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Articles

Access to water service and vulnerability to COVID-19: The case of Mexico City

El acceso al servicio de agua y la vulnerabilidad al COVID-19: el caso de la Ciudad de México

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Abstract

Domestic water supply is essential for coping with the COVID-19 pandemic, particularly in urban contexts where social proximity increases the risk of infection. This article explores the association between the number of COVID-19 cases in marginalized households, and access to water supply in Mexico City, highlighting spatial distribution patterns. A neighbourhood database was created using official information on the number of COVID-19 infections, the population, the Social Development Index, and inadequate water supply. Results show that these variables significantly affect the number of COVID-19 infections registered in neighbourhoods. Moreover, inadequate water supply increased the number of COVID-19 cases by at least 17 % during the period under study.

Keywords: Water access, COVID-19, Mexico City, social development, spatial distribution.

Resumen

El acceso al servicio de agua en los hogares es fundamental para enfrentar la pandemia de COVID-19, sobre todo en contextos urbanos donde el riesgo aumenta por la cercanía social. En este artículo se exploran las relaciones entre el número de contagios de COVID-19 con la marginación de los hogares y los problemas de acceso al servicio de abasto de agua potable en la Ciudad de México, resaltando los patrones de distribución espacial. Se generó una base de datos a nivel de colonia con información oficial sobre el número de contagios, número de habitantes, índice de desarrollo social y acceso deficiente del abasto de agua. Se encontró que todas estas variables tienen un efecto significativo sobre el número de casos que se registran en las colonias. En particular, el deficiente acceso al servicio de agua aumentó en al menos 17 % el número de casos de contagio de COVID-19 durante el periodo de estudio.

Palabras clave: acceso al agua, COVID-19, Ciudad de México, desarrollo social, distribución espacial.

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Introduction

The COVID-19 pandemic declared on March 23, 2020, had claimed more than 4.4 million lives worldwide by August 23, 2021 (WHO, 2021). The World Health Organization has recommended that countries implement measures to control the virus and delay the spread of infection. The most widely used measures globally have been lockdown, together with isolation and, more recently, wearing face masks to prevent infections from continuing to rise and health systems from collapsing.

Although urban areas concentrate 90 % of reported infections (ONU, 2020a; ONU, 2020b; ONU, 2020c), this does not mean that all cities follow the same pattern. At the global level, certain megacities have been among the worst hit by the pandemic, such as Brussels, Paris, Santiago, Stockholm, and Mexico City (OECD, 2021). Evidence suggests that the poorest areas of cities are the most vulnerable (Aminjonov & Bargain, 2021; Khavarian-Garmsir & Sharifi, 2020). The relationship between poverty and COVID-19 infections may be due to multiple factors, such as the need to go out to work to earn an income to survive, job loss, lack of access to health services, inadequate water supply and transportation and unequal access to technology (Merino, Valverde, & Ziccardi, 2020; Aminjonov & Bargain, 2021). The 2020 Human Development Report noted that people's skills play a key role in the response to the COVID-19 crisis and highlighted the importance of reducing human pressures on ecosystems (UNEP, 2019).

Although marginalized urban households are known to report more infections, the question is how factors associated with marginalization affect vulnerability. Access to safe drinking water has been identified as an essential element for reducing vulnerability to the virus (Sivakumar, 2021; Neal, 2020).

This article seeks to explore the relationship between the number of COVID-19 infections, the level of marginalization of households, and poor water supply in Mexico City, highlighting spatial distribution patterns. The article is structured as follows. Section Two explores the relationship between domestic water supply and COVID-19. Section Three describes the pandemic in Mexico and CDMX, emphasizing water service. Section Four describes the methodology, together with the information sources and the procedure undertaken for the analysis. This is followed by an account of the patterns of insufficient water supply and COVID-19 cases, including the spatial distribution of these variables. The last section reflects on the importance of access to sufficient water to address the current COVID-19 crisis, from an urban resilience perspective.

Relationship between access to water and COVID-19 infections

Access to water is considered a human right that meets the basic needs of any household —even without a pandemic—, while the risk of COVID-19 makes water a crucial means of preventing contagion and ensuring human health (Chavez, McDonald, & Spronk, 2020; UNESCO, 2021). In both households and public spaces, the easiest way to sanitize is by using soap and water. The range of problems caused by household water insecurity in rural and urban contexts have implications for handwashing, personal and housing hygiene, the possibility of safe distancing, and of course the emotional state of family members (Adams *et al*., 2021). Households with access to water are better equipped to fight the virus, since they have a safe, affordable means of sanitizing. However, households with a limited water supply are less likely to wash their hands before eating, or after going to the toilet or to engage in other water-related activities inside or outside the home. The lack of this service becomes a factor that increases the vulnerability of households and their residents to the spread of contagious diseases such as COVID-19 (Ortega *et al*., 2021).

One indicator of the importance of water during the pandemic has been the increase in residential water consumption. A study by Brikalski, De Luca, Henning, Kalbusch and Konrath (2020) analysing water use patterns in a Brazilian city found that after the emergency declaration, the greatest increase was observed in the residential sector (+11 %), compared to a major contraction in other sectors such as industry (-58 %). In Mexico, Delgado-Escalera (2021) observed a 2.8% increase in domestic water consumption following the official declaration in Monterrey, combined with a decrease in users' ability to pay. The decline in water revenue was one effect of the crisis reported in different studies, with reductions of between 40 and 70 % (World Bank (2020), cited in Chavez *et al*., 2020).

Sanitation is linked to water management, since viruses excreted in faeces, urine, and vomit require proper handling in health facilities (Orta, 2022). Studies have cited the lack of drainage systems as a contributing factor to the vulnerability of housing infrastructure to COVID-19, particularly since there are municipalities with low service coverage (Ortega *et al*., 2021).

Although households with inadequate water supplies have been mentioned as an area of concern, the specific impact of the latter on infections has not been documented. Twenty-seven per cent of the inhabitants of cities in developing countries lack access to running water (ONU, 2020a; ONU, 2020b, ONU, 2020c). Moreover, studies have analysed water supply problems in cities, including the lack of connections, extended interruptions in water service and poor water quality (Adams *et al*., 2021; Soto, 2008). It is also necessary to address the issue from the perspective of socio-spatial inequalities, since service provision conditions often mean that peripheries and specific areas of cities are more vulnerable (UNEP, 2019). In this context, it is essential to analyse the effect of the lack of access to safe drinking water on the number of cases of COVID-19 infections, since social marginalisation is expected to increase the number of cases. The patterns of households lacking access to clean water will also be explored.

