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Research article

Infectious Intestinal Diseases and Residential Water Services in Mexico: a Spatial Analysis

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Abstract: Infectious intestinal diseases (IID) represent a widespread public health problem in Mexico. The country also faces major challenges with respect to the provision of residential water services (piped water and sewer)—an essential input for hygiene and cleanliness in homes. This paper analyzes morbidity rates from several IID associated with unsanitary living conditions along with a series of residential water services indicators for Mexico's 2,456 municipalities. With data obtained through a special request to the federal epidemiological authority as well as official census data for 2010, we find stark regional contrasts and identify interesting spatial structures for both IID morbidity and residential water services indicators. In particular, municipalities tend to present values similar to neighboring municipalities, forming clusters of relatively high-value (or low-value) municipalities. Moreover we find that municipalities with a relatively high level of access to residential water services tend to present relatively low IID morbidity rates. These results have multiple public policy implications. In order to reduce the incidence of IID effectively and efficiently, interventions should explicitly consider the spatial structure of morbidity and target problem spots—which typically spill over state, municipal and other administrative boundaries. Moreover, improvements in the quality of access to piped water (for example, increasing the frequency of supply) may be as important for reducing morbidity as the expansion of basic access to this service.

Keywords: infectious intestinal diseases; residential water services; spatial analysis; municipalities; Mexico.

1. Introduction

Infectious intestinal diseases (IID) represent a widespread public health problem in Mexico. This paper focusses on five specific IID caused by distinct pathogens: protozoan (Amebiasis, Giardiasis and IID from other protozoan pathogens), bacterial (Shigellosis) and viral (IID from rotavirus). These diseases generate over half a million of diagnosed cases per year in Mexico and despite their diverse pathogenic origins, share significant common characteristics. All five fall under the category of “waterborne diseases” and as such may spread through contaminated water. More importantly, the fecal–oral transmission route is also of great relevance for these IID: infections can thus occur in a number of ways, for example as a consequence of improper hand washing. Mexican health authorities recognize that unsanitary living conditions and lack of hygiene play a significant role in the incidence of these ailments [1].

Mexico also faces major challenges with respect to the provision of residential water services. The Census data [2] we review in detail in the next section reveal for example that in 3.2 million homes, people do not have access to piped water. Moreover where available the piped water service may be of low quality, for example access limited to a tap outside the home, or water available only sporadically i.e. less than one day per week on average.

A long standing literature addresses the impact of water and sanitation on public health, for example Hollister et al. [3], Esrey et al. [4], Redlinger et al. [5] and Cairncross et al. [6]. That literature mostly focusses on the consequences of contaminated water consumption or exposure to raw sewage. This paper tackles a related but more general issue: the relationship between IID morbidity and access to residential water services. We motivate this with a straightforward premise: piped water and sewer services are essential for personal hygiene and cleanliness in homes. In fact showering, flushing toilets, washing dishes and other hygiene-related activities account for most of the water used in homes with access to those services. Therefore lack of access may foster unsanitary living conditions and cause a host of health problems, including the aforementioned IID.

We seek two main objectives: first, to describe the spatial structure of both IID morbidity and access to residential water services across Mexico’s 2,456 municipalities; second, to explore the statistical relationship between the two. Our results show that both municipal IID morbidity rates and residential water services indicators present interesting spatial patterns, in particular pronounced regional contrasts and clusters of municipalities with similar values. Furthermore our analysis suggests that municipalities with a relatively high level of access to residential water services tend to present relatively low IID morbidity rates.

2. Materials and Methods

2.1. IID morbidity and residential water services: data and indicators

We compute municipal morbidity rates (y_{ij}) as:

$$y_{ij} = \left(\frac{CASES_{ij}}{POP_j} \right) \cdot 100 \qquad (1)$$

In (1) *CASES* represents the number of cases diagnosed in a municipality, *POP* is the municipality's population, i = (1,2,3,4,5) refers to a particular IID (respectively: Amebiasis, IID from other protozoan pathogens, Giardiasis, Shigellosis, IID from rotavirus) and j = (1,…,2456) identifies a municipality. We obtained the data on IID cases diagnosed in 2010 from Mexico's federal health ministry (*Secretaría de Salud*) through a formal request to its epidemiological division (DGE, *Dirección General de Epidemiología*). Population data comes from the federal statistical agency's 2010 Census [2]. Following (1) we define the total IID morbidity rate for municipality j as:

$$IID_j = \sum_{i=1}^{5} y_{ij} \qquad (2)$$

In 2010 Mexican authorities recorded 579,280 IID cases nationwide. Amebiasis accounted for 80% of those cases and only 165 municipalities (6.7% of the total) did not report any IID case (Table 1).

Table 1. Number of IID cases diagnosed, summary statistics, 2010.

	Amebiasis y_1	***Other Prot.*** y_2	***Giardiasis*** y_3	***Shigellosis*** y_4	***Rotavirus*** y_5	***Total IID***
Cases (% of total)	462,767 (79.9)	81,065 (14.0)	20,677 (3.6)	11,367 (2.0)	3,404 (0.6)	579,280 (100)
Municipalities without cases (% of total)	225 (9.2)	894 (36.4)	1,348 (54.9)	1,418 (57.7)	2,059 (83.8)	165 (6.7)

With a total population of 112,336,538 inhabitants in 2010, the national IID morbidity rate amounted to 0.52%. The average of municipal morbidity rates (0.81%) surpassed that national figure considerably and reached a maximum value of 26.1%. Municipal morbidity rates for all five diseases show skewed distributions, with averages larger than medians (Table 2). Morbidity rates for all five diseases are positively but not strongly correlated; the highest correlation coefficient (0.25) is between Amebiasis and Shigellosis (Appendix 1).

Table 2. Morbidity rates (percentage of population), summary statistics, 2010.

