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Comparative spatial analysis 2021-2022 of the Covid-19 pandemic and its effects on poverty in Mexico

Análisis espacial comparativo 2021-2022 de la pandemia por covid-19 y sus efectos en la pobreza en México

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Abstract

The central hypothesis of the project considers that the presence and contagion of SARS-CoV-2 (COVID2019) has been developing under a systematic pattern, that is, not randomly; There are specific areas of the country where it is concentrated, mainly due to the size of the population that lives in said municipalities, but additionally, correlated with environmental variables (social and economic) that have determined the severity of the effects of the disease in said territories. . The results of this research will make it possible to compare and identify COVID-19 contagion "hot spots" from January 2021 to January 2022, not only due to the size of the population, but also due to the social conditions in which they were found. population lives and thus be able to observe the impacts of the disease over time.

JEL Code: R58, R59, I38
Keywords: geospatial correlation; COVID-19; social vulnerability and poverty

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Resumen

La hipótesis central del proyecto considera que la presencia y contagios del SARS-CoV-2 (COVID-2019) se ha estado desarrollando bajo un patrón sistemático, es decir, no de forma aleatoria; existiendo zonas específicas del país en donde se concentra, primordialmente por el tamaño de la población que habita en dichos municipios, pero adicional, correlacionado con variables del entorno (sociales y económicas) que han determinado la gravedad de los efectos de la enfermedad en dichos territorios. Los resultados de esta investigación permiten comparar e identificar "puntos calientes" de contagio por COVID-19 de enero 2021 a enero 2022, no sólo por el tamaño de la población, sino por las condiciones sociales en que vive dicha población y con ello, observar los impactos de la enfermedad en el tiempo.

Código JEL: R58, R59, I38
Palabras clave: correlación geoespacial; COVID-19; pobreza y vulnerabilidad social

Introduction

This study was conducted based on the central hypothesis that the presence and contagion of SARS-CoV-2 (COVID-2019) has developed in a systematic pattern, i.e., not randomly; there are specific areas of the country where it is concentrated, primarily due to the size of the population living in these municipalities, but also correlated with environmental variables (social and economic) that have determined the severity of the effects of the disease in these areas. The comparative analysis is from January 2021 to January 2022.

The first section of the research includes a national overview, where a diagnosis of the socio-economic conditions prevailing in Mexico prior to the presence of COVID-19 is presented, highlighting that before the pandemic, Mexican society was decimated by the effects of persistent poverty, which was evident in the presence of marked gaps in access to health care, among other elements.

The following section reviews the data used in this project, which come from official and public sources, and details the methodology used: first, the development of a linear regression model that associates COVID-19 incidence and deaths with social and economic factors; second, the use of spatial correlation, through the Moran index and the identification of "hot points" as a tool for analyzing the health crisis, comparing the results obtained from 2021 to January 2022.

Subsequently, a results section is presented, where the comparative analysis (January 2021 to January 2022) of the most important correlations between COVID-19 incidence and deaths concerning variables such as income vulnerability, economic inequality, and access to health care is evaluated. In addition, the central hypothesis of the project is proven by identifying, through geospatial analysis, that the evolution of the disease in the national territory has not been random; on the contrary, it shows a marked "hot point" behavior that circumscribes the disease to specific regions of the country.

Finally, as a conclusion, some final comments are presented, which emphasize that the development of the disease has not had a homogeneous evolution in the country, comparing the periods of January 2021 and January 2022.

National overview

Poverty and inequality in Mexico

Defining poverty is not simple. There are multiple conceptions. For example, the World Bank defines it as the inability of people to obtain a minimum standard of living, a somewhat ambiguous definition given the complexity of elements that can explain it. Defining it is not enough; however, it is equally important to measure it. Its measurement provides governments with an instrument to implement public policies aimed at mitigating or eliminating the shortages suffered by their inhabitants. Hence, determining how to measure poverty makes it possible to quantify the number of poor people, where they are located, and what are the main afflictions they suffer and, therefore, to propose strategies for solutions (Ortiz & Ríos, 2013).

In Mexico, the institution in charge of measuring poverty is the National Council for the Evaluation of Social Development Policy (CONEVAL) (Spanish: Consejo Nacional de Evaluación de la Política de Desarrollo Social), which uses the multidimensional poverty measurement, carried out biannually at the state level from 2008 to date, and at the municipal level every five years, the latter with results for the periods 2015 (CONEVAL, 2018) and 2020 (CONEVAL, 2022).

The results of the measurement of poverty in Mexico for 2020 (CONEVAL 2022) were not very encouraging, given that from 2018 to 2020, the number of poor people increased in the country as a consequence of the SARS-CoV-2 (COVID-2019) pandemic. This situation could worsen even more if the pandemic is extended longer. According to CONEVAL estimates, by the year 2020, there were 55 million 654 thousand 225 people living in poverty, representing 43.9% of the total population. Comparing such figures with those of 2018 reveals a percentage increase of 2.0% (for 2018, the value stood at 41.9%, i.e., 51 million 890 thousand 880 people), which in absolute terms represented an increase of just over three million 763 thousand people.

In the case of the population living in extreme poverty, an increase also occurred from 2018 to 2020, going from 7.0 to 8.5 percent, which in real terms meant an increase of 2 million 096 people, going from 8 million 696 thousand to 10 million 793 thousand extreme poor in that period (CONEVAL, 2022).