The COVID-19 Crisis in Mexico and Mexico City

Mexico is one of the countries worst hit by the COVID-19 virus. By August 22, 2021, the country had reported 3 217 415 confirmed cases of COVID-19, with 252 927 deaths. Mexico ranks 15th in infections worldwide, together with seven other developing countries or emerging economies (India, Brazil, Turkey, Argentina, Colombia, Iran, and Indonesia), although it has the fourth highest number of deaths (after the United States, Brazil, and India) (Google Noticias, 2021). Mexico has featured in studies highlighting worrying aspects of COVID-19 crisis management (Macip, 2020; Aminjonov & Bargain, 2021). The Mexican government has implemented a series of measures, which initially included travel restrictions, social distancing, school closures, and the suspension of non-essential activities. Its strategy for the normalization of economic activities is based on a traffic light system to alert residents to the epidemiological risks of COVID-19 in states and municipalities. The economic crisis reduced the GDP by 8.5 % in 2020, severely impacting the employment of large swathes of the population (INEGI, 2021). Given that vulnerability to the crisis is associated with marginalisation, it is worth noting that in Mexico 41.9 % of the country´s population was classified as living in poverty in 2018. Predictably enough, this percentage increased, rising to 43.9 % in 2020 (Coneval, 2021).

Studies have found that infections are higher among households living in marginalised conditions. Ortiz-Hernández and Pérez-Sastré (2020) observed that living in a more marginalized municipality was associated with a higher risk of pneumonia, death, hospitalisation, and death nationwide. In sociogeographical terms, being Indigenous and living in the southern region increased the severity of COVID-19. These disparities based on geographic location and ethnicity are intimately linked to socioeconomic inequality. In Mexico City, Jaramillo-Molina (2021) found that the prevalence of infections in the poorest neighbourhoods is five times that of the wealthiest ones. Whereas 27 % of the poorest neighbourhoods have concentrated the largest number of cases, only 5 % of the richest ones have high infection rates. Merino *et al*. (2020) qualitatively analysed elements showing how occupational inequality, the habitability of dwellings in terms of overcrowding and women's workload, and access to water affect marginalized areas of the city. They highlighted the importance of cohesion and social networks for addressing the crisis among the most vulnerable strata.

Mexico has poor access to water supply, even though it has extensive drinking water service coverage —95.3 % of households— (Conagua, 2018). According to the National Household Income and Expenditure Survey, only 70.2 % of households receive water daily. Sixteen per cent receive it every other day; 13.8 % do so twice a week, once a week or from time to time, while 6.6 % of households (2.3 million) have no water supply. They obtain water by fetching it from another dwelling, a public tap, wells, rivers, streams, lakes or lagoons or water tankers INEGI, 2021a). These data coincide with a CONAGUA urban household survey (CIDE & Conagua, 2012), which found that approximately 30 % of urban households experience water rationing problems, in addition to receiving water just seven hours a week on average. In other words, households that only receive water a limited number of hours a week are extremely vulnerable to the threat of COVID-19.

According to the Official Gazette of Mexico City, there are 277 registered neighbourhoods that experience water rationing or interruptions in service (GOCDMX, 2020), while payment is waived for 72 neighbourhoods in the municipality of Iztapalapa (GOCDMX, 2020a) because the supply is considered insufficient to meet user needs. Both groups are more vulnerable because of intermittent water supply. Since the Gazette does not describe the specific characteristics of water rationing or the reasons for service interruptions, it is impossible to determine the extent of water rationing or water quality. According to a disaggregated study by the Environmental and Territorial Planning Attorney's Office (PAOT) (Soto, 2008), the degree of water rationing varies. Whereas in Álvaro Obregón, residents received water an average of 63 hours a week according to 2008 data, in Tlalpan, they did so for 35 hours, in Iztapalapa for 20 hours and in Tláhuac and Milpa Alta for just 14 hours a week. Moreover, this study found that the poorest population was more likely to experience unequal water distribution, since approximately 60 % of residents of low-income neighbourhoods earned less than two minimum salaries a month. Households that experience water rationing or receive poor quality water incur both financial and time costs. In these cases, households will have to store water, seek other water supply sources —such as purchasing water from water tankers—, buy it in bottles or fetch it (Soto, 2007). It is also important to note that households experiencing supply interruptions may solve the problem by storing water in cisterns and tanks.

Approximately 870 518 cases of COVID-19 had been reported in Mexico City by August 22, 2021, accounting for 27 % of the total number of cases in the country. The percentage of cases seems high given that only 4.5 % of the national population lives in Mexico City (9.2 million people) (INEGI, 2020). As mentioned earlier, this could be explained by the type of risk that increases with social proximity, which leads to cases being concentrated in urban areas. In any case, together with three other areas, Mexico City has seen some of the worst infection rates in the world (OECD, 2021).

In terms of access to safe drinking water, Mazari-Hiriart, Merino-Pérez, Pérez-Jiménez, and Rodríguez-Izquierdo (2020) spatially analysed inequalities regarding COVID-19 in Mexico City (CDMX) to learn how water availability and household overcrowding affected the distribution of COVID-19. Results failed to show a strong association with either variable, although they did find the expected patterns for the municipalities of Xochimilco, Milpa Alta and Tlalpan. We will refer to this study in the discussion section to highlight the differences from our analysis.

Methodology

To estimate the possible effects of inadequate domestic water supply on COVID-19 cases, a systematic analysis was conducted of the public information available on drinking water supply conditions and COVID-19 infection, for which the Historical Database of COVID-19 cases at the neighbourhood level in Mexico City of the CDMX Open Data Portal (2021) was used. Table 1 shows the data used for the study. The considerations made for processing the information are described below.

Table 1. Spatial data at the neighbourhood level to explore the relationship between COVID-19 cases and water access.

