

Molina-Torres, R.; Nolasco-Jauregui, O.; Rodriguez-Torres, E. E.; Itzá-Ortiz, B. A.; Quezada-Tellez, L. A.

Article

A comparative analysis of urban development, economic level, and COVID-19 cases in Mexico City

Journal of Urban Management

Provided in Cooperation with:

Chinese Association of Urban Management (CAUM), Taipei

Suggested Citation: Molina-Torres, R.; Nolasco-Jauregui, O.; Rodriguez-Torres, E. E.; Itzá-Ortiz, B. A.; Quezada-Tellez, L. A. (2021) : A comparative analysis of urban development, economic level, and COVID-19 cases in Mexico City, Journal of Urban Management, ISSN 2226-5856, Elsevier, Amsterdam, Vol. 10, Iss. 3, pp. 265-274, <https://doi.org/10.1016/j.jum.2021.06.007>

This Version is available at:

<https://hdl.handle.net/10419/271429>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

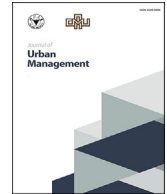
HOSTED BY



ELSEVIER

Contents lists available at ScienceDirect

Journal of Urban Management

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

Research Article

A comparative analysis of urban development, economic level, and COVID-19 cases in Mexico City

R. Molina-Torres^a, O. Nolasco-Jáuregui^b, E.E. Rodríguez-Torres^{c,*}, B.A. Itzá-Ortiz^c, L.A. Quezada-Téllez^d^aIndoor Environmental Quality & Architect, Mexico City, Mexico^bBiostatistics Department of Tecana American University, W Cypress Creek Road Suite, 300, Fort Lauderdale, FL, 33309, USA^cÁrea Académica de Matemáticas y Física, Universidad Autónoma del Estado de Hidalgo, Hgo, Mexico^dDepartamento de Física y Matemáticas, Universidad Iberoamericana, Prolongación Paseo de Reforma 880, Lomas de Santa Fe, C.P.01219, Ciudad de México, Mexico

ARTICLE INFO

Keywords:

COVID-19
per capita income
Mexico City
Dwelling occupancy
Population density

ABSTRACT

The pandemic caused by the SARS-CoV-2 virus spreads more rapidly in densely populated areas. The number of confirmed cases is counted by the millions in some countries, such as USA, Brazil, and Mexico. These three countries also report the world's highest cumulative death tolls caused by the disease as of February 2021. In this study, a comparative analysis of urban development, economic level, and the number of COVID-19 cases in Mexico City, is conducted. Mexico City, the capital city of Mexico, is among the most densely populated metropolitan areas and one of the largest financial centers in the continent. Among the sixteen municipalities, in which Mexico City is divided, there exist enormous economic and urban development gaps. Based in a comparability index (CI), this study found a correlation between the number of confirmed cases of the COVID-19 disease with the population density, the per capita income, and the dwelling occupancy index in each municipality.

1. Introduction

In the midst of the 21st century, humanity faces a huge public health challenge. On December 31st, 2020, the World Health Organization's (WHO) Country Office in China picked up a report on some cases of 'viral pneumonia of unknown cause' in Wuhan, China. Chinese authorities soon reported that the outbreak was due to a novel coronavirus, now known as the SARS-CoV-2. Coronaviruses are known to emerge periodically, in different areas and in mutated forms, causing diseases such as Severe Acute Respiratory Syndrome (SARS, 2002), Middle East respiratory syndrome (MERS, 2012), and also less-severe disease such as the common cold. One year after this WHO's report, the virus has been extended in almost all regions of the planet. The number of confirmed cases and death toll due to COVID-19 varies widely from one country to another, due in part to the different responses by the government authorities (Hui et al., 2020; Sharma, Ahmad and Lal, 2021; Tao et al., 2021).

In trying to limit the further spread of the virus, in an increasingly complex urban setting, it is becoming clear that mathematical models for epidemics (Wang, 2020), such as the SIR model or its extended versions, must considerate the incorporation of parameters like the urban development and the economic level as primary sources of virus spread in the cities in order to influence mitigation in the

* Corresponding author.

E-mail address: erikart@uaeh.edu.mx (E.E. Rodríguez-Torres).<https://doi.org/10.1016/j.jum.2021.06.007>

Received 15 November 2020; Received in revised form 1 May 2021; Accepted 18 June 2021

Available online 15 July 2021

2226-5856/© 2021 The Authors. Published by Elsevier B.V. on behalf of Zhejiang University and Chinese Association of Urban Management. This is

an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

transmission of COVID-19. Some studies have already shown the effectiveness of social distancing policies in those countries with high population densities (Jawad, 2020; Moosa, 2020). Indeed, those studies evaluated data from different countries in terms of density and compared it with the number of infection cases registered (Auerbach & Thachil, 2021; Teller, 2021; Abouk & Heydari, 2021). They have concluded that one way of managing the ensuing public health crisis and keeping the number of massive infections under control is precisely through the implementation of social distancing policies in crowded places, especially during rush hours (Auerbach & Thachil, 2021; Teller, 2021; Castex, Dechter, & Lorca, 2020; Matrajt & Leung, 2020). On the other hand, although there seem to be no serious studies validating a relationship between the death toll and economic fluctuations during the COVID-19 global crisis, it is a fact that in the early months of the pandemic, stock markets suffered historic losses while daily deaths growth factor stayed constantly above one around the world. However, economists do point out that there is a negative influence on the economy due to the COVID-19 pandemic, called stagflation, appearing when inflation rate rises beyond the anticipated, economic growth rate slows, and unemployment remains steadily high (Asare et al., 2021). Market prices are expected to increase due to the negative effect on the supply chains, factories and other business closure, and mass layoff (Garnier, Benetka, Kraemer, & Bansal, 2021; Chowdhury, Khan, & Dhar, 2021). All economic sectors have been badly affected; for example, in the USA, the application for unemployment benefits has soared and the poverty rate has risen (Asare et al., 2021).

