7%) (INEGI 2020). Furthermore, this region has the lowest levels of schooling (between 10 and 10.8 years of formal education received), apart from Cuajimalpa and Tlalpan (with 11.4 and 11.5 years of education, respectively) (Tab. 1).

In contrast, poverty (between 32.4% and 54.7%), illiteracy (between 1.5% and 2.8%), overcrowding (ranging from 17.85% to 25.9%), lack of quality of housing spaces and services (between 6.3% and 11.6%), lack of health services (between 21.9% and 34.6%) and lack of basic housing services (between 3.1% and 23.3%) have the highest levels in the city. At the same time, the south of the city has the highest percentage of the indigenous population, especially in the districts of Milpa Alta (with 20.32% of the state total), Tláhuac (with 14.63%), and Xochimilco (with 12.40%) (Tab. 1) (INEGI 2020). Thus, the population of these districts is characterized by a primarily young population (between 30 and 34 years old), with low levels of schooling and high percentages of problems associated with the quality of housing and the distribution of spaces, including a high level of overcrowding.

3.2 The impacts of COVID-19 in Mexico City

The first active case of COVID-19 was confirmed in Mexico City on 27 February 2020 (Suárez et al. 2020).

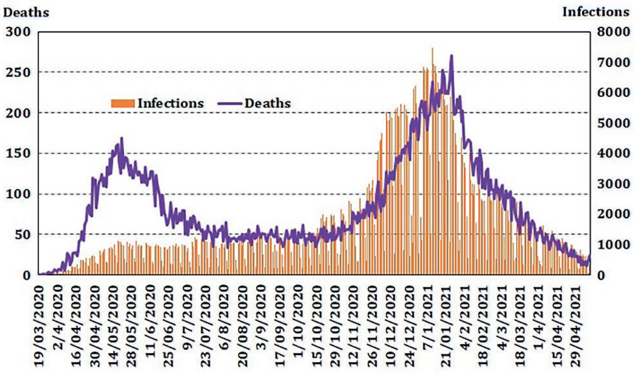

Fig. 2 Total number of infections and deaths in Mexico City from March 2020 to May 2021.

Since then, two waves of the virus have affected the population, significantly increasing infections and fatalities (Fig. 2). The first wave occurred between April and August 2020, at the start of the health crisis. The second wave, which saw the highest incidence of cases in January, occurred between November 2020 and May 2021, with up to 250 deaths per day (DGE 2021). These are the findings of a study conducted until May 10 2021.

For the dates mentioned, the damage in terms of infections and deaths amounted to 648,479 and 33,027, respectively, representing 27% and 15% of the national total. The districts with the highest rates of confirmed cases were Álvaro Obregón, Tlalpan, and Tláhuac, with 11,000, 9,323, and 8,804 cases per 100,000 inhabitants, while the lowest rates were in Benito Juárez (5,198), Miguel Hidalgo (5,672) and Iztapalapa (5,743) (DGE 2021), as shown in Fig. 3.

On the other hand, the highest death rates were in Azcapotzalco, Iztacalco, and Gustavo A. Madero, with 565, 561, and 469, respectively, in contrast to Milpa Alta, Cuajimalpa, and Tláhuac, which have rates of less than 250 deaths per 100,000 inhabitants (Fig. 3) (DGE 2021).

Demographic and socio-economic characteristics constitute some factors that induce the vulnerability and exposure of Mexico City's population to COVID-19.

4. Methodology

The study period covers sixty-three weeks, from the beginning of the pandemic in Mexico – 27 February 2020 – until 10 May 2021, the estimated date of the end of the second wave. In the time after this period, there was a drastic decrease in the lethality of the virus in the population of the capital (DGE 2021), which could be explained by the effects of the National Vaccination Campaign COVID-19 that began at the end of December 2020 and was applied in the first instance to health personnel and older adults (Secretaría de Salud 2020).

The methodological route was based on the search for and processing of information on the impacts in terms of health and mortality at the district level in Mexico City, considering the data issued from the official website of the Ministry of Health, from the National Council of Humanities, Sciences and Technologies CONAHCyT (DGE 2021). With regard to mortality, the portal's statistical record provides a detailed breakdown that correlates the percentage of patients with different comorbidities to COVID-19-related deaths. Furthermore, it also highlights the age range of those who have been infected, which can aid in the analysis of the correlation between these factors and COVID-19 fatalities.