Data	Coding for regression	Resolution	Source
COVID-19 infections	Natural logarithm of continuous variable of cases grouped into two- week periods	Neighborhood	CDMX (2021)
Neighborhoods with poor water supply (water rationing, payment waived)	Poor service=1 Other=0	Neighborhood	GOCDMX (2020), GOCDMX (2020a), Betanzos (2018)
Social Development Index	High SDI=0 Medium SDI=1 Low SDI=1 Very low SDI=1	Neighborhood	Sideso (2021) and supplemented by Conapo (2010)
Total population	Natural logarithm of continuous variable	AGEB, to calculate neighbourhood-level data	INEGI (2020) and datos.gob.mx

The information was organized based on the number of COVID-19 cases per neighbourhood between June 29, 2020, and February 7, 2021, grouped into successive two-week periods. It was decided to group cases by this amount of time because, according to the same source, cases remain active for a fortnight. The total sum of cases reported during the entire period was calculated. Figures proved to be lower than what happened, since, as noted in official reports, the publication of each two-week period excludes the number of cases when they amount to fewer than six. The database reported 252 772 out of a total of 523 333 cases that should have been reported by February 7, 2021 (Gobierno de la Ciudad de México, 2021). Since neighbourhood records were published as of June 29, a total of 466 952 cases had been registered in the period studied. In this database, 214 180 infections had been under-reported. In principle, these cases are not reported due to personal data protection, but they must have been distributed among neighbourhoods that reported fewer than six cases in the two-week periods.

A dichotomous variable was included in the database to identify neighbourhoods with a poor-quality domestic water supply, either because the neighbourhoods had water rationing or because the payment of their water bills had been waived. Information was drawn from the official CDMX gazettes for water rationing (GOCDMX, 2020) and payment waivers (GOCDMX, 2020a). The first case includes 277 records of neighbourhoods in ten municipalities subject to water rationing, without specifying the specific characteristics of the rationing other than the fact that the authorities would charge the fixed rate for the service. In the second case, seventy-two neighbourhoods in the municipality of Iztapalapa were included, where payment has been waived because the water supply is regarded as insufficient for meeting user needs. Another source of information on water rationing cases was the list of neighbourhoods included in a point of agreement, approved by the

Permanent Deputation of the Legislative Assembly of the Federal District to request payment waivers for sixty-five neighbourhoods in the municipalities of Cuajimalpa, Álvaro Obregón and Magdalena Contreras with acute water shortage (Betanzos, 2018). These records therefore included neighbourhoods with service cuts, probably some with water quality problems, and others with rationing and poor water quality.

To capture the effects derived from the differences between neighbourhoods with various levels of marginalization, the Social Development Index (SDI) per neighbourhood was included in the database. This index, reported by the Mexico City Secretariat of Inclusion and Social Welfare for 2010, grouped neighbourhoods into four categories: high, medium, low, and very low (Sideso, 2021). The SDI measures unmet basic needs, based on information on the quality and size of housing, which includes access to water supply, together with other features such as drainage and toilets, energy adaptation, Internet access, telephony, as well as educational lag, healthcare access and social security (CDMX, 2020). Since some neighbourhoods with rationing or which were included in the COVID-19 reports did not appear in this register, they were estimated by assigning them the equivalent level of the Marginalization Index of Basic Geostatistical Areas (AGEB) for these neighbourhoods, compiled by the National Population Council (Conapo) for 2010.

The current population of each neighbourhood was also included. This estimate was based on information provided by the National Institute of Statistics and Geography (INEGI) from the Population and Housing Census, conducted during the first quarter of 2020. Its geostatistical framework was used to obtain the cartographic coverage of urban blocks grouped by AGEB. This was subsequently combined with the cartographic coverage of the limits of neighbourhoods, available for 2019 in the open data portal of Mexico (datos.gob.mx). Both cartographic coverages, displayed in a Geographic Information System (GIS), made it possible to adjust the block overlaps to all the neighbourhood limits.

As a result of this cartographic exercise, 1 803 neighbourhoods were delimited with an estimate of the number of inhabitants in 2020, yielding a total population of 9 130 334. This figure is 0.86 % lower than that reported by the 2020 Population and Housing Census for Mexico City (9 209 944 inhabitants), possibly because of inaccuracies in the available map of neighbourhoods. The statistical analysis considered the enormous heterogeneity of the neighbourhoods in terms of the number of inhabitants, given that the term "neighbourhood" is used to refer to a housing complex, neighbourhood, housing estate, housing unit, district, or town.

To make results comparable between neighbourhoods, the data analysis used the number of infections per 10 000 inhabitants. Although the basic observation unit of the study is the neighbourhood, most results are presented at the municipal level. Data management was supported by the SPSS statistical program, both for the calculation of descriptive statistics and for the regression analysis required to evaluate the types of relationship between the active case variable and poor water supply. The control variable was the Social Development Index in each neighbourhood.

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Results

Explaining the possible impact of water supply on the spread of COVID-19 requires first examining the characteristics of water rationing and payment waivers found for Mexico City (CDMX). A total of 334 neighbourhoods have inadequate water supply, equivalent to 18 % of the total number of neighbourhoods in CDMX. Approximately 2.6 million people live in these neighbourhoods, equivalent to 29 % of the total population registered in the study. It is important to recall that there is no official public information on the patterns of water rationing and/or poor-quality water to be able to determine the extent to which access to water, adequate in terms both of quantity and of quality, could compromise the hygiene measures required to protect oneself from the virus. There is also a lack of information on other indicators such as storage and hygiene habits within the household, which can also influence infections. However, as shown below, the inadequate water supply indicator demonstrates that restricted access to water affects the spread of infection.

The spatial distribution of inadequate water supply encompasses neighbourhoods in the southern periphery and eastern zone of the city (Figure 1).