In this paper, an analysis of some factors influencing the number of COVID-19 cases in Mexico City is presented. The proposed factors are the population density, the dwelling occupancy index, and the per capita income, which have been separately shown to influence COVID-19 spread (Biglieri, S., De Vidovich, L., and Keil, R., 2020; Nathan, M., and Overman, H., 2020; Wright, A. L., et al., 2020; Bonaccorsi, G., et al., 2020; Goutte, S., Péran, T., and Porcher, T., 2020). By means of a comparability index (CI), it is found that there exists a correlation between the number of confirmed cases of COVID-19 and a high population density, low per capita income and high dwelling occupancy index. While the economic level is arguably an expected factor in the high incidence of COVID-19 cases in any big city, it is demonstrated the urban development also plays a substantial role. We reach this conclusion by contrasting the cases of Milpa Alta and Cuauhtémoc municipalities, which have the lowest and highest per capita income in Mexico City, respectively. While Milpa Alta turned out to have the lowest CI index, Cuauhtémoc ranked among the highest CI indexes of the sixteen municipalities. The discernible difference relays in the low population density, allowing Milpa Alta inhabitants to maintain a tacit social distance despite not being able of following government dispositions of staying home, as the population has the need to leave home for work. In contrast, Cuauhtémoc holds the second largest population density among the sixteen municipalities. Finally, Iztapalapa, a municipality with high population density and low per capita income, has the highest CI index.

The article is organized as follows. Section 2 contains the background of the study, explaining the scenario behind the main problem, that is, the urban setting and the economic levels in contemporary Mexico and in particular, in its capital city. Section 3 contains the modeling and data analysis leading to the comparability index, the main contribution of this study. It also contains a description of the characteristics of each municipality after and before the COVID-19 arrived in Mexico City. Section 4 contains a discussion of the analysis and methodology used, and finally, in Section 5, the conclusions are provided.

2. Background

2.1. Urban pattern, economic level, and health in Mexico

Mexico, with a population of about 126 million by 2010, is the most populous country in the Americas after the United States and Brazil. From its total population, the 48.6% is female and 51.4% is male. Since the beginning of the XXI century, Mexico is a highly urbanized country with nearly 80% of its population living in urban areas. As of the year 2005, it has 367 cities; however, 83% of the total national urban population concentrates in only 57 metropolitan areas. (Garza and Scheingart, 2010; Aguilar, Ward, & Smith Sr, 2003).

Mexico faces enormous challenges in public service, especially in urban areas, such as infrastructure for electricity, telecommunications, water supplies, drain housing systems, road and highways maintenance, education, healthcare, public safety, and others. Both industry and commerce, which are essential for the international competitiveness of the country, relay in the efficiency of public services (Garza and Scheingart, 2010; Aguilar et al., 2003).

Economic development and urbanization are two inseparable processes that characterize the structure of the society. By the end of 2019, Mexico had a Gross Domestic Product (GDP) of 18,406,850 millions of pesos and a population of 126.014 millions, so the GDP per capita was 146,070 (INEGI, 2021). In 2019, the inflation rate was 4.9%, the unemployment rate was of 3.3%, and the GDP rate grew 2%. The distribution of the population is around of 67% living in cities, as a consequence the rural areas have very high poverty levels. Almost 46% of Mexico population lives below the poverty line, making Mexico rank first in income inequality among the Organisation for Economic Co-operation and Development (OECD) countries (Iniguez, 2014; Iniguez and Kurosaki, 2018; Keeley, 2015; Loria, 2020).

According to the National Institute of Statistics, Geography and Informatics (INEGI), in 2019, Mexico was the largest export market in Latin America with almost 19% of the total. The bilateral trade volume increased 1.8% and it reached 1.2 billion USD. Mexico is the second largest economy in Latin America after Brazil and the 15th largest in the world. Mexico occupies the 12th position as an exporter in the world and it is principal importer in Latin America and the Caribbean region. It also has almost the 42% of the total exports and imports of the region. Nearly the 77% of the country's exports and 47% imports are between Mexico and the USA. In the first quarter of 2019, the FDI (Foreign Direct Investment) incomes to Mexico mounted to 10.16 billion USD. The investments increased 7% compared to the same period of the previous year. Remittances transferred by Mexicans abroad have been one of the major sources of income. It is known that approximately 33.5 billion dollars from remittances entered Mexico in 2019, of which 95% were sent by Mexicans residing in the USA. On the other hand, 65% of the Mexican GDP is made up of the service sector, while the participation of industry is 32% and

agriculture is 4% (INEGI, 2021).

Mexico is one of the Latin American countries that has easily inserted into the global neoliberal economic model. However, the benefits brought by this model has not been evenly distributed. One of the economic sectors that is still under great vulnerability is the healthcare sector. Since 2000, Mexico has gone through an epidemiological transition characterized by an increase in morbidity and mortality in chronic non-communicable diseases. During 2019, Mexico's deaths were due to illnesses and health-related problems (88.4%), while 11.6% were due to external causes, such as accidents, homicides, suicides, and others. It should be noted that Mexico's deaths due to health problems have three similar causes (both men and women): heart disease (20.7%), diabetes mellitus (14%), and malignant tumors (11.9%) (Loría, 2020).