		Amebiasis y_1	***Other Prot.*** y_2	***Giardiasis*** y_3	***Shigellosis*** y_4	***Rotavirus*** y_5	***Total IID***
National		0.41	0.07	0.02	0.01	0.00	0.52
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.67	0.10	0.02	0.02	0.01	0.81
Municipal	Median	0.33	0.02	0.00	0.00	0.00	0.46
	Maximum	25.74	3.75	0.59	1.26	3.30	26.10
	Stan. Dev.	1.19	0.26	0.05	0.07	0.11	1.28

We compute municipal residential water services indicators (x_{kj}) as:

$$x_{kj} = \left(\frac{h_{kj}}{H_j} \right) \cdot 100 \qquad (3)$$

In (3) k identifies a particular water services characteristic, h_{kj} is the number of homes in municipality j possessing such characteristic and H_j is the total number of homes in the municipality. We consider seven distinct water services characteristics, grouped into three main categories (Table 3). Note that in Mexico rooftop water tanks (with a capacity ranging typically from 600 to 1000 liters) are commonly used to mitigate deficiencies in the frequency of piped water supply; in the best case, homes are also equipped with a larger capacity underground cistern—hence our inclusion of the "Water reserve" category in Table 3.

Data from the aforementioned 2010 Census [2] show that access to residential water services in Mexico is varied and unequal. Of a total 28.1 million homes, 88% were reported to have access to piped water; in the remaining 3.2 million homes, residents had to fetch their water from an outside source. For homes with access to piped water, the quality of the service proved uneven: in many cases, access only consisted of an outside tap within property limits (the case of 5.2 million homes) and in more than a million homes, service was only sporadic i.e. water supplied less than one day per week on average. Access to wastewater disposal also presented notable disparities. Less than three quarters of homes had access to a public sewer system; 2.7 million homes were not equipped with any wastewater disposal system and for the remaining 5.1 million homes, this usually consisted of a pipe discharging directly outside property limits or less commonly, a septic tank.

Table 3. Residential water services characteristics.

	k	*Indicator*	*Definition*
Piped water	*1*	Water	Home with access to piped water
	2	Inside	Tap connection inside home
	3	Sporadic	Water supplied less than one day per week
Water reserve	*4*	Tank	Home equipped with rooftop tank
	5	Tank&Cis	Home equipped with rooftop tank and cistern
Wastewater disposal	*6*	Sewer	Home with some form of wastewater disposal
	7	Public	Home with access to a public sewer system

Municipal water services indicators in 2010 varied widely with respect to national averages. For example the percentage of homes with access to piped water inside the home stood at 69.5% nationwide, however in some municipalities this setup was non-existent and in others, almost universal (Table 4). Low correlations between most of the seven residential water services indicators reflect the great variety of water services configurations across municipalities (Appendix 2). Access to piped water inside the home (k = 2) and access to a public sewer system (k = 7) present the highest correlation coefficient (0.72) between any pair of indicators.

Table 4. Water services indicators (% of homes), summary statistics, 2010.

		Water x_1	*Inside* x_2	*Sporadic* x_3	*Tank* x_4	*Tank&Cis* x_5	*Sewer* x_6	*Public* x_7
National		88.2	69.5	4.3	32.4	13.2	90.3	72.1
	Minimum	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	Average	79.5	43.9	4.6	33.0	10.1	74.4	42.1
Municipal	Median	87.2	39.7	1.9	31.5	6.1	83.4	40.9
	Maximum	100	98.6	79.1	86.2	74.7	100	99.3
	Stan. Dev.	20.0	28.4	7.6	18.6	11.04	24.4	33.0

2.2. Methods

First we map municipal morbidity rates and residential water services indicators using a color-coded scheme in order to visualize the distribution of values across the country. Second we compute for each indicator Moran's *I*, the standard spatial autocorrelation statistics originally developed in Moran [7]:

$$I = \left(\frac{n}{S}\right)\frac{\sum_{j=1}^{n}\sum_{l=1}^{n} w_{jl} v_j v_l}{\sum_{j=1}^{n}\sum_{l=1}^{n} v_j v_l} \qquad (4)$$

In (4) v_j (v_l) is the value (expressed in deviation with respect to the mean) of a morbidity rate or residential water services indicator in municipality j (l), n is the number of municipalities (n = 2,456), w_{jl} is an element of a n x n matrix W of spatial weights ($w_{jl} = 1$ if j and l are neighbors, $w_{ij} = 0$ if not—the criterion we employ is "queen") and S is the sum of all elements in W. This exploratory analysis finishes with the production of *LISA* (*Local Indicators of Spatial Association*) cluster maps as proposed in Anselin [8]. Next the regression analysis begins with the following linear model:

$$Y = X\beta + \varepsilon \qquad (5)$$

In (5) Y is a 1xn vector of municipal morbidity rates, X a matrix of municipal water services indicators, β a vector of coefficients to be estimated and ε, a vector of residuals. We run several Ordinary Least Squares (OLS) regressions on (5) using distinct combinations of residential water services indicators and diagnose the residuals following the procedure established in Anselin et al. [9]. On the basis the diagnostic, we proceed with a spatial regression specified either as a spatial error model (6) or a spatial lag model (7):

$$Y = X\beta + \varepsilon \qquad (6)$$
$$\varepsilon = \lambda W\varepsilon + u$$

$$Y = \rho WY + X\beta + u \qquad (7)$$

In (6) and (7) respectively, λ and ρ are (scalar) parameters to be estimated and μ is a vector of residuals. Finally we consider an additional, alternate regression model. Municipal morbidity rates are either 0 or positive. We can thus think of an underlying, unobserved variable y^* (such as "lack of hygiene") driving the morbidity process. We therefore estimate the following classic version of the TOBIT model [10]:

$$
\begin{aligned}
y_{ij} &= y_{ij}^{*} \quad if \quad y_{ij}^{*} = 0 \\
y_{ij} &= y_{ij}^{*} \quad if \quad y_{ij}^{*} > 0 \qquad\qquad (8) \\
y_{ij}^{*} &= \sum_{k} \beta_k x_{kj} + e_j
\end{aligned}
$$

3. Results and Discussion

Municipal morbidity rates for aggregate IID and Amebiasis (Figures 1 and 2) appear spatially structured, with relatively low values predominating in the Central, Central-Western and Northern parts of the country and relatively high values concentrated mostly in the South. Municipal indicators for access to piped water inside the home and access to a public sewer system (Figures 3 and 4) show a similar but inverted pattern, with relatively high values predominating in the Central, Central-Western and Northern parts of the country and relatively low values mostly concentrated in the South.