Given the above, although the COVID-19 pandemic indeed increased the proportion of people living in poverty, it is also true that prior to the existence of the pandemic (2018), the situation prevailing in Mexican society was not optimal, as almost half of the population suffered from some degree of poverty. Thus, the health crisis only exacerbated the conditions of inequality and poverty present among the Mexican population, which were particularly affected by sudden increases in i) lack of access to health services and ii) lack of access to social security.

In the specific case of access to health, there was a very important setback between 2018 and 2020, as it increased from 16.2% to 28.2% over the period, a situation that, in absolute terms, meant an increase of around 15.6 million people, from 20.1 to 35.7 million in the analyzed timeframe (CONEVAL, 2022). Figure 1 shows that, of the population with access to health services, slightly more than half is affiliated with IMSS (51%), 35.5% to the Health for Wellness Institute (INSABI) (Spanish: Instituto de Salud para el Bienestar), formerly Seguro Popular, and 8.8% to ISSSTE (INEGI, 2021).

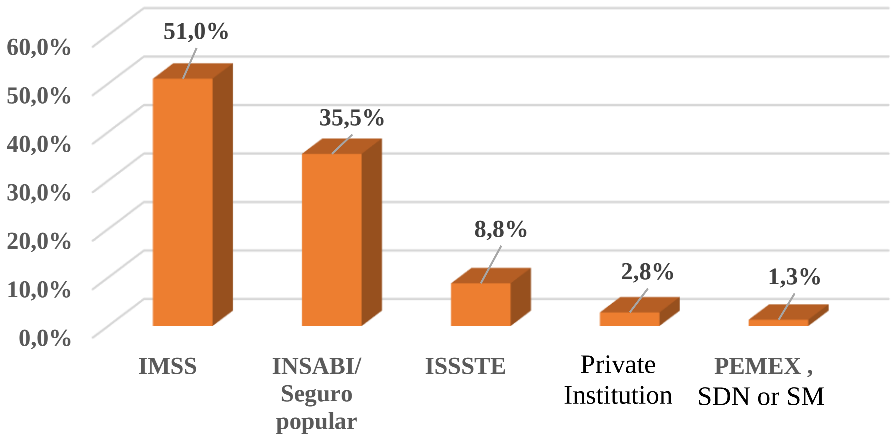

Figure 1. Enrollment in health services in Mexico, 2020
Note: The sum of the percentages may be greater than 100 because of the eligible population in two or more institutions.
Source: created by the authors with data from INEGI Population and Housing Census 2020

The results presented above provide an overview of the conditions of poverty and access to health among the Mexican population, showing that, long before the declaration of the health crisis, a large part of the country's population was immersed in poverty, day by day facing deep inequalities in access to basic satisfactory goods/rights, as well as the inability of the national economy to provide sufficient income to provide families in Mexico with better material conditions and access to development opportunities (CONEVAL, 2022).

Health capabilities prior to COVID-19

From a global perspective, as shown in Figure 2, the hospital system in Mexico is limited. According to data from BBVA Research, in Mexico, there are 1.5 beds per thousand people (BBVA Research, 2020), a value below the world average of 2.7. China has the highest average number of beds per person, with 4.2 per thousand.

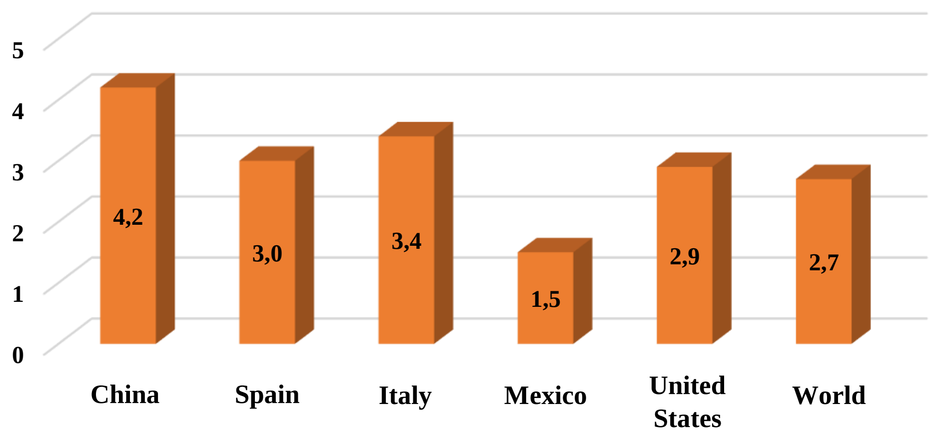

Figure 2. Hospital beds per 1 000 people in Mexico, 2020-2021
Source: created by the authors with data from BBVA Research, based on World Bank, 2020

In terms of the number of doctors, Mexico is above the world average and China (2.25 per 1 000 people), but below the indicator of doctors per 1 000 people, compared to countries such as Spain, Italy, and the United States (BBVA Research, 2020).

