Research Article

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Household water consumption on the outskirts of Mexico City

Abstract

This research paper sets out to identify if household water inequality consumption in Mexico City is expressed itself in a spatial distribution pattern. The methodology is based on spatial data analysis performed on Geoda software. Data were obtained from the city's water operating agency for 2019. The results reveal that exist a household water consumption' spatial pattern: households located in the central-western area register a high consumption of water, while those in peripheral areas of the southern and southeastern register a lower consumption. This pattern confirms that water consumption increases as households move from the poorest periphery to the central area of the city. These findings suggest the urgency of the city's public water utility to adopt strategies to reduce discrimination in the poorest areas. Thus, this research contributes to closing the information gaps on inequality water consumption in cities in developing countries.

Keywords: water inequality, household water consumption, water spatial pattern, Mexico city, water utility

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Introduction

Water is an essential element for human health and quality of life both individually and socially. The world's population should have access to safely managed water – available when they need it, and of potable quality. Though, 663 million people, predominantly from developing countries, lack adequate access to reliable water supplies.[1] The United Nations 2030 Sustainable Development Goals (SDGs), states goal number six, which seeks to guarantee the availability and sustainable management of water, demonstrating the growing attention that issues related to water have on the world political agenda. By setting this goal, it recognizes that social development and economic prosperity depend on the sustainable management of freshwater resources and ecosystems.[2] The 2030 agenda points out that growing social inequalities in access to water, environmental degradation, and climate change are among the greatest challenges of our time.

Inequality is considered a socioeconomic concept that denotes growing societal fragmentation, manifested through persistent and emerging risks to human health, rising unemployment, widening digital divides, and youth disillusionment.[3] Hence, water inequality is understood as the differentiated endowment between the households of a specific population (be it a country, city, region, or community).

Inequality in access to water among the population is one of the main reasons behind the water crisis around the world.[1] Like other resources, the distribution of water is not equitable among various sectors of the population.[4] Households that do not have access to water from safe sources exhibit negative impacts on their health, such as diarrheal diseases due to enteric pathogens such as *E. coli and E. hystolitica*;[5] illnesses causing growth retardation;[6] preterm delivery; low birth weight,[7] and more recently, they increase the risk of Covid-19 infection. In contrast, households that have access to improved water sources (supervised in their quality) show a favorable impact on the social dynamics of their populations, on public health, their education rate, gender equality and on their economic development.[8,9]

Globally, urban regions tend to generally have better water services compared to rural ones.[10] Official statistics for large cities in developing countries report significant coverage of access to water in homes, especially in contrast to rural coverage. However, various independent investigations reveal the profound inequalities that exist in water consumption among households in cities.[10–13,1] For instance, in India, two studies measure urban inequality in households. The first one reports that Gini coefficients estimated in several cities regarding the use of tap water in households show an increased inequality.[14] The second one concludes that water inequality in urban areas and the growth of its population constitute a great challenge for its water distribution system.[15] Further studies in other countries display results that point in the same direction, namely: Cameroon,[16] Jordan,[17] Colombia,[18] Nepal,[19] China,[20] and Mexico.[21]

According to various studies, the factors that explain disparities in household water consumption in cities span multiple dimensions. Gerlach and Franceys indicate that poor and socially marginalized urban households are those with the greatest limitations in access to water and in opportunities to influence decision-making processes for its distribution.[22] Poor households are more likely to experience water deprivation in contrast to higher-income households. Studies coincide that there is a correlation between the level of consumption of drinking water and the socioeconomic level of households.[22–24] The latter expressed as the level of household income, in such a way that, as the monetary income of households increases, the per capita consumption of water increases as well. The latter is because households with high incomes have access to larger houses, with elements that require greater water consumption such as garages, patios, gardens, and swimming pool.[22–28]

A different group of researchers argue that spatial location of the houses is the factor that explains water inequality. It is said that in the cities of developing countries there is structural heterogeneity. That is, the place of residence matters since the pattern of location segments and excludes lower-income sectors towards areas with fewer services, highlighting poor access to water.[29,30] Other studies identify that households located on the periphery of cities experience severe inequalities and precariousness in terms of limited access to water, housing, job opportunities, economic income, infrastructure, and access to basic services.[32]