2.2. Mexico city

Mexico's capital city was founded on the ruins of Tenochtitlan. Tenochtitlan was a city founded by the Mexica people (or Aztecs) in the XIII century, it was located on an island in a lake that existed in the Valley of Mexico. Tenochtitlan was one of the emblematic and highest-ranking cities in Mesoamerica. It boosted a hydraulic systems and its use of natural resources stood out. The city restrained the waters to avoid floods and, on the other hand, it supplied fresh water, that circulated in the interior of the city, for growing crops. They moved in the canals through *chinampas*. It is important to mention the harmonious relationship between multifaceted architecture combined with nature, that could be seen throughout the city, which astonished the *conquistadores* by its beauty and size. There was a startling contrast between possessing the biggest and largest pyramids in the continent and yet featuring the commodities of a modern city. During that period, the population amounted to more than 230,000 inhabitants (Trillo, 1996; Hamnett, 2006; Smith, Chatterjee, Huster, Stewart, & Forest, 2019; Carballo, D. M., 2016; Romero Lankao, P., 2010; Losada, H., et al., 1998; Mundy, B. E., 2015).

In 1920, Mexico City had a population of 600, 000 people. By 1960, it had grown to 4, 870, 876 inhabitants, a 59.7% increase from the 1950 census population of 3, 050, 442 people. The city continued to grow at an accelerated rate as the industrial zones did. The peripheral areas of the city were being absorbed by urban growth (Izazola, H., Martínez, C., and Marquette, C; Boudreau, J. A., Gilbert, L., and Labbé, D., 2016).

Due to the economic growth during the period from 1950 to 1980, the urban development of the city was forced to solve the following challenges. 1) Urbanization exceeded the geographical limits, extending the municipalities areas toward the limits of other state entities. 2) Over-demand for houses in Mexico City, causing the rise in the cost of houses and buildings in the metropolitan area, while building a house devalued outside the metropolitan area. 3) Building of suburbs along the neighboring Mexico State border. Mexico State offered millions of workers that must daily commute to their workplace in downtown Mexico City (Pezzoli, K., 2000; Mautner, M. R., et al., 2020; Guerra, E., 2014).

One of the solutions proposed by the federal and local governments, at the end of the XX century, was the construction of a large number of houses located in strategic geographic areas in the city limits. (Delgadillo, V., 2016). At the early XII century, a typical building apartment in Mexico City was around 83 m^2 and a common building house was almost 270 m^2 . In the case of self-building houses, they have an average of 7.5 inhabitants per home and space allocated for self-cultivation. The main building materials are cardboard, wood, and wood sheets (Bredenoord & Cabrera, 2014; Sánchez Corral, 2012).

2.3. The COVID-19 in Mexico

The first suspected case of COVID-19 in Mexico was announced on February 27th, 2020. The patient was receiving medical treatment at the National Institute of Respiratory Diseases who had traveled to Bergamo, Italy, where he had been in contact with an infected person. The next day, on February 28th, the Institute for Diagnosis and Epidemiological Reference “Dr. Manuel Martínez Baez” (InDRE) confirmed the patient had tested positive to COVID-19. Subsequently, four other people who had traveled to Italy tested positive to COVID-19. Three of them had presented only mild symptoms, two of these three patients were from Mexico City and the last one was from Sinaloa. Soon, new confirmed cases of the disease emerged. On February 29th, a positive case was reported in a female patient who returned to Torreón, Coahuila, who had traveled to Italy as well. Her symptoms were mild and she stayed home for care. The following case was confirmed in Tuxtla Gutiérrez, Chiapas. It was an 18-year-old girl with mild symptoms, who had also arrived from Italy and had been in contact with Torreón's patient. Until March 1st, 2020, all COVID-19 cases in Mexico were imported (Aragó et al., 2019; Salinas-Escudero et al., 2020).

Almost a year later, by February 24th, 2021, according to the WHO statistics, in Mexico there have been 2, 043, 632 confirmed cases of COVID-19 with 180, 536 deaths. This places Mexico as the country with the third highest death toll worldwide.

3. The methodology and modeling

3.1. Data and analysis

From the economic censuses of the INEGI 2015, the variables of population density, per capita income, and dwelling occupancy index are described in Tables 1–3 and Figs. 1–3.

Table 1 and Fig. 1 show the population for the year 2015. It is important to note that since INEGI census occur every 5 years, it is the most up-to-date information available to carry out the present analysis. The municipalities with the largest and smallest populations are Iztapalapa (1,827,868) and Milpa Alta (137,927), respectively. Iztacalco is the municipality with the highest population density (17,905.87).

Table 1

Mexico City's population density. The fourth column describes the population density per municipality calculated from the total population divided by the surface (in square kilometers). Source (INEGI, 2021).