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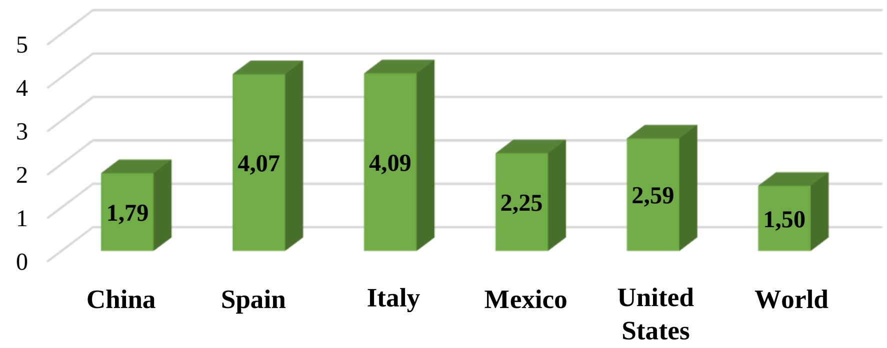

Figure 3. Physicians per 1 000 people in Mexico, World Bank 2020-2021
Source: created by the authors with data from BBVA Research, based on World Bank, 2020

Nevertheless, the distribution of health infrastructure and resources is not homogeneous in Mexico, particularly due to the economic level of each region, which varies widely in the country, as can be seen in Figure 4, Maps 1a and 1b, where Nuevo León, Jalisco, the State of Mexico, and Mexico City are the states with the highest GDP levels for the country, with Nayarit, Zacatecas, and Tlaxcala representing the lowest percentage.

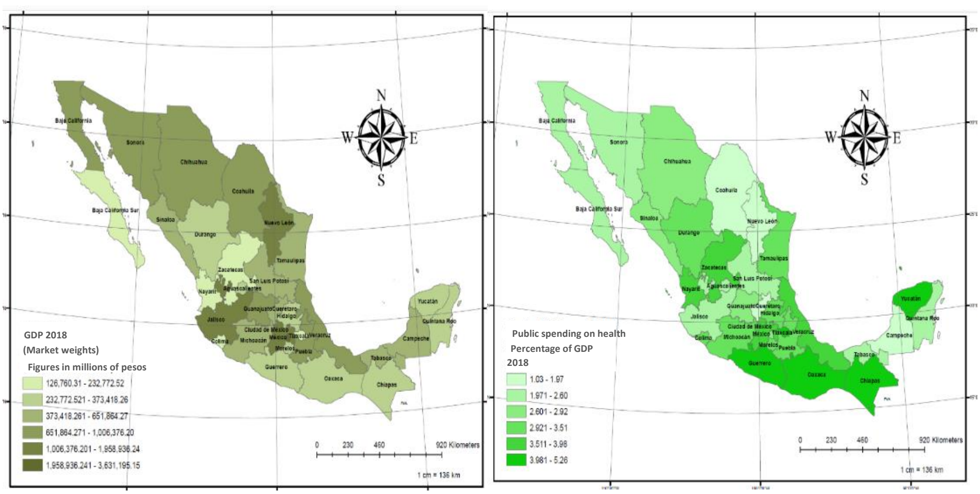

Figure 4. Maps 1a and 1b. GDP 2018 and government spending on health by State in Mexico, 2018
Source: created by the authors based on the Ministry of Health Information System DGIS 2018, available at: http://sinaiscap.salud.gob.mx:8080/DGIS/

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Figure 5, Maps 2a and 2b shows the number of medical and nursing personnel, which are concentrated in the states near the center of the country, such as Mexico City (CDMX), the State of Mexico, Puebla, Guanajuato, Veracruz, and Jalisco, and further north, the state of Nuevo Leon. In the case of the number of hospital beds available per 100 000 inhabitants, Mexico City (CDMX), Baja California Sur, Sonora, Durango, Coahuila, Tamaulipas, Colima, Campeche, and Yucatán have the highest availability. In contrast, the State of Mexico, Querétaro and Hidalgo have the lowest values for the indicator of medical and nursing personnel and hospital beds.

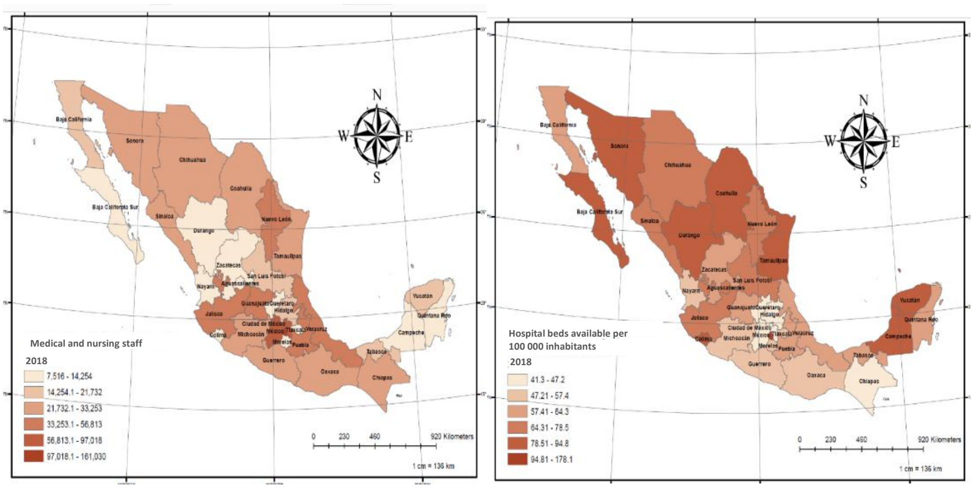

Figure 5. Maps 2a and 2b. Medical and nursing staff and available hospital beds in Mexico, 2018
Source: created by the authors based on the Ministry of Health Information System DGIS 2018, available at: http://sinaiscap.salud.gob.mx:8080/DGIS/

The previous data highlight the deep inequalities that have historically prevailed in the country. On the one hand, some states have a thriving economy, which is reflected in a greater proportion of their contribution to the national GDP, higher income levels of their inhabitants, and greater physical capacities in terms of hospital and health care infrastructure. Conversely, some states have high poverty rates, marginalization, and limited access to basic rights (Gamboa & Messmacher, 2002; Székely et al., 2007; Ortiz et al., 2015).