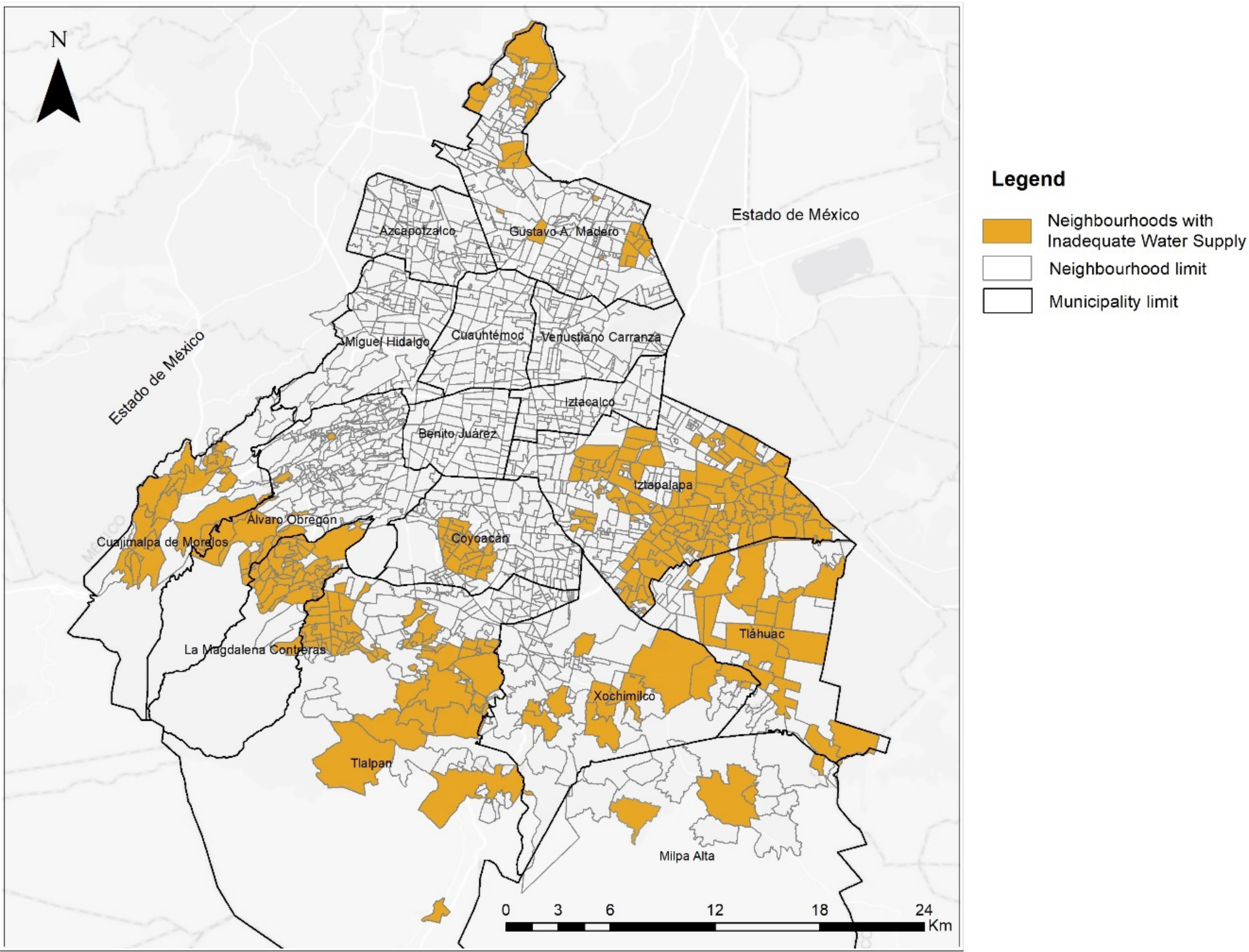

Figure 1. Neighbourhoods with Inadequate Water Supply. Source: Compiled by the authors with data from GOCDMX (2020), GOCDMX (2020a), Mexico City Government (Gobierno de la Ciudad de México, 2021), and INEGI (2021).

Ten municipalities have neighbourhoods with problems, 113 neighbourhoods are in Iztapalapa, sixty-five in Tlalpan, forty in Magdalena Contreras, twenty-nine in Gustavo A. Madero, twenty-three in Cuajimalpa, twenty-one in Tláhuac and nineteen in Coyoacán. The municipalities with the highest percentage of population with water rationing are Iztapalapa with 33.8 %, Tlalpan with 19.5 % and Magdalena Contreras with 12 %. Four municipalities concentrate half the population with water supply problems in the city: Iztapalapa (16.2 %), Álvaro Obregón (13.7 %), Gustavo A. Madero (12.8 %) and Tlalpan (9.8 %). Conversely, six fully urbanized municipalities have no neighbourhoods that have reported problems (Table 2).

Table 2. Indicators of Neighbourhoods with Inadequate Water Supply by Municipality.

Municipality	No. of neighbourhoods	No. of neighbourhoods with inadequate water supply	No. of inhabitants with inadequate water supply	% of population with inadequate water supply of total
Álvaro Obregon	249	13	101 293	3.9
Azcapotzalco	111	0	0	0.0
Benito Juárez	64	0	0	0.0
Coyoacán	153	19	187 055	5.7
Cuajimalpa de Morelos	43	23	128 521	6.9
Cuauhtemoc	64	0	0	0.0
Gustavo A. Madero	232	29	193 905	8.7
Iztacalco	55	0	0	0.0
Iztapalapa	293	113	1 066 987	33.8
Magdalena Contreras	52	40	220 903	12.0
Miguel Hidalgo	87	0	0	0.0
Milpa Alta	12	3	38 905	0.9
Tlahuac	58	18	170 630	5.4
Tlalpan	178	65	379 423	19.5
Venustiano Carranza	80	0	0	0.0
Xochimilco	80	11	164 976	3.3
Total	**1 811**	**334**	**2 652 598**	**100**

Source: Compiled by the author with data from GOCDMX (2020), GOCDMX (2020a), Mexico City Government (Gobierno de la Ciudad de México, 2021) and INEGI (2021).

Areas characterized by scarcity and poor-quality water sources, especially Iztapalapa, have limited access to water. The same is true of municipalities on the southern periphery, such as Tláhuac, Tlalpan, Magdalena Contreras, Álvaro Obregón and Cuajimalpa, which boast conservation land, where ironically, there is a greater abundance of natural sources. It is important to note that the publication of the Mexico City Water System (Sacmex), through the official gazettes on neighbourhoods with water rationing and payment waivers, suggest the existence of water rationing in other more peripheral neighbourhoods of the city in municipalities with conservation land, particularly Milpa Alta.

For the period studied, 253 neighbourhoods are not included in the COVID-19 database because they registered fewer than six cases every two weeks. Most of these neighbourhoods have a very high SDI, (39 %), as opposed to neighbourhoods with a very low SDI (8.3 %). The analysis presented below on the relationship between COVID-19 cases and social development indicators and water rationing considers population subgroups with over five cases in successive fortnights in the study period.