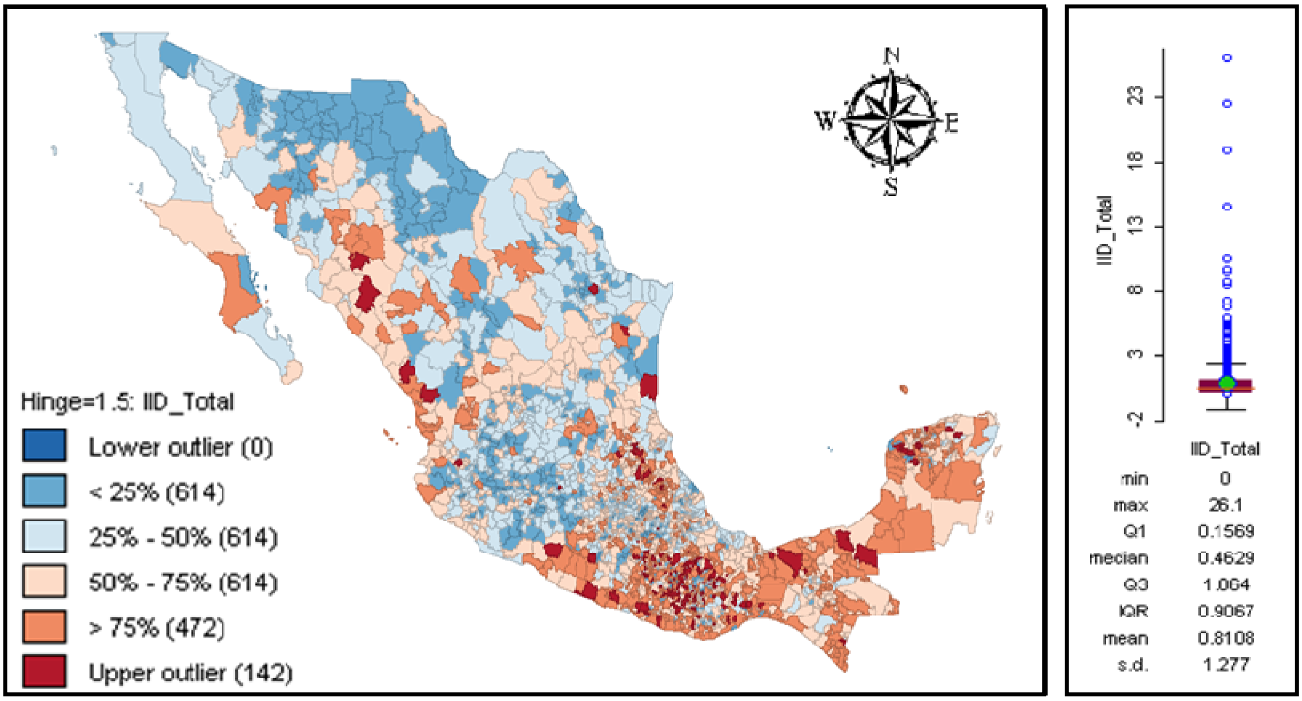

Figure 1. Municipal IID morbidity rates, map and box diagram.