Municipality	Population	Surface (Km ²)	Density
Álvaro Obregón	749, 982	93.7	8, 004.08
Azcapotzalco	400, 161	34.5	11, 598.87
Benito Juárez	417, 416	28	14, 907.71
Coyoacán	608, 479	59.2	10, 278.36
Cuajimalpa	199, 224	72.9	2, 732.84
Cuauhtémoc	532, 553	32	16, 642.28
Gustavo A. Madero	1, 164, 477	91.5	12, 726.52
Iztacalco	390, 348	21.8	17, 905.87
Iztapalapa	1, 827, 868	124.5	14, 681.67
M. Contreras	243, 886	62.2	3, 921.00
Miguel Hidalgo	364, 439	46.8	7, 787.16
Milpa Alta	137, 927	268.6	513.50
Tláhuac	361, 593	88.4	4, 090.42
Tlalpan	677, 104	309.7	2, 186.32
Venustiano Carranza	427, 263	30.7	13, 917.36
Xochimilco	415, 933	134.6	3, 090.14

Table 2

Per capita income in Mexico City. The fourth column describes the per capita income per municipality calculated by dividing the total income in the second column (in millions of pesos) by the total population in the third column. Source (INEGI, 2021).

Municipality	Income	Population	PC Income
Álvaro Obregón	37, 672	749, 982	0.050
Azcapotzalco	28, 776	400, 161	0.072
Benito Juárez	22, 331	417, 416	0.053
Coyoacán	9, 864	608, 479	0.016
Cuajimalpa	10, 352	199, 224	0.052
Cuauhtémoc	121, 719	532, 553	0.229
Gustavo A. Madero	7, 287	1, 164, 477	0.006
Iztacalco	5, 030	390, 348	0.013
Iztapalapa	12, 266	1, 827, 868	0.007
M. Contreras	978	243, 886	0.004
Miguel Hidalgo	98, 643	364, 439	0.271
Milpa Alta	119	137, 927	0.001
Tláhuac	1, 307	361, 593	0.004
Tlalpan	12, 115	677, 104	0.018
Venustiano Carranza	9, 332	427, 263	0.022
Xochimilco	2, 524	415, 933	0.006

Table 3

The dwelling occupancy indices in Mexico City. The fourth column represents the dwelling occupancy index per municipality calculated by dividing the number of permanent residents in the second column by the total number of dwellings in the third column. Source (INEGI, 2021).

Municipality	Resident	Dwelling	DO index
Álvaro Obregón	749, 595	214, 895	3.49
Azcapotzalco	399, 845	119, 027	3.36
Benito Juárez	416, 775	159, 700	2.61
Coyoacán	608, 419	186, 317	3.27
Cuajimalpa	199, 075	55, 478	3.59
Cuauhtémoc	531, 561	188, 135	2.83
Gustavo A. Madero	1, 163, 420	324, 587	3.58
Iztacalco	390, 271	110, 174	3.54
Iztapalapa	1, 827, 345	495, 665	3.69
M. Contreras	243, 878	66, 676	3.66
Miguel Hidalgo	364, 311	128, 042	2.85
Milpa Alta	137, 836	34, 086	4.04
Tláhuac	361, 204	94, 678	3.82
Tlalpan	676, 979	190, 591	3.55
Venustiano Carranza	426, 490	126, 002	3.38
Xochimilco	415, 816	107, 270	3.88

In order to have a measure of marginalization among the municipalities, the per capita income was calculated for each one of them. The per capita income for each municipality is shown in Table 2 and Fig. 2. It is important to mention that per capita income alone may not accurately reflect the marginalization of the represented municipalities. For example, the Milpa Alta municipality still relays on agricultural activities for subsistence. Due to insufficient statistical data for a more accurate measurement of marginalization, we kept using per capita income.

On the other hand, the municipality with the highest per capita income is Cuauhtémoc. In this municipality the main economic activity is commerce, which absorbs a large portion of the population. In second place is Miguel Hidalgo municipality, it also concentrates a large share of the tertiary sector (retail, tourism, banking, entertainment, etc.) of the local economy. Milpa Alta, with deprived economic activity, represents the lowest per capita income in all the Mexico City municipalities.

Despite a good performance of the national economy and the positive levels of economic growth, there has not been an even economic development of Mexico's population. Due to low income levels, young Mexicans cannot purchase a house and unable to become independent. So, most of the houses in the metropolitan area have at least two families on average.

Considering this situation, the chosen third variable for this research is dwelling occupancy index, shown in Table 3. The largest dwelling occupancy indices occur in the municipalities of Iztapalapa, Gustavo A. Madero, Tlalpan and Cuauhtémoc; while Milpa Alta, Cuajimalpa and M. Contreras municipalities have lowest.

Table 4 and Fig. 3 show the percentages of infections by COVID-19 in each of the municipalities of Mexico City. The municipalities with the highest number of infected cases are Iztapalapa, Gustavo A. Madero, and Tlalpan; while municipalities with the lowest number of infected cases are Milpa Alta and Cuajimalpa. The data used in this study is available on-line through the Public Health Department website, a branch of the Federal Government. To harvest the data, a software tool was constructed. A hierarchical method was employed, that is, in the first level all data related with symptomatic patients and asymptomatic patients who tested positive for COVID-19 were placed in a spreadsheet. The database analyzed in the article includes records from April 12th, 2020, to January 30th, 2021. A total of 584,832 records were contabilized.