Conclusively, several variables explain the levels of water consumption in households are found across several dimensions, socioeconomic, climatic, or physical, in addition to their geographical location and their relationship with neighboring regions.[33,34] The variables that determine consumption levels typically tend to present spatial distribution patterns. These variables influence water consumption not only through their direct effect, but also indirectly through the effect of spatial association patterns.[35]

Research on domestic water consumption and inequality with a spatial approach is limited due to the complications for collecting georeferenced information. Di Mauro et al. document how difficult it is to access *ad hoc* databases to examine domestic water consumption. The authors identify 92 water demand datasets in the last 45 years, only 20 were identified at district scale.[36] The latter are generally owned by water utilities, which make them available to researchers usually only temporarily and for *ad hoc* case study analyses. In the search for similar research in Latin America, the authors of this paper only identified two studies, the first in the city of Fortaleza, Brazil,[36] and the second in Mexico City.[37]

The present study is interested in addressing the case of domestic water consumption in Mexico City, which is the area of greatest political, economic, and social importance in Mexico. The city ranks globally as one of the most threatened by extreme water scarcity and inequality in its distribution (Rojas-Quesada & Valenciano-Hernández, 2019). Given the inequities in the consumption of drinking water, it is known as one of the cities with the highest per capita consumption of bottled water worldwide, even before the pandemic.[38] The water distribution system is inadequate or insufficient, with roughly 40% of the water lost due to leaks.[39–41] The quality of the water services continues to be a key of concern, particularly regarding water quality and the frequency of the supply.[42]

Currently, there is barely any research on water consumption in Mexico City. In the period 2004-2018, Tapia-Pacheco et al. researched on various aspects of the access to drinking water in communities.[43] The study identified 79 documents distributed in the following way: 58 research papers (most of them, 48 from WoS-Scopus), 3 review papers, 8 proceeding contributions, 6 books, and 4 final project reports. The authors concluded that the number of documents retrieved in their sample is too small and therefore reflects the scarce interest of scholars on the subject related to the access of drinking water in Mexico City. In addition, of the total number of documents, only 5 refer to the social issue inequality in water access, quality, or quantity; and none apply a spatial perspective. As previously mentioned, in 2021 an article that examines the residential demand for water in the city with a spatial approach was published; the latter includes variables on urban density and determinants of access to water services.[37] However, the information it analyzes is from 2010, which reflects the great difficulty in obtaining georeferenced and updated information.

Mexico City registers a population of 9,209,944 people, of which 90.5% have piped water inside their home.[44] The water service is provided by the Mexico City Water System (SACMEX by its acronym in Spanish), which faces countless complaints from households connected to the service. There are households that, even when they have a connection, do not receive water, others indicate variations in the volume received, ranging from intermittence of several times a day to a few times a month, others indicate very low pressure in the water supply, among others. The previous assessment suggests the importance of spatially identifying the levels of water consumption among households in the city. It is of particular interest to identify the group that systematically faces shortages and that is forced to live with low water consumption, thus affecting their quality of life.

The investigation of domestic water consumption in Mexico City is approached under a spatial methodology, which makes it possible to find a more precise explanation of the variations in water consumption between households and identify the areas of greatest conflict in the city. These factors configure a valuable tool for decision-makers and an important basis for formulating efficient water policies.[36,45,46] In this context, this study aims to investigate whether inequality in water consumption among households is characterized by a spatial distribution pattern. It is of particular interest to identify the georeferenced variable that significantly explains the formation of the spatial pattern, as well as working with updated information so that the results make it possible to identify spatial information from which meet pressing water needs for vulnerable groups.

This research helps to address the recurring demand in the literature for more empirical works on domestic water consumption of cities in developing countries. In addition, this effort forms part of an attempt to address the issue of water inequality at the household level with a spatial focus in Mexico City.

Methods

Study area

Mexico City is in the center of the country within the Valley of Mexico Basin, which is characterized by its high-water stress. It houses 2,756,319 homes[44] and is the most densely populated region in the country. To supply water to a population of more than 9 million, water is drawn from the city's aquifer (two-thirds of the total), and it imports water from surface and underground water bodies in nearby watersheds (one-third of the total). The main external supply is surface water and comes from the Cutzamala system located 124 km away. The city faces high water stress and recognizes limitations in meeting the demand of its entire population; about one million people do not have piped water inside their home.[44]