At the same time, a bibliographic analysis was carried out to determine those elements linked to

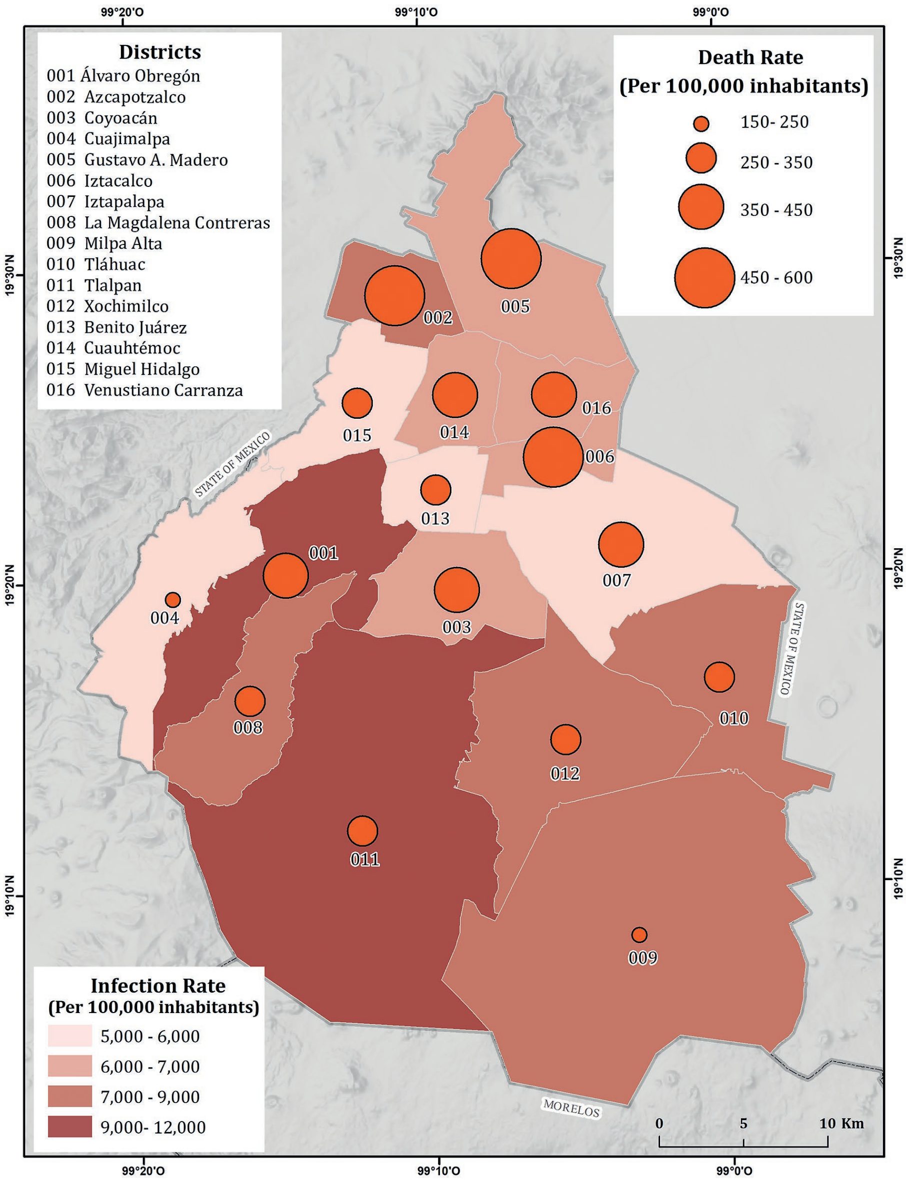

Fig. 3 Infection and death rates by districts, Mexico City (Source: Own elaboration with data from DGE 2021; INEGI 2020; CONAPO 2020; CONEVAL 2020).

greater vulnerability and exposure of the population to COVID-19, which acted as disaster risk drivers (Fig. 4).

Thus, seventeen demographic and socio-economic indicators were determined and obtained through the pages of the Population and Housing Census of the National Institute of Statistics and Geography (INEGI 2020), the marginalization indices by district generated by the National Population Council (CONAPO 2020), as well as the poverty indicators for each district of the National Council for the Evaluation of Social Development Policy (CONEVAL 2020) (Tab. 2).

The demographic dimension variables are mainly related to the characteristics of the population, such as age or the presence of certain comorbidities. The socio-economic indicators, urban marginalization and poverty indices were considered in the first instance, as both express some of the fundamental deprivations of the population numerically.