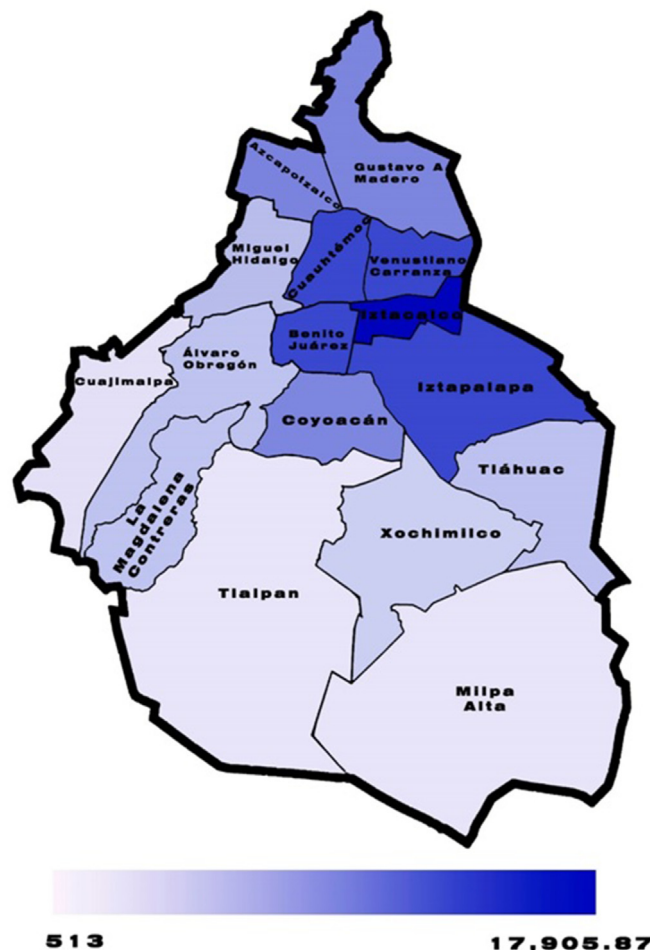


Fig. 1. Image of Mexico City map divided by municipalities and their density patterns. Data presented is in Table 1.

3.2. COVID-19 comparability index

The final step in the analysis is the definition and computation of the comparability index (CI). This parameter has the purpose of integrating the information of all previously introduced variables, namely, population density, per capita income, and dwelling occupancy index, in connection with the number of COVID-19 cases in each of Mexico City's municipalities. In this way, a correlation between the number of confirmed cases of COVID-19 and the economic level, and urban development in each municipality is established.

Recall that the population density PD_i (Table 1 and Fig. 1) is defined by Equation (1)

$$PD_i = \frac{P_i}{S_i}, \tag{1}$$

where P_i and S_i are the population and the surface of the i th municipality.

The per capita income PC_i (Table 2 and Fig. 2) is defined by Equation (2)

$$PC_i = \frac{I_i}{P_i}, \tag{2}$$

where I_i is the total income and P_i the total population of the i th municipality.

Now, the dwelling occupancy index DO_i (Table 3) is represented by Equation (3)

$$DO_i = \frac{R_i}{D_i}, \tag{3}$$

where R_i is the number of permanent residents and D_i is the total number of dwellings of the i th municipality.

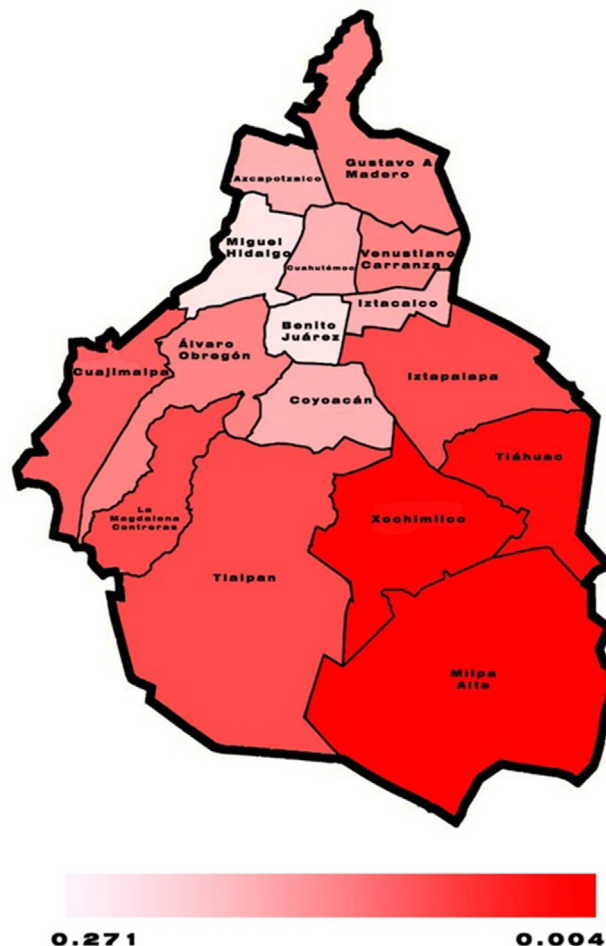


Fig. 2. Mexico City map divided by municipalities and illustrating the per capita index introduced in Table 2.