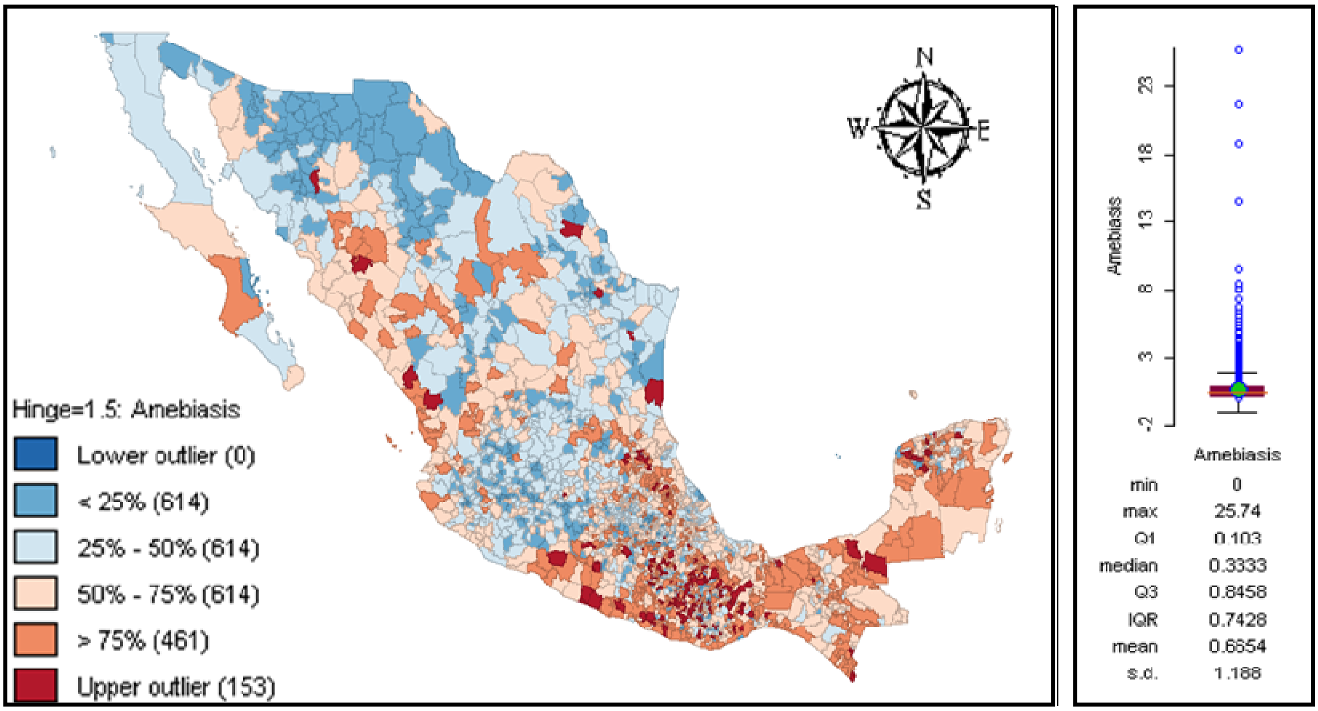

Figure 2. Municipal Amebiasis morbidity rates, map and box diagram.

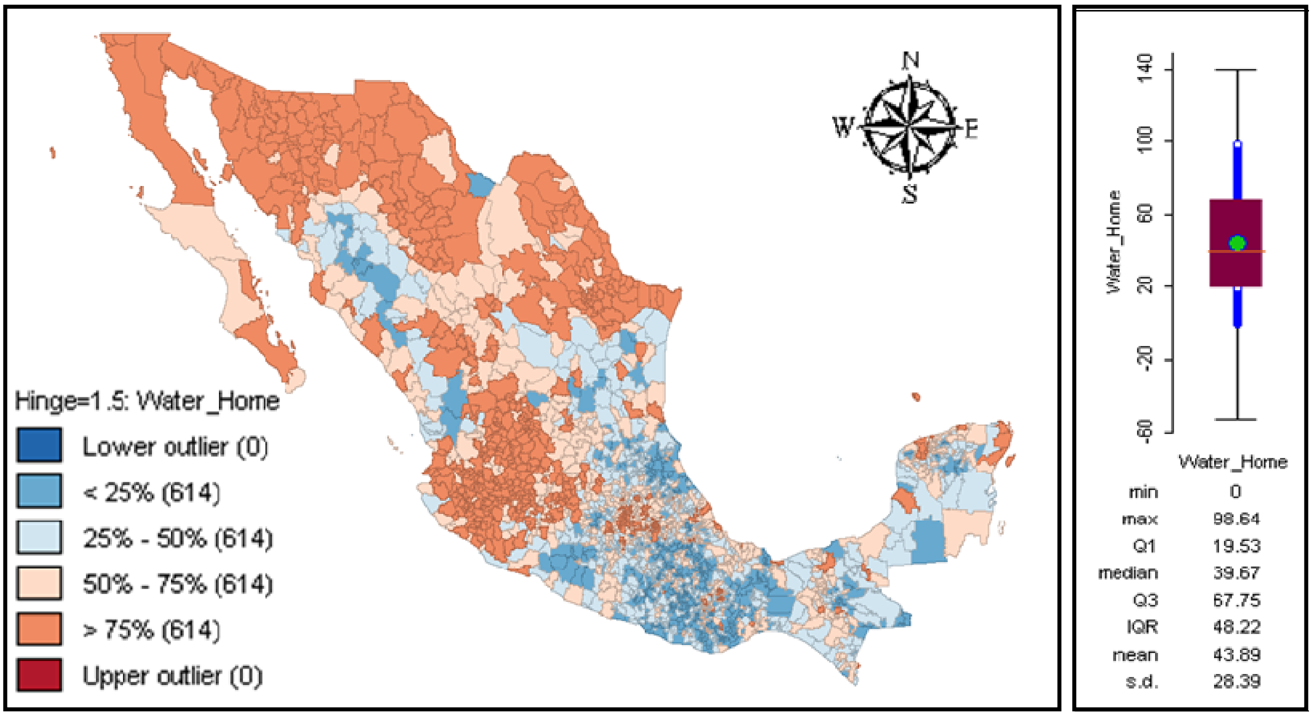

Figure 3. Access to piped water inside home (percentage of homes, by municipality), map and box diagram.