In addition, some indicators associated with the social dimensions that make up both variables were analyzed to determine their direct influence on the construction of vulnerability and exposure of the population. Finally, other indicators linked to the presence of indigenous or Afro-descendant groups, the level of education, and the economically active population by sector of occupation were included.

4.1 Statistical analysis

Using R Studio software version 4.2.1, 34 statistical tests of Pearson's Correlation Coefficient (r) were carried out between pairs of continuous variables, which made it possible to establish in numerical form the linear relationship and intensity between the two (Vargas 1995). For this paper, the infections and deaths per 100,000 inhabitants at the district level in

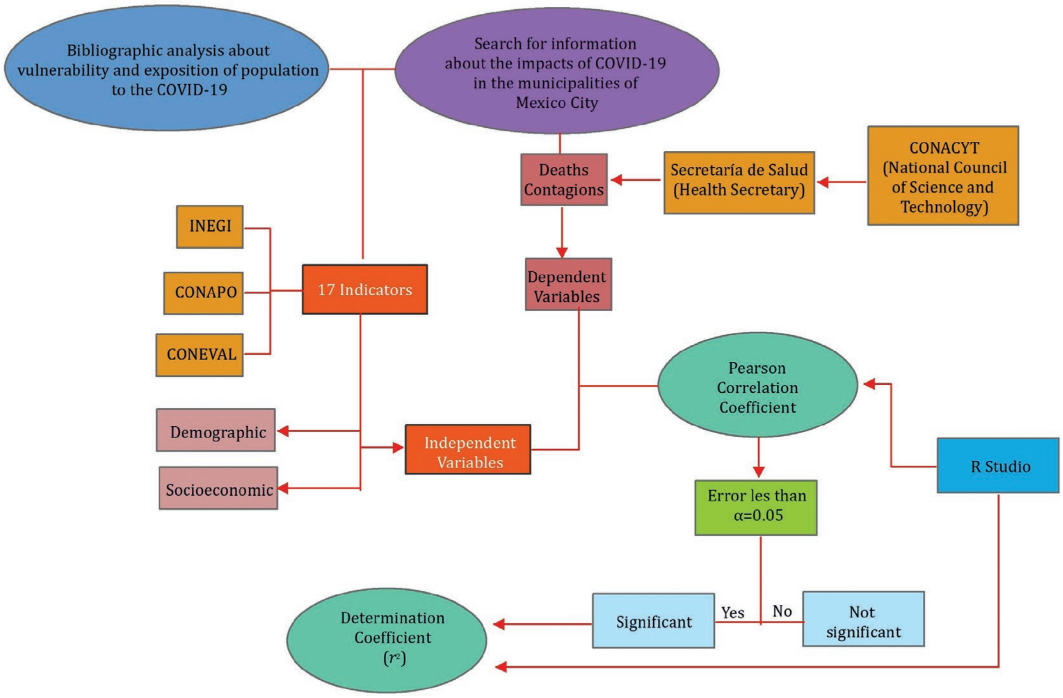

Fig. 4 Scheme of the procedure from literature search to correlation analysis.
INEGI: National Institute of Statistics and Geography. CONAPO: National Population Council. CONEVAL: National Council for Evaluation of Social Development Policy. CONACHyT: National Council of Humanities, Sciences, and Technologies.

Mexico City were considered dependent variables. In contrast, demographic and socio-economic indicators were considered as independent variables.

The conventional confidence level of α = 0.05 was used for the statistical tests, i.e., with a probability of error of less than 5%. The values obtained reflect the magnitude and direction of the correlation and can range from −1 to +1, where positive results refer to directly proportional linear correlations and vice versa. For Social Sciences, a magnitude greater than ±0.30 is considered high.

Additionally, Pearson's Coefficient of Determination (r^2) was calculated with significant tests to determine the strength of association between the variables. This made it possible to establish, as a proportion, the variation of the dependent element that its association with the independent variable explains.

Upon obtaining the results of the correlations, the interpretation was made to identify the factors driving disaster risk. These factors are manifested in specific socio-economic and demographic characteristics that give rise to conditions of vulnerability and exposure among the population.

5. Results

The data collected from the official website of the General Directorate of Epidemiology (DGE 2021) showed a differentiated distribution regarding mortality and infections in the different districts that constitute Mexico City. The districts with the highest rates of confirmed cases did not reflect a similar trend in the pattern of deaths in the entity.