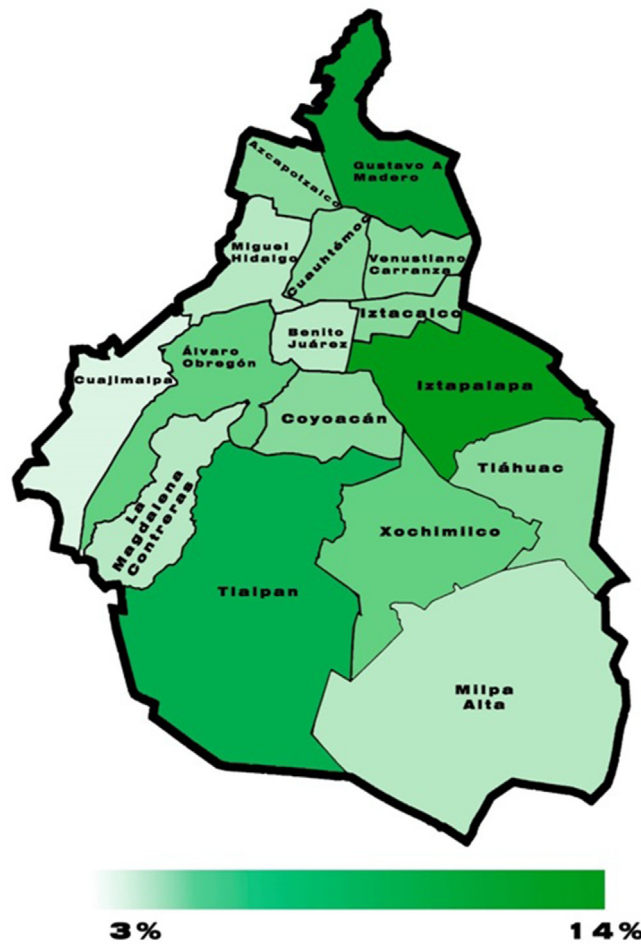


Fig. 3. Image of Mexico City map divided by municipalities showing the number of COVID-19 infected cases, Table 4.

Table 4

COVID-19 in Mexico City. The second column shows the number of confirmed cases of COVID-19. The third column describes the percentage of total cases of coronavirus infected in Mexico City. The data is available at: <https://datos.gob.mx/busca/dataset/informacion-referente-a-casos-covid-19-en-mexico>. (January 30th, 2020).

Municipality	COVID-19	%
Álvaro Obregón	10840	8%
Azcapotzalco	7469	6%
Benito Juárez	4703	4%
Coyoacán	8959	7%
Cuajimalpa	3932	3%
Cuauhtémoc	7212	6%
Gustavo A. Madero	16248	12%
Iztacalco	5939	5%
Iztapalapa	18586	14%
M Contreras	5021	4%
Miguel Hidalgo	5538	4%
Milpa Alta	3421	3%
Tláhuac	6707	5%
Tlalpan	11692	9%
Venustiano Carranza	7094	5%
Xochimilco	7597	6%

$$CI_i = (\alpha_1 PD_i + \alpha_2 PC_i + \alpha_3 DO_i) * (COVID - 19). \tag{4}$$

The comparability index CI_i , defined in Equation (4), is the multiplication of the weighted average of the three variables: population

Table 5
 COVID-19 Comparability Index (CI) of Mexico City. The second column is the CI calculated by Equation (4).

Municipality	CI
Álvaro Obregón	220.72
Azcapotzalco	220.35
Benito Juárez	178.31
Coyoacán	234.23
Cuajimalpa	27.36
Cuauhtémoc	305.25
Gustavo A. Madero	525.95
Iztacalco	270.46
Iztapalapa	694.04
M. Contreras	50.11
Miguel Hidalgo	109.70
Milpa Alta	4.50
Tláhuac	69.83
Tlalpan	65.11
Venustiano Carranza	251.11
Xochimilco	59.77

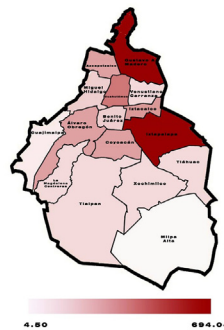


Fig. 4. Image of Mexico City map divided by municipalities, showing their level of COVID-19 Comparability Index. Data presented is in Table 5.

density PD_i , per capita income index PC_i , and the dwelling occupancy index DO_i , by the number of COVID-19 cases in the i th municipality. The non-negative coefficients α_1 , α_2 , and α_3 satisfy the condition $\alpha_1 + \alpha_2 + \alpha_3 = 1$. These coefficients α_1 , α_2 , and α_3 represent the participation weighting of the variables PD_i , PC_i , and DO_i , respectively, in the CI. In this study, the equal values $\alpha_1 = \alpha_2 = \alpha_3 = 0.333$ were chosen, as it is assumed a uniform contribution of each variable in the spread of the COVID-19 disease.

The results are shown in Table 5 and Fig. 4. According to the resulting CI, there exists a correlation between the number of confirmed cases of COVID-19 with a high population density, low per capita income, and high dwelling occupancy index. More precisely, if the income level alone were the only factor in determining the number of COVID-19 cases, one would expect that a high income municipality has lower CI compared with a low income municipality. While this is true for the municipalities of Cuauhtémoc (the second highest income after Miguel Hidalgo) and Iztapalapa (the third lowest PC income), it is not true of Cuauhtémoc and Milpa Alta (the second lowest PC income). Similarly, if the only factor in determining the number of COVID-19 cases were high population density, then Iztacalco should have the highest CI. However, this is not the case, as Iztacalco is in fourth place. Finally, if just the dwelling occupancy index were the main factor in determining the number of COVID-19 cases, then Milpa Alta should have the highest CI, but the contrary is true, as this municipality has the lowest CI. Therefore, it is the combination of the three variables, namely, high population density and high dwelling occupancy index, combined with a low per capita income, as in the case of Iztapalapa, which implies a high CI. (see Table 5 and Fig. 4).