The conditions of poverty and scarcity that have historically affected the population, the growing consumption of junk food, and a sedentary lifestyle, have led to a precarious state of health and nutrition among the population, as well as the increasing presence at younger ages of chronic degenerative diseases such as obesity, hypertension, and diabetes, among others (Soto et al. 2015; Hernández, 2015; Salud, 2016; Barrera, 2021; and ENSANUT, 2021).

Given the above, as pointed out by Cárdenas (2021) and Nieves (2021), the existence of a fragile health system to which only a few have access, as well as the high percentage of the population suffering from comorbidities, led to the differences in the mortality impact of the COVID-19 pandemic. In addition, some other early studies have shown that socio-economic and environmental variables have played a key role in the magnitude of infection and its effects on different populations (Gonzalez, 2020).

The trends observed in some other studies suggest that the effects of the pandemic are not only due to the biological characteristics of the virus (mortality) but also to the unavailability of resources (monetary and infrastructure) to deal with it, which are distributed (unequally) by social processes (Luna, 2020). Thus, those residing in more marginalized regions have a higher risk of presenting severe infections. The indigenous population or those with lower income levels have a higher risk of pneumonia, hospitalization, and death (Ortiz & Pérez, 2020; Bacigalupe et al., 2022).

The subsequent sections of this project analyze the relation between different social/demographic variables and their interaction with the country's regions, showing the prevalence of certain patterns in its development.

Analysis of current literature

Undoubtedly, since COVID-19, measures have been taken around the world that have changed the normal state of affairs, thus encouraging the government to formulate public policies that guarantee the well-being of its citizens in different aspects.

A direct example of this is public health policies, which have had to adapt to the global situation caused by the SARS-CoV-2 virus. Cruz-Meléndez and Valencia López (2020) show in their work how the use of technologies, governance, and the pandemic led to the creation of e-health policies that seek to take advantage of the use of technologies to encourage self-care in households as well as to provide timely and clear information about the pandemic.

Landeros-Olvera, Arroyo-Cruz, and Rodríguez-Hernández (2021) point out that public health policies must be adapted to the financial and cultural reality of each country, so as to address health challenges; nevertheless, health professionals, when proposing public policies, must seek congressional support, which is the voice to represent the proposals of those who are on the ground.

The government has had to implement strategies through public policies to react to the social, economic, and health aspects that were affected by the pandemic. The policies implemented aimed to increase the budget, anticipate and organize the response, take advantage of environmental benefits, rearrange infrastructure and public spaces, increase the money supply, and support MSMEs.

The research by Chiatchoua and Neme (2022) emphasizes that these public policies have reduced the impact of the pandemic. Nevertheless, because they were a reaction rather than planned, in the beginning these measures did not have the expected results, so efforts should be directed at strengthening existing policies and guiding future policies to have a timely reaction in the event of a crisis such as the one unleashed by the SARS-Cov-2 virus.

Another case analyzed can be seen in the work of Vázquez and Ortiz (2022), where they analyzed regulatory policies in Michoacán to regulate activities in public and private establishments and put in place health controls. In addition, distributive policies were formulated for support and food programs, credit for micro and small companies, and virtual cultural programs that supported citizens' health care and were able to lessen the economic and social effects.

Regarding other important dimensions, such as education, the pandemic has also generated policies that seek to reduce the impact of isolation by using virtual platforms and digital resources to ensure the continuity of studies from home. Research by Navarrete, Manzanilla, and Ocaña (2020) confirms the importance of adapting the education system to the digital environment to address the pandemic and improve the quality of education received by students at different levels, adding to this the challenge of the new technologies and digital resources that are used to teach and take classes.

Ordoñez (2021) analyzes all public policies implemented in Mexico to confront the COVID-19 pandemic in terms of citizens' political rights and whether they were restricted or violated by these measures, emphasizing that the Mexican government must find a balance between the public policies implemented and the safeguarding of political rights.

Despite new technologies, there is a strong need to design public policies to reduce the negative social and economic effects due to the lag in learning and social and cultural activities.

This affirmation is supported by the work of García Tejeda (2020), which shows that the local agendas of the 31 states and Mexico City are diverse and, in some cases, wide-ranging. However, they face the crisis in a similar fashion, so that the responses of local public administrations may have a limited effect in the face of the economic problems caused by COVID-19.

Spatial correlation and its application to health crises

Data used

For this study, an empirical model is proposed based on the analysis of the database compiled by the federal government through the National Council of Science and Technology (CONACYT) (Spanish: Consejo Nacional de Ciencia y Tecnología) - CentroGeo - GeoInt - DataLab, referred to the COVID-19 control board and available at https://datos.covid-19.conacyt.mx/#DOView.[1] This database provides statistical information on confirmed cases and deaths in Mexico related to COVID-19 at the municipal level and is updated daily in the country.