Data

Data on household water consumption were obtained from the water supply database by operating agency SACMEX, corresponding to the year 2019. The database has restricted access and is exclusively used for academic purposes (SACMEX, 2019 onwards). The database includes 6 bimonthly bills for metered consumption service and a fixed fee for the concept of water supply in cubic meters (m^3) at neighborhood level, corresponding to domestic use. The average water consumption in households for each neighborhood (liters/day) was estimated in a total of 1,338 that define the city. For the size of the household to not influence water consumption among households, the variable per capita daily water consumption per household (liters/inhabit/day) is estimated. Per capita consumption for each neighborhood was obtained through the association between average water consumption in liters/day and the number of household members at the neighborhood level. These last data were obtained from the 2020 population and housing census of the National Institute of Statistics and Geography of Mexico.[44] The georeferencing of consumption was carried out using vector information of the Mexico City neighborhoods, updated to the year 2020 using ArcGis 10.3 software.

Other database on household water consumption were taken from the Survey of Water Consumption, Service and Quality Habits in Homes in Mexico City (EHCSCA), collected by researchers from the Metropolitan Autonomous University, which is not accessible to the public (UAM, 2011 onwards). The survey was applied to permanent resident households in private homes between August and September 2011, and reports data from the previous year. The sample of 689 dwellings was determined randomly, with a confidence level of 99%, and with a margin of error of 5%, from a sampling frame of 1,903,983 dwellings in 2010. This database records information by household on the consumption of water and the family monetary income.

The Urban Poverty Index (UPI) was estimated for the National Council for the Evaluation of Social Development Policy (CONEVAL by its acronym in Spanish) for the year 2019 at level of the urban basic geostatistical area (AGEB by its acronym in Spanish), which is the largest-scale unit of spatial analysis in urban areas of Mexico. UPI estimates the percentage of the population living in poverty by AGEB, it is constructed based on nine socioeconomic indicators such as current per capita income, average household educational gap, access to services, access to social security, housing quality and spaces, access to quality and nutritious food, the degree of social cohesion, and degree of paved road accessibility.[47] UPI is classified in six categories ranging from 1 to 5, where 1 represents less percentage of the population in poverty, and 5 a high percentage in poverty prevails. Subsequently, each neighborhood was assigned the poverty rank according to its geographic location within the corresponding AGEB.

Methods

The analysis was carried out in three steps as indicated in Figure 1. The first step measures the degree of inequity in family water consumption among households, estimating the Lorenz curve and the Gini coefficient.

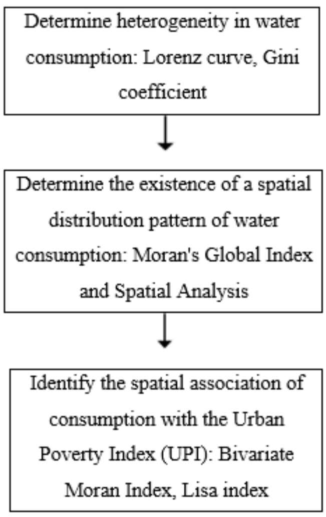

Figure 1 Applied methodology.

In the second step, the question of whether the water consumption variable defines a spatial distribution pattern was investigated. The potential existence of a spatial distribution pattern was identified through exploratory spatial data analysis and Moran's global index. Two groupings of households were discovered: The first group corresponds to the household consumption in a box map where the atypical values and the ranges of higher and lower water consumption in Mexico City are shown according to their oscillation in relation to the median and mean of the observation data (corresponding to the quintiles of the Gini Coefficient). The second group classifies households into five ranges defined by the per capita consumption standards established at the international and national level.

Georeferenced maps were fixed and analyzed for both groups using ArcGis and Geoda software. Subsequently, the existence of the spatial pattern was investigated with statistical indicators. The Moran dispersion graph was estimated, which determines the existence or not of a spatial autocorrelation between the water consumptions of the different neighbors of Mexico City. The Moran Index (GMI) examined each characteristic in the context of neighboring entities, measuring the degree of correlation between them. The Geoda software was used to identify spatial patterns of high and low water consumption, using a first order "queen" contiguity weight matrix in which spatial units that share a common border or vertex were considered as neighbors. GMI results were evaluated using a reliability test of 999 permutations, with a significance level of $p < 0.05$.