In terms of mortality, the data obtained from the interpretation of the statistics provided on the CONACHyT portal revealed that a high percentage of deaths were linked to the presence of comorbidities in the population, including hypertension (39.7%), diabetes (33.2%), and obesity (20%).

The findings of the study are showcased using scatter graphs (Fig. 5) that adeptly depict the relationships between pairs of variables that had a considerable correlation with the number of deaths or infections. Furthermore, a radial graph (Fig. 6) facilitates a comparison of the strength of relationships between the variables. The scatter graphs reveal the direct or inverse linear relationships that exist between the independent variables (demographic and socioeconomic indicators) and the dependent variables (the disease's behavior in terms of deaths and infections).

The radial graph shows the 17 indicators that were selected for the study and the extent to which they are associated with deaths and infections. The data presented in the figure highlights the correlation between infections in Mexico City and socioeconomic variables and the association between deaths and demographic variables of the population.

The results of the study indicate a significant correlation between the age variable and the progression of the disease (Fig. 5). It was observed that the

Tab. 2 Demographic and socio-economic indicators used in the analysis.

Dimension	Indicator	Definition	Source
Demographic	Mean age	The mean age of the population per district.	INEGI 2020
	Population over 60 years of age	Percentage of population over 60 years of age by district.	INEGI 2020
Socioeconomic	Indigenous population	Percentage of the population aged five years and over who speak an indigenous language.	INEGI 2020
	Afro-descendant population	Percentage of the population that considers itself Afro-descendant.	INEGI 2020
	School grade level	Number of years that, on average, persons aged 15 and over passed in the National Education System.	INEGI 2020
	Illiteracy	Percentage of persons aged 15 and over who cannot read and write.	CONAPO 2020
	Poverty	Percentage of the population living in poverty, i.e., when exercising at least one of their rights for social development is not guaranteed, and their income is insufficient to acquire the goods and services they require to satisfy their needs.	CONEVAL 2020
	Marginalization	Marginalization Index. A summary measure identifies the level of deprivation in a population due to lack of access to education, basic services, quality housing, and insufficient income. In this index, a larger number shows a lower degree of marginalization. That is, a larger number implies a smaller lack of the factors that make up the index.	CONAPO 2020
	Lack of space and quality in housing	Percentage of population living in dwellings with at least one of the following characteristics: – material of earthen floors, – roofs of sheeting, cardboard, or waste, – material of mud, bark, reed, bamboo or palm, cardboard, metal, or asbestos sheeting, – having greater than 2.5.	CONEVAL 2020
	Overcrowding	The average number of inhabitants per room in the home. It is considered an index of overcrowding by the National Institute of Geography and Statistics.	INEGI 2020
	Lack of basic housing services	The percentage of the population living in dwellings with the following characteristics: – The water is obtained from a well, river, lake, stream, pipe, or piped water by carrying it from another dwelling or the public tap or hydrant. – They do not have sewerage service or the drainage is connected to a pipe that leads to a river, lake, sea, ravine, or crevice. – No electricity is available. – The fuel used for cooking or heating food is wood or charcoal without a chimney.	CONEVAL 2020
	Economically Active Population	Percentage of economically active population by district.	INEGI 2020
	Percentage of the population employed in the primary sector	Percentage of persons engaged in economic activities in agriculture, animal husbandry, forestry, beekeeping, aquaculture, logging, hunting, and fishing.	INEGI 2017
	Percentage of the population employed in the secondary sector	Percentage of persons engaged in economic activities in mining, oil and gas extraction, manufacturing, electricity generation and distribution, water distribution, and construction.	INEGI 2017
	Percentage of the population employed in trade	The proportion of persons engaged in economic activities in communications, transport, finance, tourism, hotels and catering, leisure, culture, entertainment, public administration, and so-called public services.	INEGI 2017
	Percentage of the population employed in services		INEGI 2017
	Lack of access to basic health services	The percentage of the population without affiliation or entitlement to medical services from any institution providing medical services, including Seguro Popular, public social security institutions (IMSS, federal or state ISSSTE, PEMEX, Army or Navy), or private medical services.	CONEVAL 2020