In addition, a set of variables was added at the municipal level from other sources to identify economic and demographic characteristics in the country. These include the marginalization index, prepared by the National Population Council (CONAPO) (Spanish: Consejo Nacional de Población), and CONEVAL's multidimensional poverty and inequality indicators for 2015. Table 1 shows the general description of the variables included in the database used for the study.

Table 1
Description of variables

Variable	Description	Maximum-minimum value	Mean	Standard deviation
state	Code of the federal state	NA	NA	NA
ent_nom	Name of the federal state	NA	NA	NA
Municipality	Municipality code	NA	NA	NA
mun_nom	Name of municipality	NA	NA	NA
Deaths	Number of COVID-19 deaths per 100 000 population in absolute terms	1 450.967 – 0 As of January 2021 2 469.163 – 0 As of January 2022	62.8867 As of January 2021 135.365 As of January 2022	68.0383 As of January 2021 122.956 As of January 2022
posit_100mil	Number of confirmed COVID-19 cases per 100 thousand inhabitants in absolute values	7 258.029 – 0 As of January 2021 20 245.274 - 0 As of January 2022	620.8412 As of January 2021 1 420.037 As of January 2022	796.0881 As of January 2021 1652.046 As of January 2022
Population20	Total population of municipality in 2020 in absolute values	1 913 345 - 90	51 750.655	148 161.043
part_pob_20	Percentage of population living in poverty	0.015047 – 0	0.000407	0.001165
Poverty20	Percentage of population living in poverty	99.6466-5.4509	61.9248	21.8981
p_extr_20	Percentage of population living in extreme poverty	84.4478 – 0	17.1893	15.3144
vul_car_20	Percentage of population vulnerable due to social deprivation	77.5833 – 0	25.0808	13.8854
vul_ing_20	Percentage of vulnerable population by income	23.6091 – 0	3.9499	3.7295
nopob_20	Percentage of population considered non-poor and non-vulnerable	57.4344 – 0	9.0034	9.7540
c_salud_20	Percentage of population lacking access to health services	83.8641 – 1.0526	25.0749	12.4575
c_space_20	Percentage of population with housing quality and space deficiencies	76.6777 – 0.7817	16.3048	12.3053

[1]The database in relation to the incidence of COVID-19 in the country is updated on a daily basis. For this project, the latest available update as of January 5, 2022 was consulted.

Variable	Description	Maximum-minimum value	Mean	Standard deviation
c_sb_viv_20	Percentage of population lacking access to basic housing services	100 – 0.0846	40.0856	29.8915
sospecho_20	Suspected cases within the municipality of COVID-19 per 100 000 inhabitants in absolute values.	6 369.952 – 0 As of January 2021 7 310.1896 – 0 As of January 2022	140.8264 As of January 2021 184.6109 As of January 2022	260.0398 As of January 2021 370.1650 As of January 2022

* The effect of the real values has been removed from the population variable, applying logarithm
Source: created by the authors with data from CONACYT (2022)

Methodology to be employed

For this study, the hypothesis considered was that the presence of COVID-19 infection correlates with environmental variables, particularly the municipality's population size, as well as the social and economic variables that characterize it. Accordingly, a simple spatial correlation analysis is presented, followed by a description and visual representation of the distribution of the COVID-19 pandemic in the country, contrasting the initial hypothesis of the project by identifying territorial distribution patterns based on statistical tools such as the Moran index and the identification of "hot points" according to location.

Spatial correlation

Regarding the second part of the analysis and in a complementary manner, the spatial autocorrelation analysis of Suberos (2018) is used, which enables the identification of the degree of association that exists between variables in the same place, taking into account that each variable represents a different geographical phenomenon (Siabato & Marique 2019). Therefore, for the present research, the following elements are sought to be identified: i) the quantitative attributes or qualitative attributes of the spatial phenomena analyzed, and ii) the location as a geographical reference or coordinate system (Siabato & Marique 2019).

As a result, the degree of association can produce the following results, according to Celemín (2009):

- Positive autocorrelation: Tendency to clustering of the spatial units studied.
- Negative autocorrelation: Neighboring spatial units have different values.
- No autocorrelation: the spatial units present randomly produced values.

Under this analysis, indices are contemplated that enable the relation between the dependence between study units and attributes to be jointly related, whose general structure is composed as shown in Equation (1).

$$\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\, C_{ij} \tag{1}$$

Where n is the total population of units in the map and W_{ij} is a matrix of weights representing the interdependencies between the analyzed units. It should be noted that, according to Perez and Fonseca, this matrix is a non-stochastic square, and each element that contains it reflects the interdependence existing between each pair of units i and j (Perez & Fonseca, 2017). The value C_{ij} is the distance of values i and j in some dimensions. Thus, spatial autocorrelation reflects the degree to which units are similar to other nearby units (Goodchild, 1987).

This statement follows the first law of geography "All things are related to each other, but things closer in space have a greater relation than distant things" (Tobler, 1970). The Moran index is a statistic that measures the spatial correlation between nearby territorial units of an indicator (Pérez and Fonseca, 217), i.e., it provides a measure of the intensity of the autocorrelation of the units considered (ECLAC, 2021). In addition, the Pearson coefficient with a weight matrix defined between -1 and 1 is considered (Celemn, 2009).