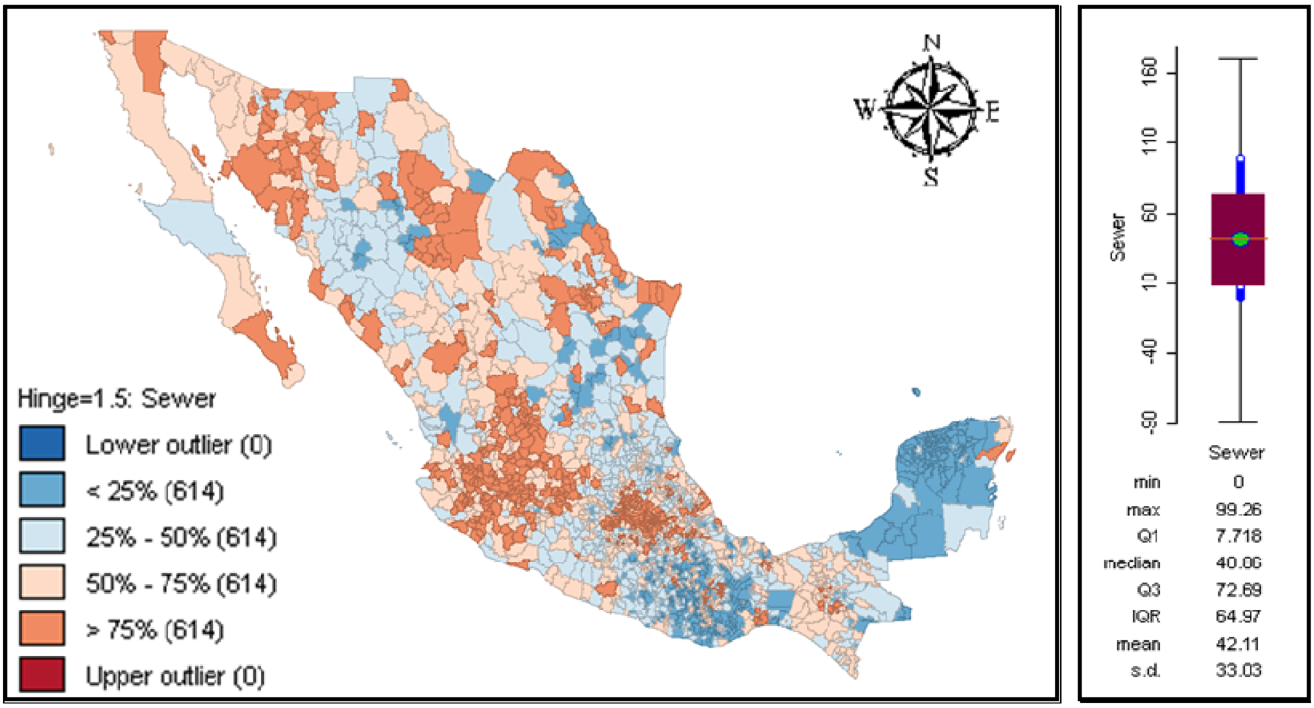

Figure 4. Access to a public sewer system (percentage of homes, by municipality), map and box diagram.

Moran's *I* statistic indicates the presence of significant spatial autocorrelation for all four variables (Table 4). In all four cases, spatial correlations are positive: municipalities tend to show values similar to neighboring municipalities–see for example Figure 5. LISA maps (Figures 6 to 9) reveal significant clusters of municipalities with relatively high (low) values for the four variables.

Table 4. Spatial autocorrelations (global).

	Moran's I	*z-value*	*p-value*
IID morbidity	0.1460	12.38	0.0001
Amebiasis morbidity	0.1297	10.84	0.0001
Access to piped water inside the home	0.7080	57.78	0.0001
Access to a public sewer system	0.6348	52.23	0.0001

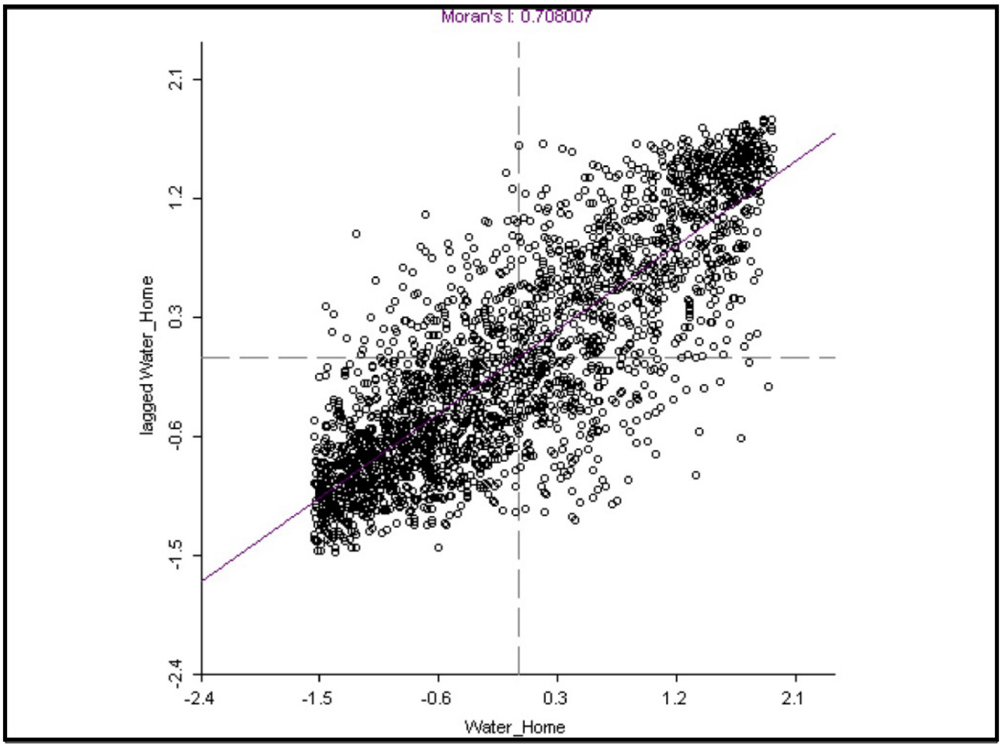

Figure 5. Piped water inside home, municipal values vs average of neighboring values.