During the period under study, 1 558 neighbourhoods with more than five cases of COVID-19 infection were reported, with a total population of 8.85 million. This subgroup is heterogeneous in terms of social development, with 16.7 % classified as having a very low SDI, 35.8 % a low SDI, 26.9 % a medium SDI, and 20.5 % a high SDI. However, 87 % of neighbourhoods with water rationing problems have low and very low social development indices (chi square 0.000) (Table 3).

Table 3. Indicators of Neighbourhoods with COVID-19 cases during the period for groups aggregated by SDI.

	Very low SDI	**Low SDI**	**Medium SDI**	**High SDI**
% of population	16.7 %	35.8 %	26.9 %	20.5 %
% of neighbourhoods with inadequate water supply	35 %	52.7 %	9.6 %	2.7 %
COVID-19 cases per 10 000 inhabitants	Average 262	Average 326	Average 303	Average 211
COVID-19 cases per 10 000 inhabitants for neighbourhoods with inadequate water supply	Without problems: 262 Inadequate supply: 262 Difference in cases: 0	No rationing: 302 With rationing: 357 Difference in cases: 55	No rationing: 299 With rationing: 332 Difference in cases: 33	No rationing: 208 With rationing: 353 Difference in cases: 55

The level of social development of neighbourhoods plays a key role in the number of COVID-19 cases. Predictably, as has been documented by other studies (Jaramillo-Molina, 2021), neighbourhoods with the highest SDI have the lowest number of infections per 10 000 inhabitants: 211 cases. Conversely, neighbourhoods with a low and medium SDI have the highest infection rates, 326 and 302 cases per 10 000 inhabitants, respectively (Table 3). Neighbourhoods classified with a very low SDI had an average of 262 cases per 10 000 people, which, although higher than that of those with a high SDI, is lower than that of neighbourhoods with a low and medium SDI, which does not fit the expected pattern. This shows that the most marginalized population has fewer cases in relative terms than the population with less severe levels of marginalization. One hypothesis is that COVID-19 cases may have gone unreported in areas with higher levels of marginalization. However, this is an issue that should be investigated and, as will be explained later, studies have found patterns linked to the degree of mobility of the most marginalized households.

COVID-19 infections increase in neighbourhoods with poor water supply. In aggregate terms, an average of 271 cases of infection were found for every 10 000 inhabitants of neighbourhoods with adequate water supply as opposed to 319 cases in those without this. However, when the effect of the social development level was included, it was found that the number of cases of infection increased in neighbourhoods with inadequate water supply in three out of the four groups (Figure 2). In those with a low SDI, it increased by an average of fifty-five cases per 10 000 inhabitants (302 *vs*. 357 cases) in neighbourhoods with inadequate water supply. In neighbourhoods with a medium SDI, it rose by an average of thirty-three cases (299 *vs*. 332) whereas in those with a high SDI it expanded by an average of forty-four cases (208 *vs*. 353). The only group of neighbourhoods in which no difference was observed between neighbourhoods with and without water supply problems is those with a very low SDI, both of which have 262 cases per 10 000 inhabitants. As explained earlier, this does not fit the expected pattern.

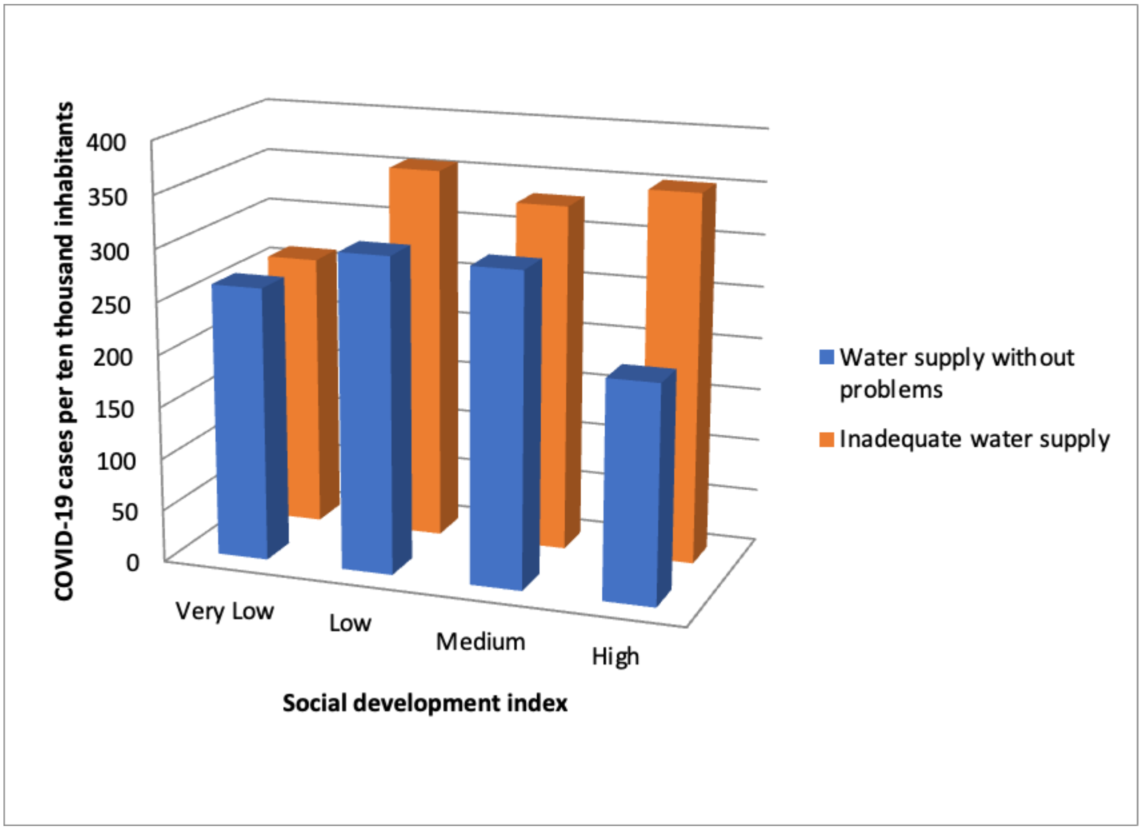

Figure 2. Average Number of COVID-19 Cases per 10 000 inhabitants Grouped by SDI.