Within the Moran Index, there are two types: global and local. While the global Moran Index detects the influence that more remote regions have when calculated with the interdependencies matrix, the local Moran Index is obtained from the global index to detect the presence of autocorrelation (Barros & Aroca, 2014). Equation (2) shows the Moran Index's general structure.

$$I = \left(\frac{n}{S_0}\right)\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} Z_i Z_j}{\sum_{i=1}^{n} Z_i^2} \tag{2}$$

Where $S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}$, as mentioned, is the weights matrix, Z is the deviations from the mean $(x_i - \bar{x})$ or $(x_j - \bar{x})$, x_i is the variable's value in a given spatial unit, and x_j is the value of the variable in another location.

Spatial correlation analysis is used to obtain classifications of homogeneous groups with similar characteristics, thus making it possible to identify clusters, which measure the degree of clustering of outliers such as high or low values. It is thus possible to identify and visually represent a territory when its analyzed values are above the mean in terms of population size, such as social conditions or the presence and contagion of COVID-19.

On the other hand, and in the same way, the "hot point" analysis uses z-scores and the resulting p-values to indicate the spatial clustering of units with high and low values. It is performed through a search within the context of neighboring units (Esri, 2021), and then it is decided whether this "hot point" is relevant. This analysis is obtained by calculating Gi* of Getis-Ord for each municipality, considering the function expressed in Equation (3).

$$G_i^* = \frac{\sum_{j=1}^{j} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \tag{3}$$

Where x_j is the attribute value for unit j, $w_{i,j}$ is the weight between feature i and j, and n equals the total number of features. The Gi* statistic is a z-score. For positive z-scores that are statistically significant, the larger the z-score, the more intense the cluster of high values (hot spot). For negative z-scores that are statistically significant, the smaller the z-score, the more intense the cluster of low values or cold spots (Esri, 2021).

Results

Next, the 2020-2021 results of identifying the correlation between social and economic variables are presented; then "hot points" in the territory are described, identifying areas of high contagion/death.

Sociodemographic variables and their correlation with COVID-19 incidence

The correlation matrix in Table 2 was used to identify the correlation between the social and economic variables. These results highlight some particularly interesting relations. First, the existence of a moderate negative correlation with the value of -0.4525 and -0.4727 for January 2021 and 2022, respectively, between the number of deaths by COVID-19 for each year and the percentage of the population living in poverty, a result that suggests that when the percentage of poverty varies in one direction the number of deaths will vary in the opposite direction, but with similar strength. The same relation is obtained for the population living in extreme poverty (-0.4146 in January 2021 and -0.4449 in January 2022). In other words, when the number of deaths increases, the percentage of the population living in poverty and extreme poverty decreases, so it could be thought that COVID-19 is affecting (causing more deaths) the less poor population, which, in the absence of evidence at this time, would suggest that this trend is attributable to the fact that COVID-19 disease has been concentrated in urban areas (fewer poor in the country), as transmission occurs primarily in highly populated areas, not necessarily with higher levels of poverty.

Second, the results in Table 2 show that COVID-19 deaths are highly positively correlated with the vulnerable population by income (with values of 0.4825 and 0.4452). This result means that when the vulnerable by income population grows, the number of COVID-19 deaths also grows, although in a different proportion. The same situation occurs among the non-poor and non-vulnerable populations but in a somewhat higher proportion than the previous variable.

Table 2
Correlation of deaths between COVID-19 and socio-economic variables*

Variable	death_100~s as of January 2021	death_100~s as of January 2022
death_100~s	1	1
lpoblac~2020	0.3433	0.2737
poverty20	-0.4525	-0.4722
p_xtr_20	-0.4146	-0.4449
vul_car_20	0.2075	0.2735
vul_ing_20	0.4825	0.4452
nopob_20	0.5322	0.5006
c_salud_20	0.0470	0.0510
c_space~20	-0.3693	-0.3904
c_sb_viv_20	-0.4440	-0.4351
sospecho_1~l	0.3117	0.2546
ir_20	-0.5026	-0.4895
im_20	-0.5191	0.4836

Source: created by the authors with Stata, 2022
*The entire correlation matrix is not included because it is not relevant to the study's objective.

Both previous situations reinforce two key elements of the COVID-19 epidemic: on the one hand, it is intensifying and has developed primarily in the most urban areas of the country (with not-so-low levels of poverty). Nevertheless, the incidence of death correlates with the income level of the family, i.e., those who do not have the means to access timely health services.

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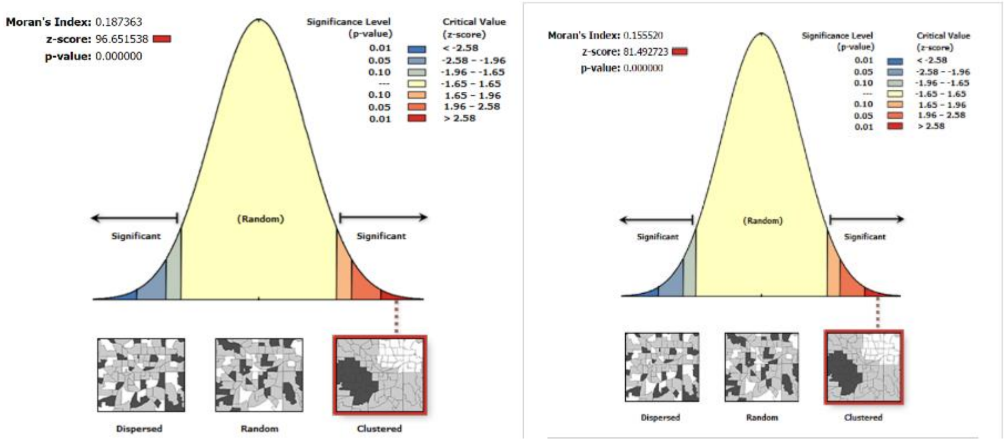
Identification of "hot points" in the national territory

In order to identify whether COVID-19 infection and death have been developing in the country in a specific pattern or randomly, the Moran index was calculated with the level of COVID-19 infections and deaths, reaching a value of 0.1873 in January 2021 and 0.1555 in January 2022, respectively, as shown in Figure 6.