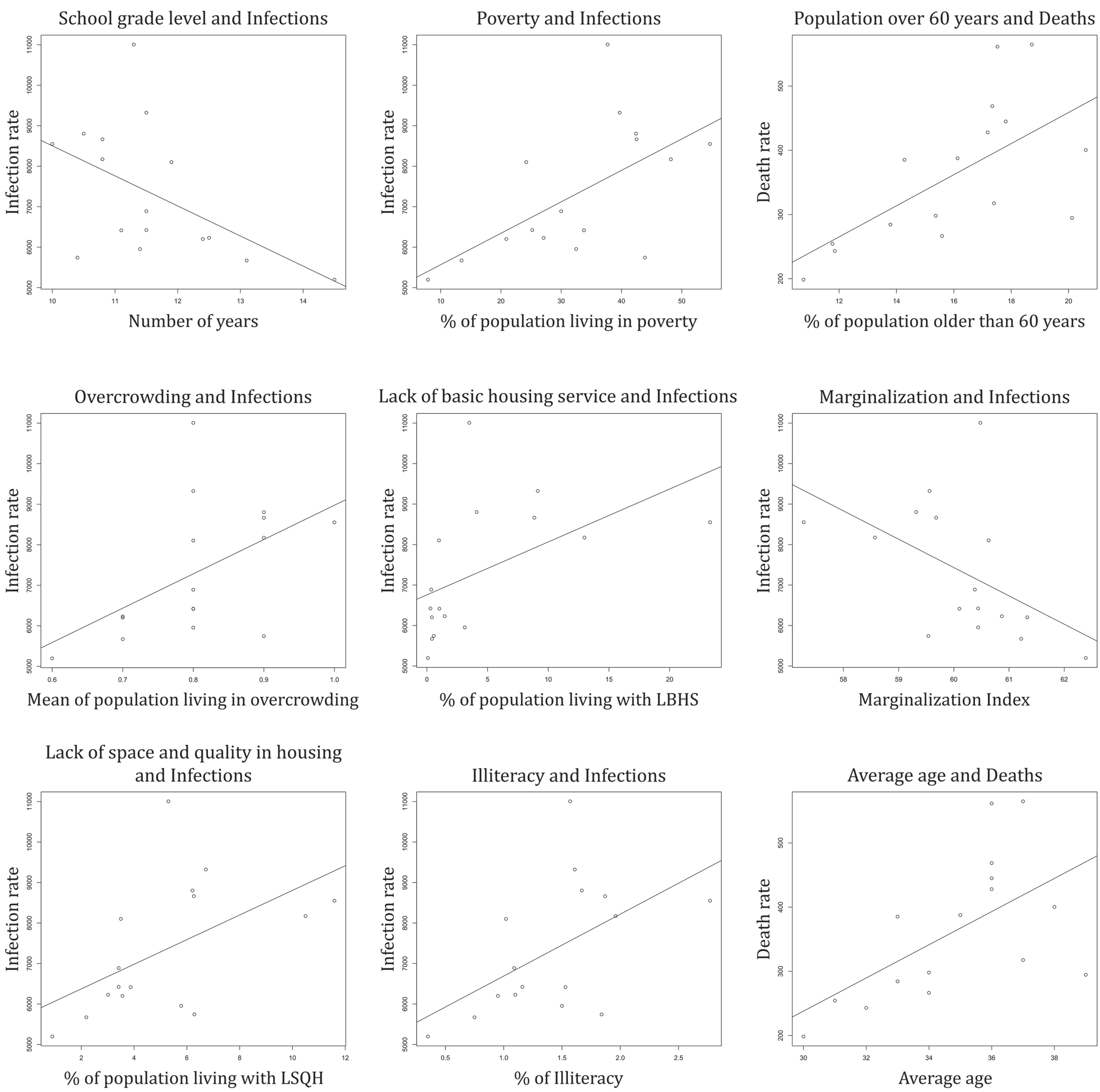

Fig. 5 Scatter plots of the variables that show significant correlations with deaths and infections.

number of deaths increased considerably with the number of years of life of the individuals, as reported by DGE (2021).

Along this vein, the results showed that the average age of the population and the percentage of adults over 60 years of age maintained a positive association with the death rate at the district level with 0.35 and 0.40, respectively; in other words, as the average age and the presence of older adults in the population increased, the number of deaths per 100,000 inhabitants increased by 35% and 40%.

In contrast, as shown in Fig. 6, there is no apparent linear relationship between deaths and the presence of indigenous or Afro-descendant populations, nor with socio-economic aspects such as marginalization, poverty or educational level, the sector of economic activity of the employed population, or access to health and housing services.