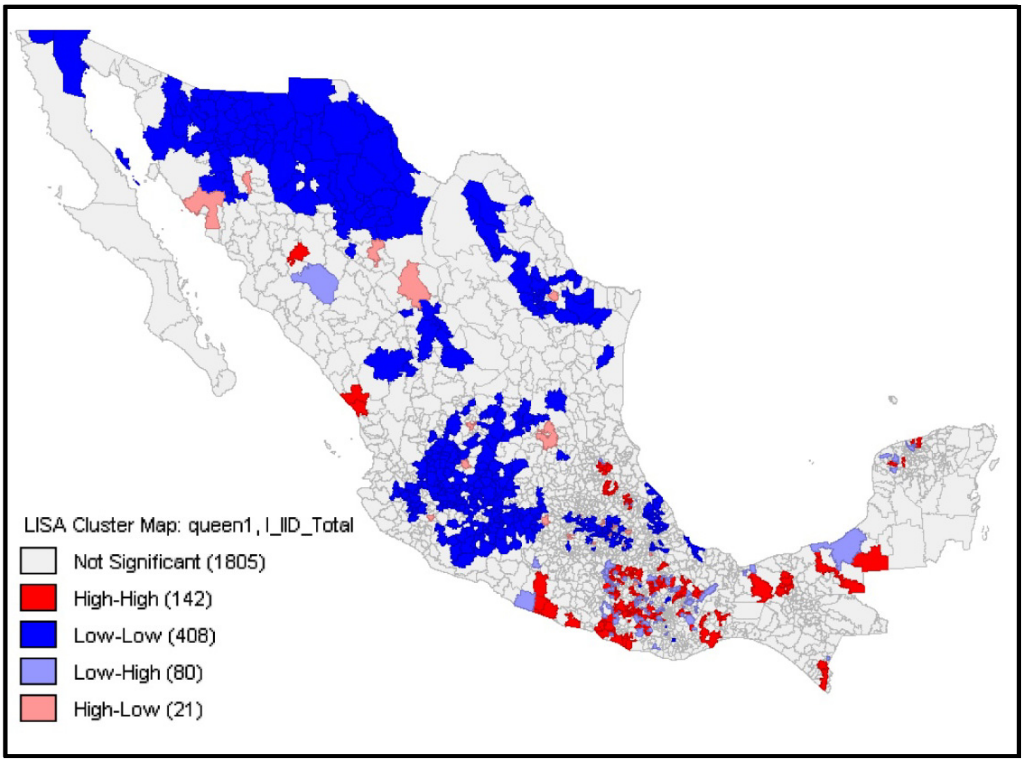

Figure 6. IID morbidity, *LISA* cluster map.

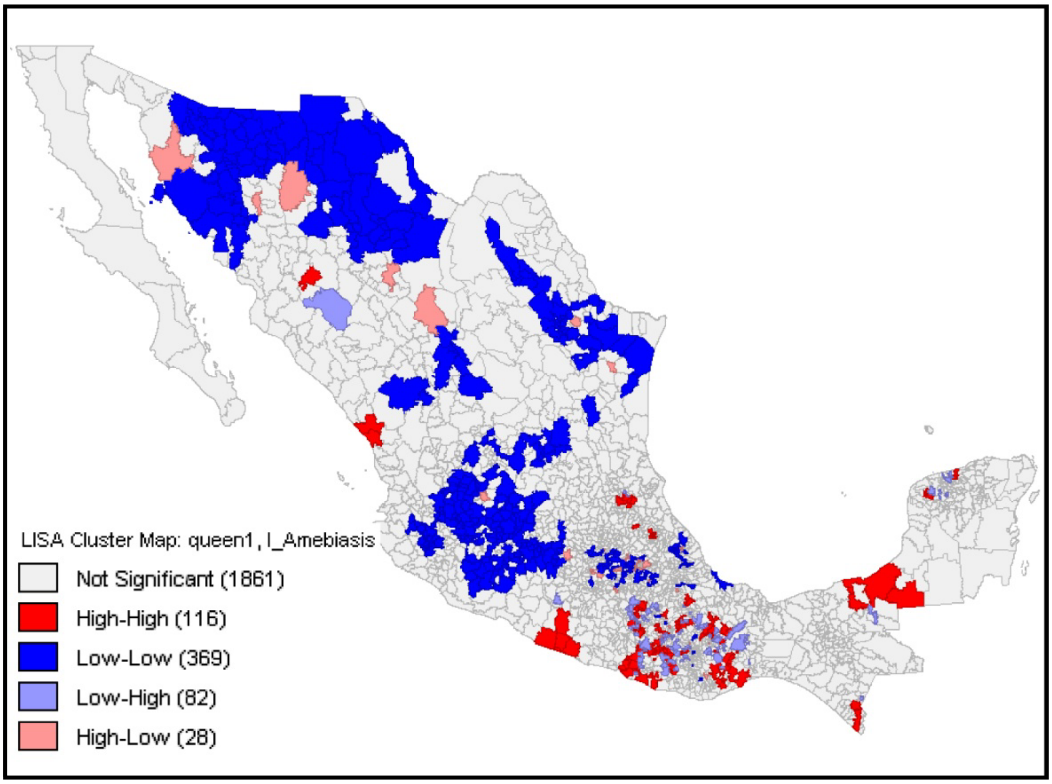

Figure 7. Amebiasis morbidity, *LISA* cluster map.

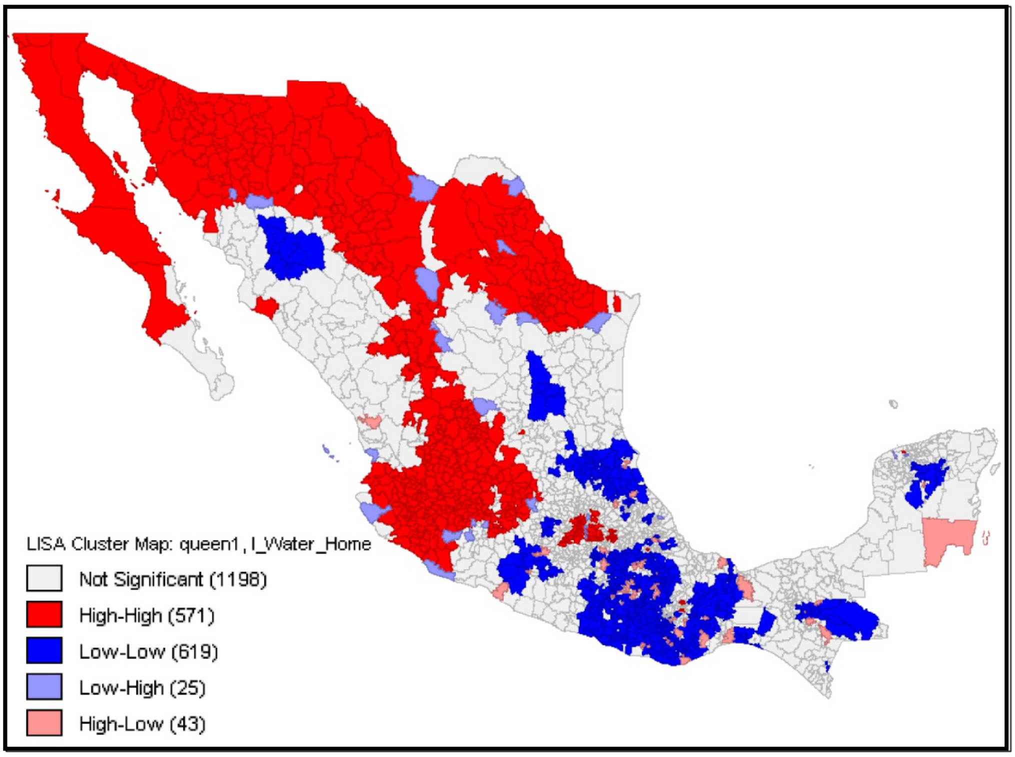

Figure 8. Access to piped water inside home, *LISA* cluster map.