4. Discussion

In big cities, high population density is associated with high coronavirus contagion rate (Biglieri, S., De Vidovich, L., and Keil, R., 2020; Nathan, M., and Overman, H., 2020). Some authors argue that poverty induces people to reduce the compliance of health protocols (Wright, A. L., et al., 2020). Also, the social and economical restrictions imposed to limit social gatherings and time spent in crowded places seem to reduce pandemic mortality (Bonaccorsi, G., et al., 2020; Goutte, S., Péran, T., and Porcher, T., 2020). Other factor that shows an increment in COVID-19 cases is a high dwelling occupancy index (Bhardwaj et al., 2020). An analysis linking both urban development and economic level in relation to the number of COVID-19 cases in each of the sixteen municipalities integrating Mexico City was conducted. The data to figure out the population density, the per capita income, the dwelling occupancy index, and the number of COVID-19 cases were collected from official government websites and organized in Tables 1–4. Illustrations of this data are presented in Figs. 1–3.

To quantify the simultaneous impact of the proposed three variables in the number of COVID-19 cases, a comparability index CI is calculated. The CI in each municipality is defined as the weighted average of the values of the three variables multiplied by the number of COVID-19 cases. It was decided that the three variables play an equally important role in the transmission of the virus. As a result, the weightings in the comparability index were taken to be equal to 0.333. We decided to keep the weighted average in the CI formula, as it may be argued that the proposed variables carry different weights in their contribution to the spread of COVID-19. However, mathematically, the conclusion of the paper, a correlation between the spread of the virus with these three variables, will still hold. The resulting values of the CI are presented in Table 5 and Fig. 4. It would be interesting to study the dynamics of the virus within a home in a typical house in Mexico City as well as the air ventilation and air ducts in a closed space, such as inside the houses. Altogether, this would allow limiting the further spread of the virus.

5. Conclusions

Mexico City is one of the largest cities in the world and has been one of the most affected by the number of infections and deaths from COVID-19. In this analysis, the population density, per capita income, and dwelling occupancy index were studied as factors of transmission of the virus for the sixteen municipalities. In order to assess the influence of the proposed variables in the number of COVID-19 cases, a comparability index (CI) was proposed for each municipality. The CI is defined as the product of the average of the population density, the per capita income, and the dwelling occupancy index, with the number of COVID-19 cases. The COVID-19 comparability index showed that the municipalities with the highest population density, low per capita income, and high dwelling occupancy index had a high CI, and therefore a high rate of infections.

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

- Abouk, R., & Heydari, B. (2021). The immediate effect of COVID-19 policies on social-distancing behavior in the United States. *Public Health Reports*, 136(2), 245–252.
- Aguilar, A. G., Ward, P. M., & Smith Sr, C. B. (2003). Globalization, regional development, and mega-city expansion in Latin America: Analyzing Mexico City's peri-urban hinterland. *Cities*, 20(1), 3–21.
- Aragón Nogales, R., Vargas Almanza, I., & Miranda Novales, M. G. (2019). COVID-19 por SARS-CoV-2: la nueva emergencia de salud. *Revista Mexicana de Pediatría*, 86(6), 213–218.
- Asare, P., & Barfi, R. (2021). The impact of covid-19 pandemic on the global economy: Emphasis on poverty alleviation and economic growth. *Economics*, 8(1), 32–43.
- Auerbach, A. M., & Thachil, T. (2021). How does covid-19 affect urban slums? Evidence from settlement leaders in India. *World Development*, 140, Article 105304.
- Bhardwaj, G., Esch, T., Lall, S. V., Marconcini, M., Soppelsa, M. E., & Wahba, S. (2020). *Cities, crowding, and the coronavirus: Predicting contagion risk hotspots*.
- Biglieri, S., De Vidovich, L., & Keil, R. (2020). City as the core of contagion? Repositioning COVID-19 at the social and spatial periphery of urban society. *Cities & Health*, 1–3.
- Bonaccorsi, G., Pierri, F., Cinelli, M., Flori, A., Galeazzi, A., Porcelli, F., et al. (2020). Economic and social consequences of human mobility restrictions under COVID-19. *Proceedings of the National Academy of Sciences*, 117(27), 15530–15535.
- Boudreau, J. A., Gilbert, L., & Labbé, D. (2016). Uneven state formalization and periurban housing production in Hanoi and Mexico City: Comparative reflections from the global South. *Environment & Planning A: Economy and Space*, 48(12), 2383–2401.
- Bredenoord, J., & Cabrera, L. (2014). Affordable housing for low-income groups in Mexico and urban housing challenges of today. In J. Bredenoord, P. van Lindert, & P. Smets (Eds.), *Affordable housing in the urban global south: Seeking sustainable solutions* (pp. 223–240).
- Carballo, D. M. (2016). *Urbanization and religion in ancient central Mexico*. USA: Oxford University Press.
- Castex, G., Dechter, E., & Lorca, M. (2020). COVID-19: The impact of social distancing policies, cross-country analysis. *Economics Of Disasters And Climate Change*, 1–25.
- Chowdhury, E. K., Khan, I. I., & Dhar, B. K. (2021). *Catastrophic impact of Covid-19 on the global stock markets and economic activities*. Business and Society Review.
- Delgadillo, V. (2016). Selective modernization of Mexico City and its historic center. Gentrification without displacement? *Urban Geography*, 37(8), 1154–1174.
- Garnier, R., Benetka, J. R., Kraemer, J., & Bansal, S. (2021). Socioeconomic disparities in social distancing during the COVID-19 pandemic in the United States: Observational study. *Journal of Medical Internet Research*, 23(1), Article e24591.
- Garza, G., & Scheingart, M. (Eds.). (2010). *Los grandes problemas de México. Desarrollo urbano y regional*. T-II. El Colegio de México AC.
- Goutte, S., Péran, T., & Porcher, T. (2020). The role of economic structural factors in determining pandemic mortality rates: Evidence from the COVID-19 outbreak in France. *Research in International Business and Finance*, 54, Article 101281.
- Guerra, E. (2014). The built environment and car use in Mexico City: Is the relationship changing over time? *Journal of Planning Education and Research*, 34(4), 394–408.
- Hamnett, B. R. (2006). *A concise history of Mexico*. Cambridge University Press.
- Hui, D. S., I Azhar, E., Madani, T. A., Ntoumi, F., Kock, R., Dar, O., et al. (2020). The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health - the latest 2019 novel coronavirus outbreak in Wuhan, China. *International Journal of Infectious Diseases*, 91, 264–266.
- INEGI. National Institute of Statistic. (2021a). *Geography and Informatics. Data*. <http://en.www.inegi.org.mx/datos/default.html>.
- INEGI. National Institute of Statistic. (2021b). *Geography and Informatics. Economic Information Bank*. <https://www.inegi.org.mx/sistemas/bie/>.
- Iniguez-Montiel, A. J. (2014). Growth with equity for the development of Mexico: Poverty, inequality, and economic growth (1992–2008). *World Development*, 59, 313–326.
- Iniguez-Montiel, A. J., & Kurosaki, T. (2018). Growth, inequality and poverty dynamics in Mexico. *Latin American Economic Review*, 27(1), 1–25.
- Izazola, H., Martínez, C., & Marquette, C. (1998). Environmental perceptions, social class and demographic change in Mexico city: A comparative approach. *Environment and Urbanization*, 10(1), 107–118.
- Jawad, A. J. (2020). Effectiveness of population density as natural social distancing in COVID19 spreading. *Ethics, Medicine and Public Health*, 15, Article 100556.
- Keeley, B. (2015). *Income inequality: The gap between the rich and the poor*. OECD Insights. Paris: OECD publishing.
- Loría, E. (2020). Poverty trap in Mexico, 1992–2016. *International Journal of Development Issues*, 19(3), 277–301.
- Losada, H., Martínez, H., Vieyra, J., Pealing, R., Zavala, R., & Cortés, J. (1998). Urban agriculture in the metropolitan zone of Mexico city: Changes over time in urban, suburban and peri-urban areas. *Environment and Urbanization*, 10(2), 37–54.
- Matrajt, L., & Leung, T. (2020). Evaluating the effectiveness of social distancing interventions to delay or flatten the epidemic curve of coronavirus disease. *Emerging Infectious Diseases*, 26(8), 1740.