On the other hand, of the seventeen Pearson Correlation tests performed to understand the spatial distribution of infections in Mexico City, only seven were significant (Fig. 5). The highest coefficient of determination was obtained when analyzing the poverty data, as this variable explains 36% of the positive cases in the entity. The marginalization index indicates that areas with the highest index are the least marginal. Therefore, the greater the depth of inequality, the higher the rate of infection.

Thus, both the marginalization index and the variables that explained the lack of space and quality in

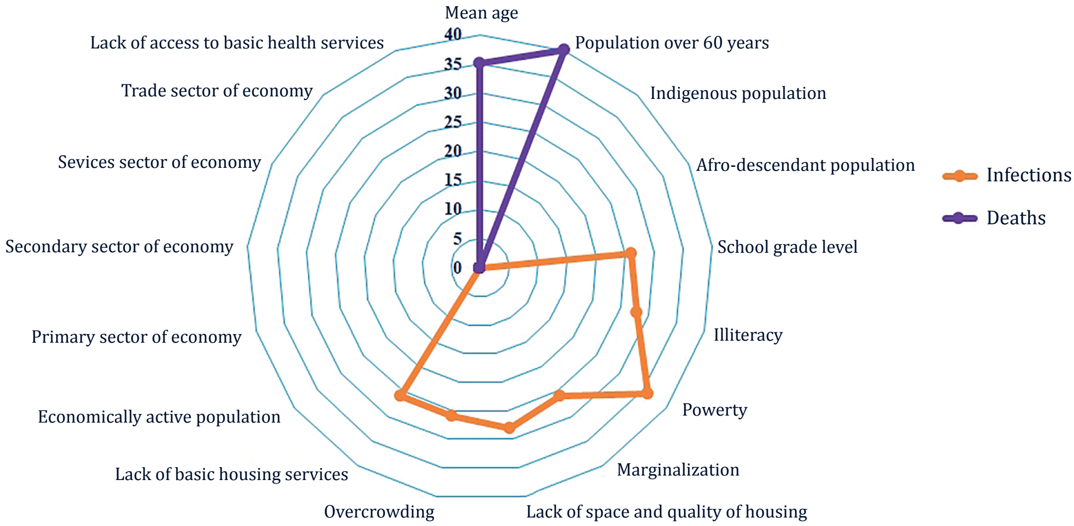

Fig. 6 Percentage of the strength of association between variables.

housing, overcrowding in the home, and the absence of basic services proved to be decisive factors in the construction of vulnerability and exposure of the population, with values ranging from 26% to 28% of the association. The lack of basic services, proper housing, and economic resources can explain 26% to 36% of COVID-19 cases in Mexico City. This is because these factors influence the spread of the virus and the effectiveness of hygiene measures to prevent infection.

Likewise, the level of education and the percentage of illiteracy by demarcation showed significant relationships with the number of infections (Fig. 5). According to the results obtained, the average number of years of schooling is inversely proportional to the infection rate per district; in other words, the lower the level of schooling in the population, the higher the number of positive cases by 26%. Similarly, as the percentage of the illiterate population increased, so did the number of confirmed cases at the district level.

The findings indicate a correlation between the education levels of a population and the range of occupations available. Typically, individuals with lower levels of education may pursue professions that require significant human interaction and are susceptible to job loss (industrial or commercial positions), resulting in greater exposure to potential risk factors.

Populations with a high proportion of illiterate individuals encounter notable obstacles in obtaining dependable information, particularly in written form. This dearth of knowledge can lead to a failure to comprehend key aspects of diseases and the critical steps required to curtail the spread of infections.

In that sense, for the infection, contrary to the behavior of deaths, neither the age of the individuals nor the presence of certain previous illnesses was determinant in the number of reported infections.

Finally, according to the results of the analyses, variables related to the economically active population and the sector of occupation did not play an important role in the population's exposure or vulnerability. Similarly, lack of access to public and private health services, as well as belonging to an indigenous or Afro-descendant group, showed no apparent linear relationship with the pandemic situation in the city.

6. Discussion

The results of the statistical analysis showed that the deaths are closely and exclusively related to factors linked to the intrinsic susceptibility of the populations, that is, to characteristics related to the internal conditions and processes of each individual – such as age or the presence of previous illnesses – that make them more sensitive to the effects of the virus on the body. Thus, the districts with the highest death rates correspond to those with statistically larger populations and some of the highest percentages of individuals aged 60 and over.