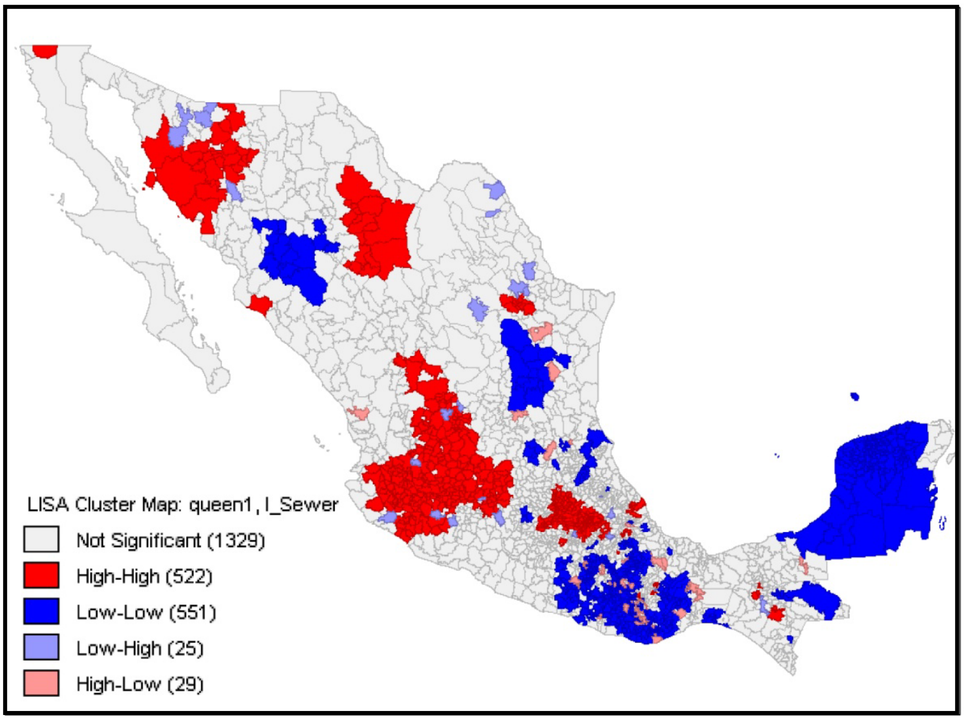

Figure 9. Access to public sewer system, *LISA* cluster map.

Regression results reveal several interesting patterns. The first set of OLS results suggests that for both IID and Amebiasis morbidity rates (Table 5 and Table 6), municipalities with higher rates of access to piped water and sewer services tend to show lower morbidity rates. In the case of piped water, the effect on morbidity is more powerful when considering specifically access inside the home as opposed to access in general (i.e. that includes access limited to an outside tap). In the case of wastewater disposal, there is no evidence that access to a public system provides any additional effect on morbidity compared to access in general (i.e. that includes alternative wastewater disposal such as septic tanks). The frequency of piped water supply is also relevant: municipalities with a higher percentage of homes where piped water is provided only sporadically tend to exhibit higher morbidity rates. Finally, municipalities with a higher percentage of homes equipped with both a rooftop tank and a cistern tend to show lower morbidity rates.

All regressions show modest levels of explanatory power. This should come as no surprise considering the inherently multi-factorial nature of disease-generating processes. Nevertheless, the high level of statistical significance as well as the magnitude of the effects of water services on morbidity rates measured here are notable. For example, the coefficient associated with access to piped water inside the home (regression 2, Table 5) yields an elasticity-at-means of 0.40. Applying this figure to national totals implies that an additional 281,000 homes with such access would have translated into approximately 23,000 fewer IID cases.

Spatial diagnostics for the OLS regressions confirm the presence of spatial auto-correlation and indicate that a spatial lag model as in (7) is the most appropriate. Estimated spatial regression coefficients do not differ appreciably from the original OLS estimates (Table 7). Finally, results from the TOBIT model (Table 8) show patterns of signs and significance in line with those previously described. Note that these coefficients hold a different interpretation than the previous ones, as they capture both the marginal effect of the associated independent variable on morbidity rates and the probability of a municipal morbidity rate being above 0. Overall, the weight of the evidence presented here suggests that our results are robust and reflect strong relationships among the variables considered.

Table 5. IID morbidity, OLS estimated coefficients (t-statistics) and spatial diagnostics.