The third and last step identifies the type of spatial association pattern, for which the Bivariate Moran index (BMI) was estimated, which measures the degree of association between household water consumption and the variable that potentially defines the pattern. Finally, the Lisa Index (LI) identified the clusters that define a pattern of spatial distribution of the highest and lowest water consumptions in Mexico City and its association with the variable that defines its agglutination. In both cases, a queen contiguity weight matrix, and a randomness test of 999 permutations, with a value of $p<0.05$, were used to evaluate the reliability of the results.

Results

Inequality in water consumption in homes

Figure 2 shows the Lorenz curve for household water consumption in Mexico City. Households are organized from lowest to highest family income and are classified into five groups with the same number of households (quintiles on the x-axis). For each group, their water consumption, and their respective participation in the total (y-axis) is estimated.

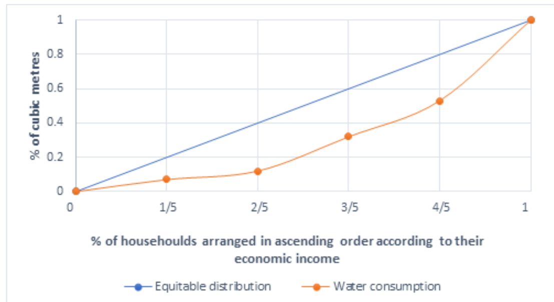

Figure 2 Lorenz curve of water consumption in Mexico City.

The Lorenz curve indicates that the first quintile (1/5), which groups households with the lowest family incomes, consume approximately 7% of the total amount of water used by households in the Mexico City (m^3). At the other extreme, the fifth quintile (5/5) brings together the households with the highest incomes, those that consumed almost 42% of the water, that is, six times more than the first quintile. The remaining 51% is consumed by 60% of the households in the second, third and fourth quintiles. This distribution of water shows that lower income households are sanctioned, and that higher income households are disproportionately favored. The Lorenz curve also indicates that there is an association between water consumption and household income, a result consistent with that reported in previous studies such as those mentioned in the introduction.

In Figure 2, the line simulates the most equitable distribution among households, which allows visualizing that when the Lorenz curve approaches it, it registers a more equitable distribution and vice versa. The estimation of the size of the area between both curves

Citation: Morales-Novelo JA, Medina-Rivas CM, Rodríguez-Tapia L, et al. Household water consumption on the outskirts of Mexico City. *Int J Hydro.* 2022;6(3):110–117. DOI: 10.15406/ijh.2022.06.00310

indicates the degree of inequality of the distribution, a value that is called the Gini coefficient, a value of zero indicates perfect equity and one maximum inequality. In the investigated case, the Gini coefficient registers a value of 0.437 which indicates the existence of inequality in water consumption among the Mexico City households.

For the size of the household not to influence water consumption among households, the daily water consumption per household (liters/inhabit/day) variable per capita is estimated. The range of this new variable confirms the presence of inequality between households, it is recorded that there are households that only consumed 16 liters/inhabit/day while others have a value that reached 710 liters/inhabit/day, that is, the latter households consume 43 times more. The new variable confirms the presence of inequality in water consumption among households, which suggests that the size of the household is not a determining factor in explaining the phenomenon. Similar information for 2019 confirms that the range of per capita water consumption among households in Mexico City remains, from 6.7 to 671.9 liters/inhabit/day, or 44 times more. Consequently, underlining the persistence of inequality today.

Is there a spatial distribution pattern in the water consumption of Mexico City households?

In this section, the presence of a spatial pattern is explored through the exploratory spatial data analysis using the box plot and two georeferenced maps, corresponding to two classifications of consumption. The box plot and the first map show the statistical variability and spatial trend of water consumption ordered in quartiles from lowest to highest per capita water consumption considering its oscillation within the median and mean of the data (Figure 3).

The box plot (Figure 3a) shows an asymmetric distribution of consumption data with a right bias with values ranging from 6.71 to 671.89 liters/inhabit/day. The average consumption is 140.52 liters/person/day; however, it is not the predominant range of consumption in the city. In the Mexico City box map (Figure 3b) it is observed that there is a great disparity in water consumption among households,