In addition to the social development index of neighbourhoods, local policies and actions may have affected the number of infections. Table 4 shows indicators at the municipal level. In absolute terms, the largest number of cases can be observed in the most populated municipalities, with Iztapalapa concentrating 15 % of cases, Gustavo A. Madero 12.4 %, and Álvaro Obregón 10 %, followed by Tlalpan with 7.7 %. However, in proportional terms, the municipalities of Milpa Alta, Magdalena Contreras and Tláhuac registered the highest number of cases per 10 000 inhabitants, with 508, 486 and 419, respectively, as opposed to Benito Juárez and Iztapalapa, which reported the lowest number of cases per 10 000 inhabitants, with 196 and 211, respectively.

Table 4. Indicators of neighbourhoods that presented COVID-19 cases during the period for groups aggregated by municipality.

Municipality	Inhabitants in neighbourhoods with more than five COVID-19 cases	Total COVID-19 cases	COVID-19 cases per 10,000 inhabitants	Percentage of total COVID-19 cases	Number of neighbourhoods with inadequate water supply	COVID-19 cases per 10,000 inhabitants for neighbourhoods with efficient water supply	COVID-19 cases per 10,000 inhabitants for neighbourhoods with inadequate water supply
Álvaro Obregón	718 969	25 505	355	10.1	13	337	462
Azcapotzalco	418 814	12 749	304	5.0	0	304	0
Benito Juárez	429 695	8 428	196	3.3	0	196	0
Coyoacán	571 775	15 822	277	6.3	19	210	414
Cuajimalpa de Morelos	203 375	5 068	249	2.0	23	125	322
Cuauhtémoc	542 906	15 845	292	6.3	0	292	0
Gustavo A. Madero	1 141 646	31 233	274	12.4	29	284	222
Iztacalco	404 643	10 375	256	4.1	0	256	0
Iztapalapa	1 790 966	37 820	211	15.0	113	210	212
La Magdalena Contreras	245 051	11 919	486	4.7	40	458	501
Miguel Hidalgo	379 800	9 592	253	3.8	0	253	0
Milpa Alta	121 469	6 176	508	2.4	3	494	540
Tláhuac	366 671	15 346	419	6.1	18	341	508
Tlalpan	642 433	19 455	303	7.7	65	235	350
Venustiano Carranza	440 070	13 462	306	5.3	0	306	0
Xochimilco	440 623	13 977	317	5.5	11	293	357
Total	**8 858 906**	**252 772**	**285**	**100**	**334**		

There is also a higher number of COVID-19 cases in neighbourhoods with an inadequate water supply than in those without water problems at the municipal level, except in Gustavo A. Madero. It is important to mention that these differences exclude the effect of the SDI (Figure 3). Although it was observed in Iztapalapa that the difference in the number of cases per 10 000 inhabitants between neighbourhoods with and without an inadequate water supply is insignificant (210 and 212 cases, respectively), it was found that the difference increases when the information is disaggregated by level of SDI in the municipality. Thus, in neighbourhoods with a very low SDI, an average of 156 cases per 10 000 inhabitants was recorded in neighbourhoods without water supply problems versus 173 cases in neighbourhoods with inadequate water supply. Municipalities with a low SDI saw an average of 213 cases in neighbourhoods without water supply problems versus 231 in neighbourhoods with supply problems. Neighbourhoods with a medium SDI had an average of 230 cases in neighbourhoods without water supply problems versus 294 in neighbourhoods with problems. None of the neighbourhoods with a high SDI experienced water rationing and registered an average of 195 cases per 10 000 inhabitants. It is striking that Gustavo A. Madero is the only municipality where neighbourhoods with inadequate domestic water supply had fewer cases than those without rationing. This suggests that certain areas of this municipality may be experiencing water rationing, though this has not been reported by the authorities.

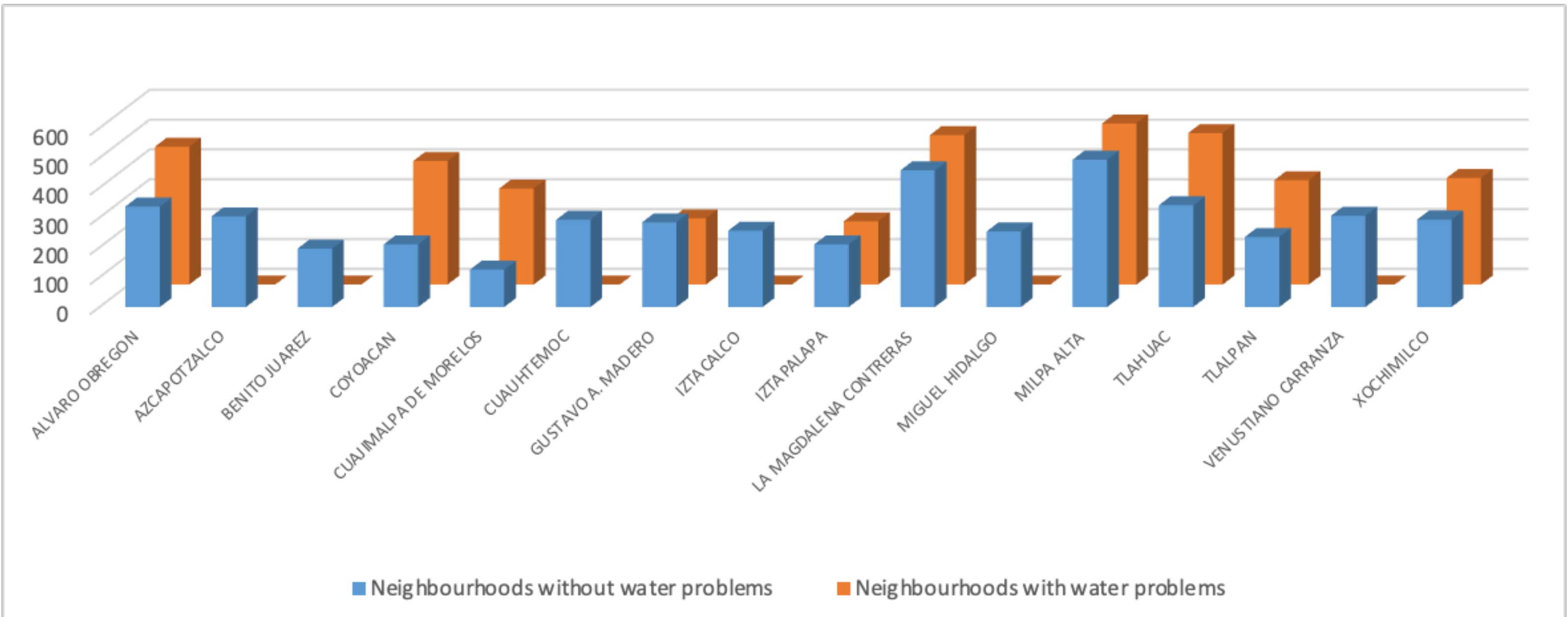

Figure 3. COVID-19 Cases per 10 000 Inhabitants by municipality in neighbourhoods with and without water supply problems.