Infections and deaths as of January 2021 | **Infections and deaths as of January 2022**

Figure 6. Spatial Autocorrelation (Moran's Index)
Source: created by the authors with data from the COVID-19 dashboard available at https://datos.covid-19.conacyt.mx/#DOView

The spatial autocorrelation results, Moran's index, confirm the existence of a spatial correlation between nearby territorial units (at the municipal level). In this case, the value achieved shows a clustered positive spatial autocorrelation due to the physical conditions in which the Coronavirus is transmitted or contagious.

Concerning the magnitude of the spatial pattern of COVID-19 infection and deaths in the country, the territorial identification of "hot points" was carried out. To analyze the above, two time slices of the evolution of the COVID-19 pandemic in Mexico were considered, the first one in January 2021 (Figure 7. map 3a), which refers to the first months of the implementation of vaccination in the country, and the second one (Figure 7. map 3b), in January 2022, once the vaccination process in Mexico had already advanced significantly. The results of both periods show that the areas of greatest transmissibility ("hot points") in the country have remained more or less stable over time, concentrated in six regions: the

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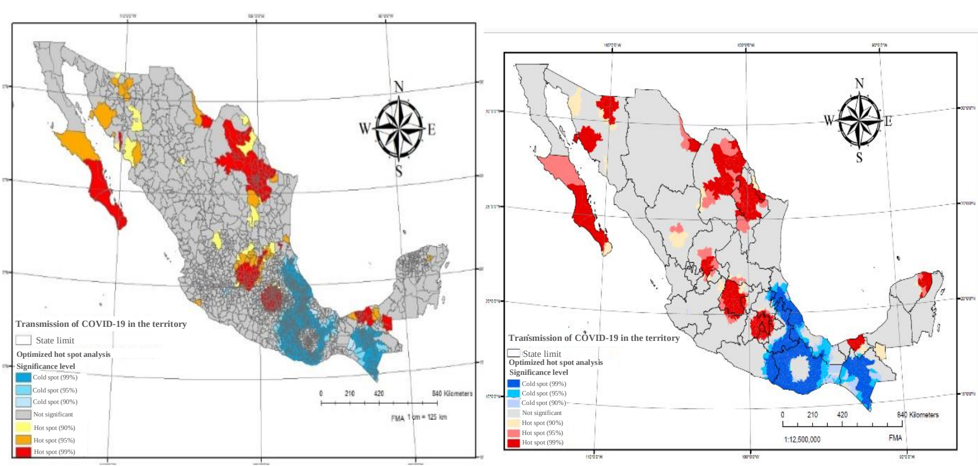
Metropolitan area of the Valley of Mexico; a strip of the Bajío; the northern part of the country comprising Baja California, Chihuahua, Coahuila, and Nuevo León and, in the southeast, the state of Tabasco. By January 2022, the situation had not changed significantly, except that Sonora, Zacatecas, and Yucatan were added to the previous regions.

In the case of regions with lower transmissibility or cold zones, Veracruz, Oaxaca, and Chiapas stand out for both samples (2021 and 2022).

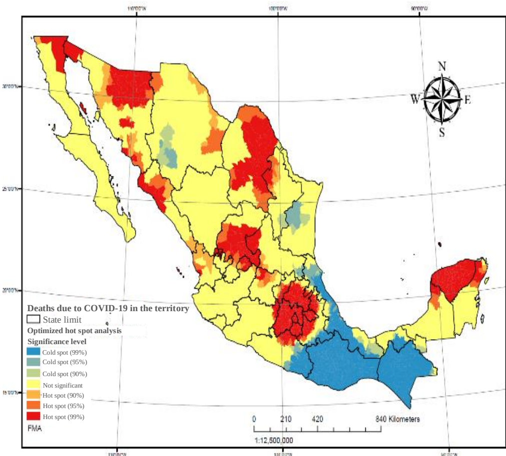


As of January 2021 **As of January 2022**

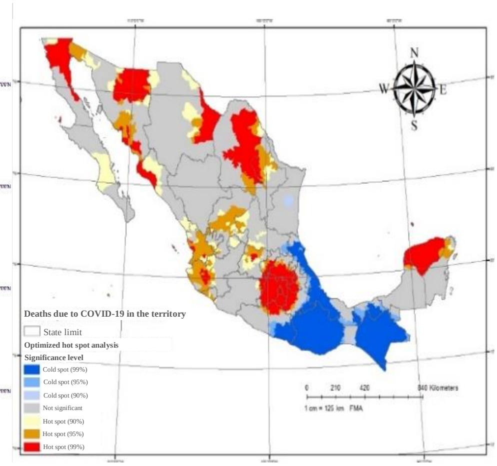
Figure 7. Maps 3a and 3b. “Hot points” transmission of COVID-19
Source: created by the authors with data from the COVID-19 dashboard available at https://datos.covid-19.conacyt.mx/#DOView