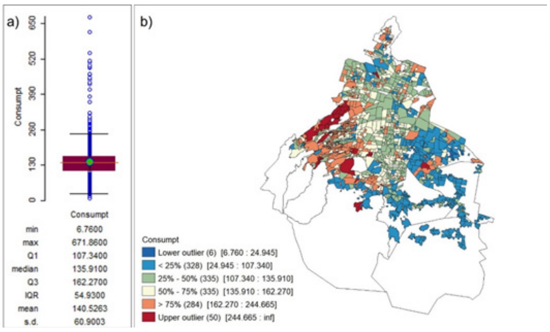

Figure 3 Spatial variation of per capita water consumption in M ity.
Source: Own elaboration based on data from SACMEX, 2019

as reported in the Lorenz Curve. The lowest consumption is located on the periphery of the southeastern and southern urban areas, in the municipalities of Iztapalapa, Tláhuac, Xochimilco, Milpa Alta and Tlalpan with minimum consumption of up to 6.70 liters/inhabit/day. The central and northern areas of the city are mainly characterized by consumption in the order of 107 and up to 135.91 liters/inhabit/day. In the western area, consumption is higher than the average with values of 162 and atypical consumption greater than 244 liters/inhabit/day and up to 671 liters/inhabit/day. This clear division of household water consumption shows the spatial inequality that exists in the supply of drinking water in the city.

Spatial variation of water consumption in households classified into five groups

Household water consumption is classified by ranges configured based on standards recommended by international and national organizations such as the World Health Organization (WHO), the National Water Commission (CONAGUA by its acronym in Spanish), and the Mexico City Government, respectively (Table 1).

Table 1 Recommended water consumption standard per person

Organization	Recommended optimal consumption (liters/inhab/day)			Needs met
WHO	100			Complete satisfaction for basic consumption and hygiene needs at home
CONAGUA	Temperate Climate			Enough consumption for a member of a family to cover their basic needs
	Socioeconomic class			
	Residential	Median	Popular	
	250	195	150	
Mexico City Government	196			Consumption to meet the needs of food, hydration, and hygiene for the population

The consumption ranges are presented in the following map (Figure 4). The households in yellow register a consumption below 100 liters/inhabit/day and represent 19.7% of the total neighborhoods in Mexico City. These households do not meet the WHO recommendation (Howard & Bartram, 2003), which is the most lenient criterion. These sets of homes are the most disadvantaged, they are located mainly in the peripheral areas of the southeastern region of the city, in a total of 264 neighborhoods where atypical consumption of 6.7 liters/inhabit/day is registered, which is clearly insufficient to satisfy the basic needs of a person. Households grouped in the green range consumed an amount of water that complies with the WHO recommendation but does not reach the minimum level established by the CONAGUA for popular-class areas (150 liters/inhabit/day). These group of households represents 46.2 % of the total neighborhoods and defines the predominant level of water consumption in the city. However, it should be noted that the median of the range does they do not even reach 110 liters in the peripheral areas of the southern part of the city. Figure 5 shows that households located in this range are distributed in great proportion in the central and northern zone of Mexico City and to a lesser extent in the southern region in a total of 618 neighborhoods.

The households within the third group are indicated in turquoise blue, their consumption range complies with that established by the Mexico City government (196 liters/inhabit/day) but does not reach the CONAGUA recommendation for residential class areas (250 liters/inhabit/day). These households represent a quarter of the total neighborhoods (24.2% with 324 neighborhoods), and they are distributed heterogeneously in east and west areas of the city.

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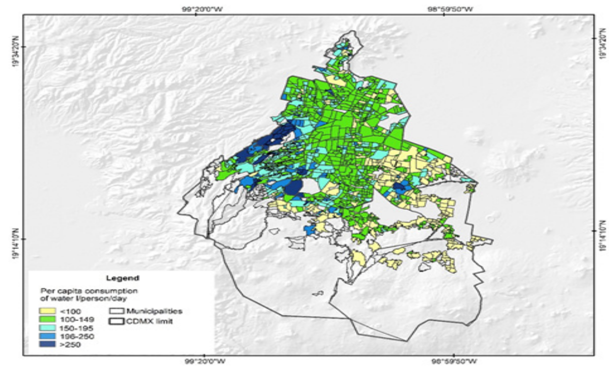

Figure 4 Groups of households according to their water consumption standard.