Research conducted on children in Mexico showed that 2.8% of confirmed COVID-19 cases were among those under 18, with a median age of 12 and a mortality rate of 1.3%. The study identified several risk factors for mortality, including pneumonia, ICU admission, obesity, hypertension, immunosuppression, diabetes, chronic lung disease, and renal disease (Wong-Chew et al. 2022). These findings are consistent with our analyses as they demonstrate that lethality in infants is significantly lower than that in older adults (over 60 years) and is closely linked to the presence of previous diseases.

Based on the research, it appears that there is a connection between comorbidities and the surge in COVID-19 mortality rates. Furthermore, the study highlights the significance of age, which is strongly linked to the rise in fatalities due to the weakening of the immune system.

On the other hand, infection rates reflect important correlations with factors related to extrinsic vulnerability, that is, with socio-economic aspects such as poverty and marginalization, particularly those related to lack of space and quality in housing, overcrowding, and lack of basic services in the home (piped drinking water, drainage, electricity, and gas cooker), which can be related to the impossibility of observing adequate hygiene and distance measures within the home. Consequently, access to basic services like water is crucial in determining how vulnerable communities are to various hazards, including socio-biological ones like Sars-Cov-2. The lack of these services in homes can create problems. During lockdowns, it made it even harder for vulnerable groups such as homeless individuals to access safe water, sanitation, and hygiene services. This highlights the challenges in applying a human rights approach to the water and sanitation sector, particularly in cases where local governments and service providers fail to operationalize human rights, such as in Mexico City (Liera et al. 2023).

Similar observations have been made in various parts of the world, including New York City. In this area, studies have revealed a positive correlation between several socioeconomic factors, including income, ethnicity, overcrowding, and the infection rate (Hamidi and Hamidi 2021). This highlights the direct impact that the structural characteristics of a population can have on disease transmission. Consequently, it is reasonable to expect that areas with greater inequality may experience more varied patterns of virus distribution.

Furthermore, according to the results, educational level and illiteracy are also important factors in the distribution of infections in the capital. This is primarily explained by the access to written information and the type of economic activity in which most of the population is employed, which prevented compliance with containment measures during the critical period of the pandemic.

The outcomes are ascribed to the societal disparities in the framework that individuals with diverse educational backgrounds encounter. These disparities incorporate the availability of information, mobility, and profession. As per Almagro and Orane-Hutchinson (2022), specific communities demarcated by their socioeconomic traits are more prevalent in various job categories. This aligns with the discoveries of Quinn and Rubb (2005), who contend that an individual's level of education corresponds to their professional undertakings, which may be more or less specialized.

Certain occupations carry a higher risk of contracting the virus, often due to the nature of the work and an individual's education level or specialization. Research by Almagro and Orane-Hutchinson in 2022 on New York City confirms this correlation, with a positive relationship between disease incidence rates and work activities. This can be classified as "occupational exposure".

According to Credit's 2020 study on COVID-19 infections in Chicago and New York, a positive correlation was discovered between the number of health sector professionals and infections in these cities. Almagro and Orane-Hutchinson's 2022 study on servers and workers in the public transportation system also observed the same result.

It is likely that in Mexico City, those with lower levels of education are at a higher risk of contracting the virus due to their participation in activities that require greater human interaction. As a result, any occupation that cannot be suspended due to its inherent nature is associated with an increased risk of exposure.

The displacement of marginalized communities is frequently linked to the widespread use of public transportation, which, when combined with high population densities, has been identified as a contributing factor to the rapid spread of the virus in numerous regions. This phenomenon has been observed in various countries, including England and Wales (Sá 2020), Brazil (Martíns-Filho 2021), and Poland (Ciupa and Suligowski 2021). In Mexico City, population density data at the municipal level may be skewed due to the presence of large geographical areas with small yet densely populated sectors.

Mexico was among the top 10 countries with the highest number of COVID-19 cases and the top 5 countries with the most pandemic-related deaths in 2020 and 2021 despite implementing the sentinel surveillance system (De La Cruz-Hernández and Álvarez-Contreras 2022). Under these circumstances, Knaul et al. (2023) recommended bolstering the Mexican healthcare system in the short term by enhancing accessibility for at-risk populations, expanding healthcare services, including telemedicine, forging public-private partnerships, implementing regulatory measures, and evaluating public health insurance initiatives.