- Mautner, M. R., Foglia, L., Herrera, G. S., Galán, R., & Herman, J. D. (2020). Urban growth and groundwater sustainability: Evaluating spatially distributed recharge alternatives in the Mexico City Metropolitan Area. *Journal of Hydrology*, 586, Article 124909.
- Moosa, I. A. (2020). The effectiveness of social distancing in containing Covid-19. *Applied Economics*, 52(58), 6292–6305.
- Mundy, B. E. (2015). *The death of Aztec Tenochtitlan, the life of Mexico City*. University of Texas Press.
- Nathan, M., & Overman, H. (2020). Will coronavirus cause a big city exodus? *Environment and Planning B: Urban Analytics and City Science*, 47(9), 1537–1542.
- Pezzoli, K. (2000). *Human settlements and planning for ecological sustainability: The case of Mexico City*. MIT press.
- Romero Lankao, P. (2010). Water in Mexico city: What will climate change bring to its history of water-related hazards and vulnerabilities? *Environment and Urbanization*, 22(1), 157–178.
- Salinas-Escudero, G., Carrillo-Vega, M. F., Granados-García, V., Martínez-Valverde, S., Toledano-Toledano, F., & Garduño-Espinosa, J. (2020). A survival analysis of COVID-19 in the Mexican population. *BMC Public Health*, 20(1), 1–8.
- Sánchez Corral, J. (2012). *La vivienda "social" en México, pasado, presente y futuro, Sistema Nacional de Creadores de Arte Emisión 2008, agosto 2009-julio 2012, México*. Disponible en.x.
- Sharma, A., Ahmad Farouk, I., & Lal, S. K. (2021). COVID-19: A review on the novel coronavirus disease evolution, transmission, detection, control and prevention. *Viruses*, 13(2), 202.
- Smith, M. E., Chatterjee, A., Huster, A. C., Stewart, S., & Forest, M. (2019). Apartment compounds, households, and population in the ancient city of teotihuacan, Mexico. *Ancient Mesoamerica*, 30(3), 399–418.
- Tao, J., Ma, Y., Luo, C., Huang, J., Zhang, T., & Yin, F. (2021). Summary of the COVID-19 epidemic and estimating the effects of emergency responses in China. *Scientific Reports*, 11.
- Teller, J. (2021). Urban density and covid-19: Towards an adaptive approach. *Buildings and Cities*, 2(1), 150–165.
- Trillo, M. T. (1996). 1910 Mexico city: Space and nation in the city of the centenario. *Journal of Latin American Studies*, 75–104.
- Wang, J. (2020). Mathematical models for COVID-19: Applications, limitations, and potentials. *Journal of Public Health and Epidemiology*, 4.
- Wright, A. L., Sonin, K., Driscoll, J., & Wilson, J. (2020). Poverty and economic dislocation reduce compliance with covid-19 shelter-in-place protocols. *Journal of Economic Behavior & Organization*, 180, 544–554.