Source: own elaboration based on data from SACMEX, 2019

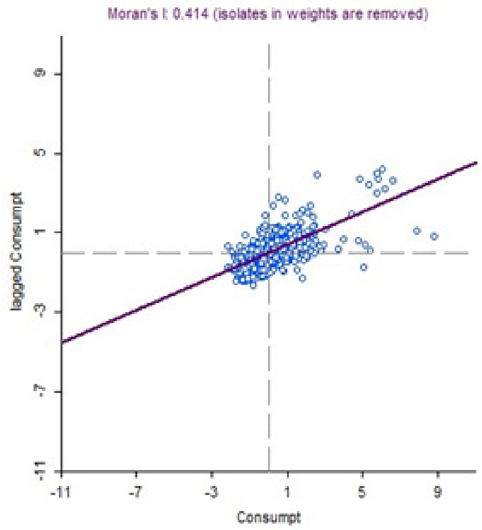

Figure 5 Scatter plot of water consumption in Mexico City and global Moran index.

Source: own elaboration based on data from SACMEX, 2019.

Finally, the fourth and fifth set, indicated in blue and navy blue, includes households with the highest consumption levels and covers the standards established by the three institutions considered. These represent 9.9% of the total (132 neighborhoods) and are in the western region of Mexico City. The visual exploration of the distribution of the five groups suggests a clear segmentation of the city into areas with three different levels of consumption: areas with low, medium, and high levels of water consumption.[45–49]

Estimation of the global moran index

The Global Moran Index (GMI) and the scatter plot[50] of the variable per capita water consumption are shown in Figure 5.

Figure 5 shows the nature of the spatial autocorrelation between household water consumption (x-axis) and those of its neighbors (y-axis). Different situations are observed in the four quadrants of the Cartesian plane. By construction, the graph is centered on the indicated median with zero on both axes. On the x-axis, all the points to the right of zero show positive deviations of per capita consumption values from the mean, and those on the left show negative deviations. Similarly, on the y-axis (neighbor consumption), values above zero show positive deviations and negative deviations below.

The first and third quadrants register positive spatial autocorrelation, the consumption of neighboring households located in these quadrants are similar. Households with high consumption are autocorrelated in the upper right quadrant, while low consumption households are autocorrelated in the lower left quadrant. In contrast, in the second and fourth quadrants the consumption of neighboring households differs, and there is no spatial autocorrelation between them.

In Figure 5, the fit line of the total data shows a positive trend, with a slope equal to 0.414. This value is known as GMI, and it can take values between zero and +-1, a value close to one indicates high correlation and vice versa. The value of the GMI denotes the existence of a significant spatial correlation between per capita household water consumption, which indicates the existence of a spatial distribution pattern.

The test of the goodness of the GMI parameter rejects the null hypothesis that assumes that the result is the product of a random situation. The median deviation value is the GMI (0.414), and the result of the standard deviation of a random scenario is 42.13, a value that is very far from the theoretical value of 1.96 estimated for a significance threshold of 5% which rejects the null hypothesis. The **p** value is close to zero, which means that the results obtained with the Moran's I have a reliability of 99% and a significance of 1%. The results obtained are robust and confirm the existence of a spatial distribution pattern of per capita water consumption in Mexico City.

Identification of the pattern through the spatial association between water consumption and Urban Poverty Index

To identify the spatial distribution pattern of household water consumption, a variable correlated with it was identified, it is also characterized by defining a spatial distribution pattern. The research discovered that the variable that meets both requirements is the UPI. The poverty index is estimated from indicators of socioeconomic exclusion in five main dimensions: level of education; access to health; per capita income; housing conditions and access to basic services.[51] UPI (in percentages) indicates a different socioeconomic situation, a first range with the highest values represents households in regions with great deprivation, whereas, at the opposite end, the fifth range with low UPI indicates areas with households in the best socioeconomic conditions. The level of family income is implicitly considered in the five dimensions that characterize the UPI, which is significant because the Lorenz curve (Figure 1) showed that there is an inverse relationship between family income and water consumption. This suggests the existence of a relation between UPI and water consumption, which is proved later.

In Figure 6 it can be observed that the Mexico City is segmented into five regions by the UPI ranges. It shows the spatial distribution pattern documented by the UPI, which defines four regions with very different socioeconomic characteristics. The brown and red areas with very high and high UPI are characterized by the worst living conditions, passing through the orange region you reach the yellow region of low UPI, which is characterized by presenting favorable conditions to guarantee a high level of well-being.

Spatial association between UPI and water consumption

At this point, correlation between the spatial distribution pattern of the UPI and the pattern of household water consumption is tested. This is statistically estimated with the Bivariate Moran Index (BMI). Figure 7 shows that the coefficient registered a value of -0.228 which indicates an inverse spatial relationship between both variables. A higher index of poverty is associated with lower water consumption and vice versa. The absolute value of the coefficient indicates that the relationship between the variables, although significant, is not very strong in a global form. However, locally there is a strong association between the poorest households and low levels of water consumption, which will be discussed in the next section.