Similarly, regarding the territorial distribution of COVID-19 deaths, the same time slices were made in January 2021 (Figure 8. map 4a) and January 2022 (Figure 8. map 4b). As shown below, the results showed similar behavior to the geographic distribution of infected individuals in the country, concentrated primarily in the central part of the country (Mexico City, State of Mexico, Hidalgo, and the northern part of Puebla), the Bajío (Guanajuato and Aguascalientes), Zacatecas and Sinaloa, and the northern part of the country (Baja California, Sonora, Chihuahua, Coahuila, and Nuevo León). In the country’s southeast, the states of Yucatán, north of Campeche, and Quintana Roo stand out. As seen in Figure 8, Maps (4a and 4b), the regions with the highest prevalence of COVID-19 deaths remained more or less stable between 2021 and 2022.

States such as Oaxaca, Chiapas, Veracruz, and the southern part of Guerrero and Puebla remained “cold” regions, i.e., with a very low incidence of deaths associated with the pandemic.



As of January 2021



As of January 2022

The above results concerning COVID-19 infection and deaths reinforce some important elements:

a) The territory is a determining factor in the dynamics of COVID-19 infection and deaths among the population in Mexico, showing that the pattern of infection and deaths is not homogeneous in the country.

b) Given the infectious behavior of the virus, the regions of the country with the highest population density have been the most affected, as can be seen in the case of the metropolitan area of the Valley of Mexico. Nevertheless, it is inferred that it is not the only important element in the virus's transmissibility since less densely populated regions, such as the Yucatan peninsula, remain "hot" regions of contagion and infection. This situation implies that the economic dynamics of the region have probably increased the potential for contagion.

c) This information makes sense when observing the situation that prevailed in the states of Oaxaca, Chiapas, and Veracruz, which remained "cold" zones of contagion and death throughout the period under analysis. This situation is partly associated with their communities' isolation, the region's low economic dynamics, and the underdeveloped relations with the rest of the country.

Conclusions

Poverty in Mexico, understood as people's inability to access a minimum standard of living, is regularly measured by the CONEVAL through a multidimensional approach; it identifies the population's access to rights, including education, health, decent housing, and food. According to its latest results for 2020, there were just over 55 million poor people in Mexico and 10 million in extreme poverty.

Within the context of the COVID-19 pandemic, CONEVAL's poverty results are significant, as they enable an understanding of the enormous backwardness prevailing in health matters since it has been found that in 2020 just over 35 million people did not have public medical services (IMSS, ISSSTE, Navy, among others). Regarding social security, almost 66 million Mexicans suffered from this deficiency. This situation correlates with the proportion of the population that is vulnerable by income, which amounted to just over 11.2 million people for the same year.

In addition, the diagnosis of the country's health capabilities before the COVID-19 health crisis showed that there was no hospital medical infrastructure to deal with the pandemic's onslaught. These will undoubtedly impact the population in the medium and long term, exacerbating the pre-existing inequality gaps in Mexican society.

From the findings obtained, a positive correlation was identified between the COVID-19 death indicators and the percentage of the population vulnerable by income, which leads to the premise that when one of the two variables grows to a greater or lesser extent, so will the other. Thus, although more studies are needed in this regard, it can be inferred that when this percentage of the population that is vulnerable by income is higher, there will be more deaths. The analysis between the two time periods showed that from January 2021 to January 2022, there was a decrease in this positive effect; nevertheless, there continues to be a positive correlation between the two variables.

In the case of the impact of COVID-19 concerning the percentage of people lacking access to health services, it is observed that if this percentage increases, so will the number of deaths from the virus, given its positive correlation and its significance in the multiple regression model carried out; it also highlights a higher correlation in January 2022 than that observed in January 2021.

On the other hand, concerning the central theme of the study, which is the identification of "hot points," an analysis of the rates of infection and death was conducted, confirming (as expected) that the highest number of infections and deaths occur in municipalities and cities where there is a greater number of people.

In order to rule out random behavior in the pattern of infection and death from COVID-19, the Moran index was used, which reached a value of 0.1873 with the number of infections and deaths in January 2021, reaching levels of 0.1555 for infections and 0.16896 for deaths. This confirms that COVID-

19 infection and deaths do not occur randomly throughout the country but rather that there is a spatial correlation.

The results obtained showed the existence of a distribution pattern of the disease, which was confirmed by the behavior detected from January 2021 to January 2022, which maintained a relatively stable transmission of the disease, specifically in particular regions of the country such as the Metropolitan Zone of the Valley of Mexico, the Bajío region, and an extensive strip in the States of Coahuila and Nuevo León, as well as isolated points in Sonora and Baja California Sur.

Similarly, a distribution in the mortality pattern was corroborated, similar to the behavior of the contagion hot spots, with the highest concentration in the central and northern zones of the country, as well as in Yucatan.

From the analysis, it is possible to conclude that COVID-19 is more acute in places with a greater population concentration, and the transmission trend has not shown significant changes throughout the studied period. Nonetheless, although mortality has decreased thanks to the application of vaccines, there are still regions with high levels of concentration, where territorial and sociodemographic variables have had an impact in reaffirming that the municipalities with the greatest lags are those that possibly face the greatest challenges to ensure that their population has access to better health conditions and can ultimately overcome the disease in the best way possible.

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