At a spatial level, the number of COVID-19 cases per 10 000 inhabitants tends to be proportionally higher in neighbourhoods in the south of the city, many of which are classified as having inadequate water supply. Figure 4 shows, through the size of the bar, the number of cases per 10 000 inhabitants at the neighbourhood level. The blue bars indicate neighbourhoods without problems while the orange ones show those with problems. As can be seen from the size of the bars, the highest proportions of infection are found in neighbourhoods with poor water supply, several of which are located on the outskirts of the city and in Iztapalapa.

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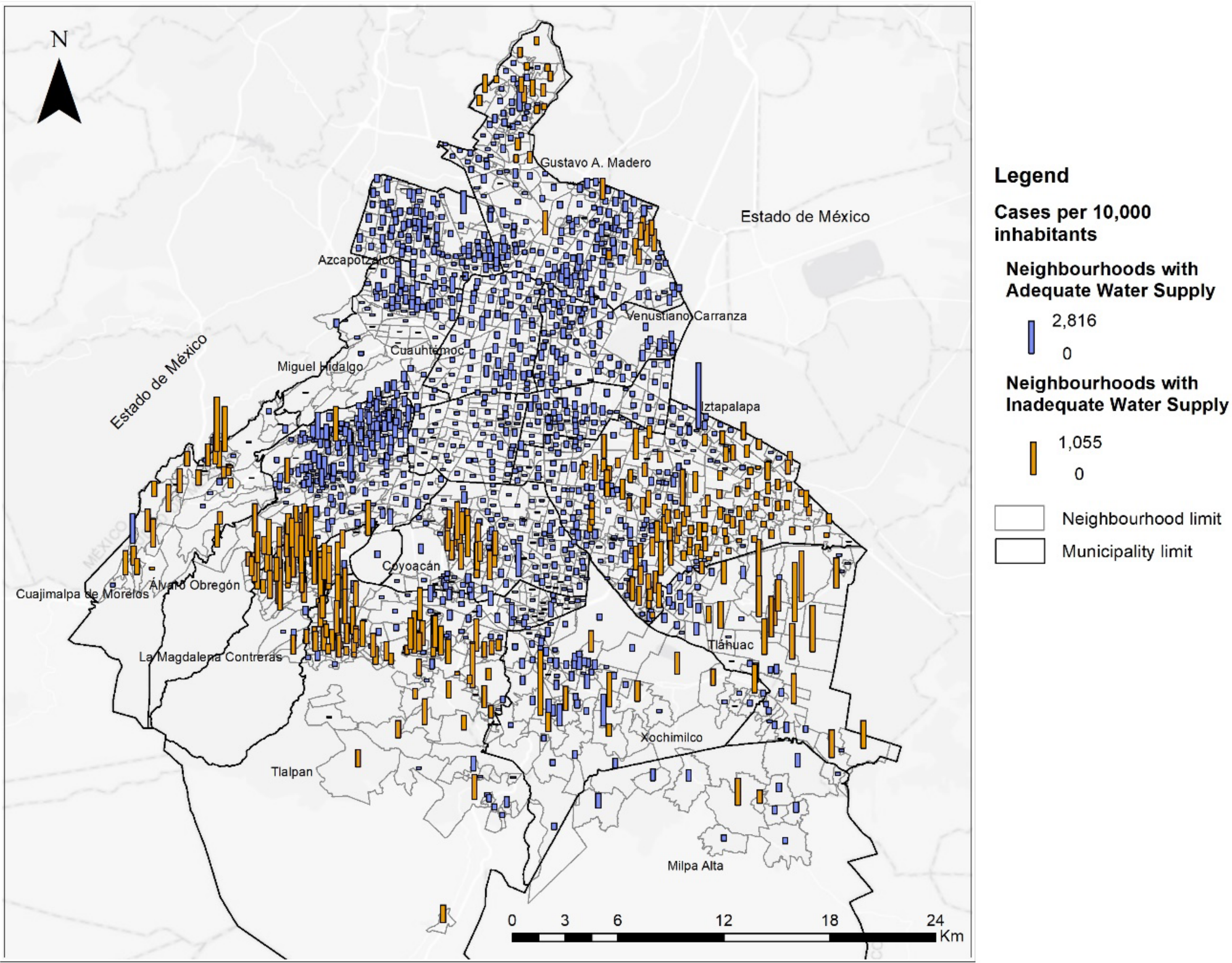

Figure 4. COVID-19 Cases per 10 000 Inhabitants in Neighbourhoods with and without Water Supply Problems.

These results confirm the relationship between the number of COVID-19 cases at the neighbourhood level and the level of social development and inadequate water supply. One way of observing the specific effect of these elements was to analyse the information through regression models.

The resulting model is presented below to explain the total number of COVID-19 cases registered by neighbourhood in Mexico City, in successive fortnights, during the period under study. The total number of infections and number of inhabitants in each neighbourhood variables were converted to a logarithmic scale (natural logarithm). To estimate the relative effect of each of the four degrees of social development into which the SDI of each neighbourhood was grouped, three dichotomous variables were included in the model. These variables were linked to the very low, low, and medium SDI, where the high SDI was the benchmark category, with the lowest average recorded number of COVID-19 cases per 10 000 inhabitants. Whether or not a neighbourhood had an inadequate water supply was included as a dichotomous variable. Table 5 shows that all the variables specified in the model have a positive, statistically significant effect (95 %). As expected, the variable that most influences the number of COVID-19 cases in a neighbourhood is the number of inhabitants, followed by the SDI of the neighbourhood, which had a slight influence on the inadequacy of water supply. A high overall fit was achieved with this model, with an R^2 of 70.2 %, which underscores the significant combined impact of these variables on explaining the number of cases of infection per neighbourhood. Using the model to estimate the total number of infections from the observed population data, the SDI, and the existence of inadequate water service, it was estimated that during the period under study, a scenario without water deficiencies would have reduced the number of infections by 17.3 %. This would mean that in neighbourhoods with inadequate water supply, 43 000 of the 252 000 cases of infection registered during the period could have been prevented.