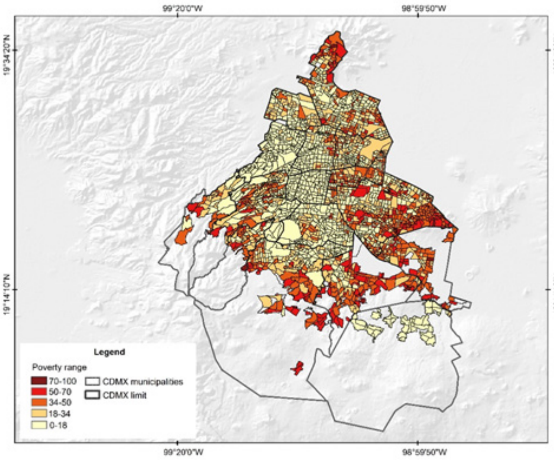

Figure 6 Spatial distribution of poverty in Mexico City.

Source: Own elaboration based on data from CONEVAL, 2019b

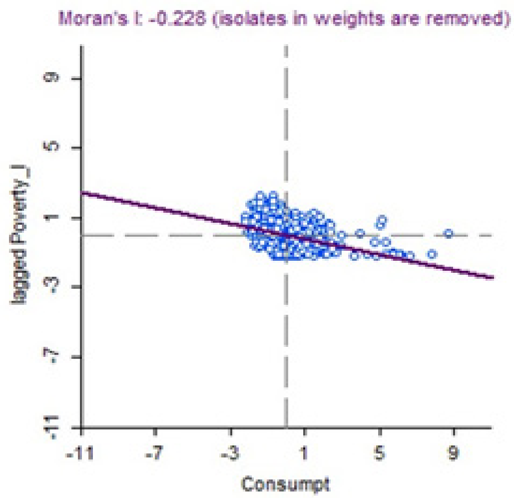

Figure 7 Correlation between UPI and household water consumption.

Source: own elaboration based on data from SACMEX, 2019

The goodness of the BMI is evaluated with the null hypothesis test that assumes that the result is the product of a random situation. Given that the median deviation value is the BMI (-0.228), and the result of the standard deviation of a random scenario is -30.20; the last value is located outside the distribution of results of numerous permutations of values, therefore it is considered a strong rejection of the null hypothesis. The results are robust with a reliability of 99% (p value close to 0) and confirm the existence of a spatial distribution pattern between the UPI and per capita water consumption in Mexico City.

Characteristics of the spatial pattern of water consumption

This section identifies the spatial pattern of water consumption with respect to UPI to identify the spatial similarity between both variables. Figure 8a presents the Lisa Index Map identifying areas where a high correlation between UPI and water consumption variables in the city (clusters) exists. Figure 8b shows the statistical significance of the results obtained with the LISA index.

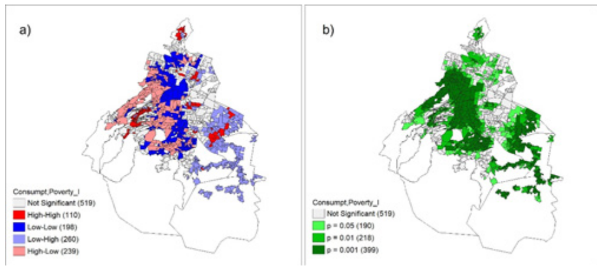

Figure 8a Lisa Index Map: clusters between water consumption and UPI. **Figure 8b** Significance map.

Source: own elaboration based on data from SACMEX, 2019 and CONEVAL, 2019b

In Figure 8a, areas in lilac are characterized by a high index of poverty and where households consumed very little water (less than 100 liters/inhabit/day). The high correlation between variables is identified in the significance Lisa Index Map (Figure 8b), this area includes 260 neighborhoods with a statistical reliability of 99 and 95% (strong and light green) respectively. This region is located mainly on the outskirts of the city, in southeast region of the urban area (Iztapalapa, Tláhuac, Xochimilco and Milpa Alta).