The COVID-19 pandemic put the scientific and technical community in the spotlight of policy-making. In some countries, governments sought their expertise to make well-informed decisions about the best action. Nevertheless, this involved challenges when holding decision-makers responsible for their actions. While scientific and technical experts can offer valuable insights into the virus's spread and the potential impact of various policies, government officials are ultimately responsible for formulating and executing those policies (Weible et al. 2020).

Older adults face multiple risks during the COVID-19 pandemic, including ageism, sexism, susceptibility to illness, and limited access to essential services. These risks threaten their health and well-being and will likely continue to impact them even after the pandemic ends. As such, it would be necessary to implement interventions to meet the unique needs of older adults. These include streamlining care, delivering necessities to their doorstep, prioritizing older adults among repatriated migrants and refugees, and providing social security measures. It is important to note that older adults with cognitive impairment and those in long-term care facilities are particularly vulnerable to COVID-19 (D'cruz and Banerjee 2020). These measures should be integrated into existing services to reduce resource burden, particularly in lower- and middle-income countries like Mexico.

According to a study by Hidayati and Situmorang (2023), it is essential to assist families and residential communities in aiding the elderly in managing the negative effects of COVID-19. These support systems have created effective coping mechanisms to help the elderly navigate the pandemic and maintain their well-being. To provide the best possible support, family members who are closest to the elderly should receive education on their physical and psychological needs. Furthermore, customized health insurance and social protection policies should be implemented to help the elderly cope with the pandemic's impact. Financial aid should also be available to purchase medication and nutritionally tailored foods for the elderly.

It is essential to take swift and unprecedented measures to protect the health and well-being of all individuals, especially the elderly, who are at a higher risk of serious illness or even death from the virus. From a pedagogical perspective, providing effective interventions and education is crucial to counter any misconceptions about COVID-19 or other viruses. To this end, Kakaşçı et al. (2022) recommend using accurate information alongside innovative methods, such as incorporating visual aids like *pecha kucha* in presentations, which have been shown to be more effective than traditional lectures in reducing anxiety among women aged 65 and older with chronic diseases. Cultural contexts should also be considered in shaping these particular approaches.

Shekhar et al. (2022) analyzed 20 global south cities, including Mexico City and concluded they have high exposure and low adaptive capacity. Accordingly, while some cities perform better in certain indicators of susceptibility, like poverty reduction and formal job provision, high population density and lack of open space remain major areas of concern. The role of urban management and governance is crucial in reducing disaster risks, and the community must be involved in risk preparation, especially vulnerable groups such as the elderly.

7. Conclusions

The disaster triggered by the COVID-19 pandemic has exposed pre-existing risk factors in societies worldwide, such as disproportionate resource use and environmental impact. The world economic system, international mobility, population concentrations, and inequality have created a scenario for new threats to emerge. Vulnerability and exposure are intertwined with socioeconomic factors, such as marginalization, poverty, and limited access to essential services. In Mexico City, several disaster risk drivers increase the risk of COVID-19, including individual traits and broader socioeconomic conditions. Marginalization, poverty, and limited access to services contribute to the spread of the virus. Additionally, uneven population distribution, living conditions, and public transportation use lead to unique transmission patterns. The development model in Mexico has resulted in rapid and disorganized urban growth, exacerbating the inequality gap and increasing vulnerability to hazards, including those of biological origin, such as COVID-19.

The COVID-19 pandemic brought to light apprehensions concerning Mexico's response. It has been observed that the country hasn't adequately catered to the specific requirements of older citizens and other vulnerable groups, who are at greater risk of contracting the virus and facing severe health implications. To overcome this challenge, it is fundamental to enhance the healthcare system, better the working conditions of healthcare workers, and grant broader access to medical services. Additionally, offering all-encompassing support to the elderly, such as financial aid and emotional assistance, can help them deal with the impacts of the pandemic.

Overall, effective disaster risk management is crucial to reduce the potential risks arising from different types of hazards. This approach should be science-informed, integrated and expeditious. It should consider the needs of vulnerable groups, such as the ageing population, and the unique complexities and realities of local contexts. Only by identifying and reducing the vulnerability and exposure of people to risks associated with known and emergent hazards can disasters be avoided.

Acknowledgments

Thanks to the National Council of Humanities, Sciences, and Technologies (CONAHCYT) who provided a student fellowship for Perla Lorena Romero-Gaeta.

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