Table 5. Regression Model for COVID-19 Cases in CDMX.

	Non-standardized coefficients	**Standard Error**	**Standardized coefficients**	**T**	**Sig.**
	B		**Beta**		
(Constant)	-4.473	0.156		-28.658	0.000
Log_Inhabitants	1.046	0.019	0.803	56.322	0.000
Very low SDI=1	0.153	0.059	0.046	2.617	0.009
Low SDI	0.423	0.045	0.173	9.345	0.000
Mean SDI	0.454	0.046	0.174	9.967	0.000
WithProb_water	0.160	0.045	0.056	3.520	0.000

a Dependent variable: Logarithm_Total_Cases.

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Discussion

The results of this study show that 334 neighbourhoods (18 % of the total) in Mexico City, which are home to 2 652 598 (29 %) of the city's residents, have inadequate water supply. These neighbourhoods experience rationing or supply interruptions, and may also receive poor quality water, although the specific characteristics are not known. Other studies have shown that rationing can lead households to receive water for sixty-three, fourteen or even seven hours a week on average (Soto, 2008; Conagua, 2018). Households that receive water for a limited number of hours a week and/or of poor quality are less well-equipped to cope with the threat of COVID-19.

An analysis of COVID-19 infections at the neighbourhood level in the period from June 29, 2020, to February 7, 2021 showed that the number of infections in neighbourhoods was linked to the number of inhabitants, the Social Development Index (IDS) and an inadequate water supply. As expected, neighbourhoods with a higher SDI had fewer cases on average, with a difference of 115 cases per 10 000 inhabitants between neighbourhoods with a high and low IDS. An interesting finding is that there were fewer cases per 10 000 inhabitants for neighbourhoods with a very low SDI (263) than in those with a low SDI (326). The study by Lu, Marx, Poynor, Rogers, and Zeng (2021) analysed various cities in Mexico, finding that people with low incomes spend more time at home and go out less, suggesting a lower overall risk of contracting the virus due to less voluntary movement. This factor should be examined in greater depth, since it contrasts with what one might expect about the vulnerability to COVID-19 infections of more marginalized groups. Another hypothesis is that people who live in the most marginalized areas may have been more likely not to report COVID-19 cases.

The relevance of access to water was confirmed since the groups of households classified by SDI reported more cases in neighbourhoods with inadequate water supply, with thirty-three additional cases per 10 000 inhabitants in neighbourhoods with a medium SDI and fifty-five additional cases in neighbourhoods with a low SDI. When the information was disaggregated at the municipality level, the expected trend was observed, except in the case of Gustavo A. Madero, where the opposite was found. There were more cases in neighbourhoods without water problems, which suggests that in this municipality there are neighbourhoods with inadequate water supply that are not officially reported.

Unlike the analysis by Mazari-Hiriart *et al*. (2020), who failed to observe a significant relationship between the distribution of COVID-19 and inadequate water supply, we found a significant effect. The reason for the differences between the two studies is that this analysis was conducted at the neighbourhood level, whereas the study by Mazari-Hiriart *et al*. (2020) was based on COVID-19 data at the municipality level. The classification of neighbourhoods with rationing problems was based on reports on water scarcity submitted to SACMEX, whereas in this study, the classification was based on the status of neighbourhoods officially reported in the Official Gazettes, complemented by a point of agreement from the Legislative Assembly. We believe that the analysis of cases by municipality rather than by neighbourhood may have overlooked the significant impact of rationing observed in this study.

A regression model confirmed that the number of COVID-19 cases at the neighbourhood level is significantly impacted by the number of residents, their social development, and inefficient water service. The model estimates that an inadequate water supply increased COVID-19 infections by 17.3 % during the period studied. This percentage confirms the damage that could be prevented by achieving adequate water supply: 43 000 cases would have been prevented in neighbourhoods that experienced problems with water service during the period studied.

Limitations of the study include problems related to the information provided by official sources. Uncertainty exists due to the possible presence of more neighbourhoods with inadequate water supply, lack of data on the type of problems they face and underreporting of COVID-19 cases.

Conclusions

To protect from the risks of the pandemic, people must be able to maintain a safe distance, have a safe means of transportation, and implement the necessary hygiene measures. In this article, we focussed on analysing the extent to which vulnerability increases for households living in poverty and in areas with inadequate water supply, since both elements make it difficult to ensure safe distancing and implement the necessary hygiene measures (ONU, 2020a; ONU, 2020b, ONU, 2020c).

This study provides evidence of the extent to which water access influences the spread of COVID-19 in Mexico City. The city requires resources to establish an efficient water supply system in all neighbourhoods to address both the challenges of the COVID-19 pandemic and other crises that lie ahead. Limiting the adverse impacts of the pandemic in the short term requires ensuring enough water both in terms of quantity and of quality, by increasing the number of hours water is supplied in neighbourhoods with rationing and/or through the delivery of safe water by tanker to meet household needs. In the medium and long term, the authorities must seek to ensure water supply throughout CDMX. Neighbourhoods of municipalities with conservation land would benefit from a social equity and environmental justice approach, since these areas have a greater abundance of natural water sources that are undoubtedly piped to other parts of the city.

Since the virus will not disappear in the short term, the authorities responsible for water management in Mexico City and the Metropolitan Zone of the Valley of Mexico should adjust their public policies because of this public health crisis. Prioritizing public investments to improve the efficiency of the water supply in areas with inefficient service is obviously a policy that would contribute to establishing favourable conditions to improve people’s ability to cope with catastrophic events.

The United Nations Organization (ONU, 2020a; ONU, 2020b, ONU, 2020c) has emphasized the urgent need to rethink and transform cities to cope with the reality of COVID-19 and future crises that will increase because of climate change. More research is required to improve decision-making processes and refine the public policy response. Ensuring that resilience plans are based on disaggregated data could help guarantee that scarce resources, particularly during critical periods, are used more efficiently to target areas needing greater support (ONU, 2020a; ONU, 2020b, ONU, 2020c; Brikalski *et al*., 2020). Health and other emergencies require cities to design policies that will invest in reducing human vulnerability to disease and the effects of a less stable climate. The results of this study point to the fact that increasing the level of future resilience and stability of cities includes achieving equitable water access.

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