The Lisa map (Figure 8a) highlights the central and west areas of the city in pink, which registered the lowest indices of poverty, and the highest consumption of water (more than 196 and until 671.86 liters/inhabit/day). Households located in this area record the amount water consumption recommended by Mexico City's Government. The upper limit meets the standards established by WHO and CONAGUA. The area is recognized in 239 neighborhoods with a high statistical significance (99 and 95%). The cluster is characterized by having the best public infrastructure, paving, public lighting, internet, water, among others. This area mainly encompasses the Miguel Hidalgo, Benito Juárez, Coyocan and Cuauhtémoc municipalities, where good socioeconomic conditions prevail.

Finally, regions with indices of medium poverty showed a medium range of water consumption, which suggests a socio-spatial transition between the peripheral areas and the central areas with a higher socioeconomic level. This transition region includes situations where some of the households located in the central area of the city that display low levels of poverty, have water consumption that does not exceed 150 liters per day, highlighted in blue on the LISA map.[52,53]

Conclusion

The results of the study indicate the presence of a spatial pattern in the consumption of water in Mexico City. Such pattern is shaped by its inequity that characterizes household consumption. Discrimination has been present since 2010, as shown by the Gini coefficient and Lorenz curve. Currently, the range of consumption per household are from 6.71 to 671.89 liters/inhabit/day.

The value of the Global Moran Index (0.414) denotes the presence of a spatial pattern. To identify it, the Urban Poverty Index (UPI) variable is used, which has a high relationship with water consumption. The UPI is directly related to household income; therefore, it is assumed to be a good variable to determine the spatial pattern. Several investigations report that household income is a determining factor of water consumption.[29,30,13]

First, the spatial analysis of the UPI confirms the existence of a spatial pattern of it. Secondly, UPI is related to household water consumption to determine the degree of correlation between both variables. The Bivariate Moran Index (BMI) registers a value of -0.228 that confirms the existence of a systematic and inverse relationship between both variables.

The Lisa Index Map identifies the areas of the city with a high correlation between households with a low level of water consumption and housing location in highly poverty areas. This region is located on the southeast outskirts of the city. The central and west regions have the highest water consumption per household, these regions are characterized by a very good socioeconomic condition. Other areas with average poverty revealed a medium range of water consumption and suggests a socio-spatial transition between the peripheral and central areas with a higher socioeconomic level.

The research findings from Ramos-Bueno et al.[37] reports that households located in the central-western area registered a high consumption of water, and those in peripheral areas of the southern and southeastern region registered low consumption.[37] However, their research does not identify the specific regions that define the spatial pattern. Ramos-Bueno et al. does not consider the household size variable, since it includes as a dependent variable total water demand of households, and not at per capita level.

An interesting finding of the research is the identification of the marginalization index as the variable that reflects the spatial pattern of water consumption. The spatial pattern suggests that water consumption increased as households move from the periphery to the central area of the city. In the outskirts areas, poverty is decisive where the greatest conflicts and low consumption of drinking water are registered. The different degree of poverty is a key element in the explanation of the decrease in household water consumption, which is reduced as they move from the center to the outskirts of the city.

The indicated results are consistent with other similar studies in cities of developing countries, such as India,[14,15] Colombia,[18] Nepal[19] and Jordan.[17] These studies systematically report inequality in water consumption in large cities, suggesting occurrence of structural factors such as urban growth pattern, limited resources for water supply, low investment in water infrastructure, scarce water resources among others.

Reducing inequality in water consumption between households is a challenge in developing countries. There is the need to start from the social consensus of the type of city and each one must reach it. Furthermore, an agreement on the type of water services that can be realistically and reasonably offered to everyone, mainly to the group of households that live in neighborhoods with a high level of marginalization, has to be made. The equitable consumption that characterizes cities in developed countries shows that it is feasible for developing countries to improve their current situation, since they have gone through similar stages to those faced.[53]

The spatial pattern of inequality in water consumption in Mexico City represent a red light for water sector authorities. It is a priority that they define public policies that improve the households' conditions that have prevailed for more than a decade in the peripheral area of the city. The vulnerability faced by the population located in the cluster with the lowest water consumption is a concern in the context of the COVID-19 pandemic. Since households do not have sufficient, continuous, and good quality water, they cannot adequately perform hand hygiene, which is a basic recommendation to reduce the risk of infection. Nevertheless, what is also clear is that the pandemic has made society's socioeconomic problems even more notable.

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Conflicts of interest

No potential conflict of interest was reported by the authors.

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