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
Water x_1	-0.0034 (-2.43)**				
Inside x_2		-0.0075 (-5.85)***	-0.0062 (-4.61)***	-0.0066 (-5.04)***	-0.0073 (-6.11)***
Sporadic x_3			0.0083 (2.50)**	0.0102 (3.01)***	0.0095 (2.81)***
Tank x_4			-0.0026 (-1.77)*		
Tank&Cis x_5				-0.0068 (-2.69)***	-0.0073 (-2.88)***
Sewer x_6	-0.0093 (-8.04)***				-0.0033 (-2.35)**
Public x_7		-0.0038 (-3.43)***	-0.0039 (-3.55)***	-0.0032 (-2.75)***	
Constant x_0	1.78 (16.3)***	1.30 (28.0)***	1.30 (21.4)***	1.25 (24.3)***	1.41 (16.5)***
F (P-value)	55.8 (0.00)	79.0 (0.00)	42.1 (0.00)	43.2 (0.00)	42.6 (0.00)
R^2 (adjusted)	0.043	0.060	0.063	0.064	0.064
Log-likelihood	-4029.7	-4007.8	-4002.8	-4000.8	-4001.8
Lagrange- lag (P-Value)				50.37 (0.00)	52.57 (0.00)
Robust Lagrange- lag (P-Value)				54.90 (0.00)	42.80 (0.00)
Lagrange-error (P-Value)				32.86 (0.00)	36.99 (0.00)
Robust Lagrange-error (P-Value)				37.40 (0.00)	27.22 (0.00)

Confidence level (two-tailed test): *: > 90%; **: > 95%; ***: > 99%.

Table 6. Amebiasis morbidity, OLS estimated coefficients (t-statistics) and spatial diagnostics.

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
Water x_1	-0.0030 (-2.26)**				
Inside x_2		-0.0066 (-5.51)***	-0.0054 (-4.33)***	-0.0058 (-4.79)***	-0.0062 (-5.52)***
Sporadic x_3			0.0064 (2.06)**	0.0081 (2.56)**	0.0075 (2.38)**
Tank x_4			-0.0027 (-1.93)*		
Tank&Cis x_5				-0.0061 (-2.56)**	-0.0062 (-2.63)***
Sewer x_6	-0.0081 (-7.44)***				-0.0030 (-2.28)**
Public x_7		-0.0030 (-2.91)***	-0.0031 (-2.98)***	-0.0024 (-2.25)**	
Constant x_0	1.50 (14.8)***	1.08 (24.91)***	1.09 (19.3)***	1.05 (21.7)***	1.19 (14.9)***
F (P-value)	47.9 (0.00)	65.3 (0.0)	34.9 (0.00)	35.6 (0.00)	35.6 (0.00)
R^2 (adjusted)	0.037	0.050	0.052	0.053	0.053
Log-likelihood	-3861.0	-3844.3	-3840.1	-3838.7	-3838.6
Lagrange (lag) (P-Value)				43.51 (0.00)	44.19 (0.00)
Robust Lagrange (lag) (P-Value)				44.62 (0.00)	36.97 (0.00)
Lagrange (error) (P-Value)				29.93 (0.00)	31.86 (0.00)
Robust Lagrange (error) (P-Value)				31.05 (0.00)	24.64 (0.00)

Confidence level (two-tailed test): *: > 90%; **: > 95%; ***: > 99%.

Table 7. Spatial regressions, estimated coefficients (t-statistics).

	IID		***Amebiasis***	
	(1)	(2)	(3)	(4)
ρ (Lag)	0.241 (8.14)***	0.238 (8.03)***	0.228 (7.64)***	0.227 (7.61)***
Inside x_2	-0.005 (-4.52)***	-0.005 (-3.89)***	-0.004 (-4.17)***	-0.004 (-3.73)***

Sporadic x_3	0.009 (2.72)***	0.009 (2.86)***	0.007 (2.29)**	0.007 (2.43)**
Tank&Cis x_5	-0.006 (-2.51)**	-0.006 (-2.43)**	-0.005 (-2.36)**	-0.005 (-2.35)**
Sewer x_6	-0.002 (-1.79)*		-0.002 (-1.76)*	
Public x_7		-0.002 (-1.88)*		-0.001 (-1.58)
Constant x_0	1.062 (11.58)***	0.949 (15.5)***	0.914 (10.7)***	0.807 (14.52)***
Log-likelihood	-3974	-3974	-3819	-3815

Confidence level (two-tailed test): *: > 90%; **: > 95%; ***: > 9 9%.

Table 8. Tobit regressions, estimated coefficients (asymptotic t-statistics).

	IID			***Amebiasis***		
	(1)	(2)	(3)	(1)	(2)	(3)
Inside x_2	-0.0066 (-6.28)***	-0.0059 (-5.52)***	-0.0061 (-6.21)***	-0.0063 (-5.99)***	-0.0056 (-5.32)***	-0.0056 (-5.66)***
Sporadic x_3		0.0079 (2.85)***	0.0074 (2.68)***		0.0068 (2.45)**	0.0064 (2.30)**
Tank&Cis x_5		-0.0043 (-2.08)**	-0.0043 (-2.10)**		-0.0035 (-1.65)*	-0.0032 (-1.54)
Sewer x_6			-0.0025 (-2.21)**			-0.0025 (-2.16)**
Public x_7	-0.0022 (-2.50)**	-0.0019 (-2.03)**		-0.0017 (-1.87)*	-0.0014 (-1.52)	
Constant x_0	0.97 (23.8)***	0.93 (20.9)***	1.05 (14.7)***	0.83 (20.6)***	0.80 (18.0)***	0.91 (12.8)***
Log-likelihood	-4001.1	-3995.8	-3995.4	-3835.3	-3831.5	-3830.3

Confidence level (two-tailed test): *: > 90%; **: > 95%; ***: > 99%.

4. Conclusions

Lack of access to residential water services and IID morbidity both pose a problem throughout Mexico. Deficiencies in the provision of the services as well as morbidity rates however do not occur randomly across the country; on the contrary, both exhibit clear spatial structures. The clusters of municipalities sharing similar levels of access to water services and morbidity rates we identify here, point to the need for national policies that explicitly address these spatial features. Taking into account specific problem spots—which typically spill over state, municipal and other administrative boundaries–would increase the effectiveness and efficiency of interventions. Furthermore investment programs should not focus solely on expanding basic access to residential water services: as our results indicate, the quality of access also matters. In the process of expanding basic access (where sparse) and improving the quality of access (where deficient), efforts required to maintain the level of access (where already acceptable) would also need to be kept up.

Our results suggest that improving access to residential water services in Mexico would lower the incidence of common ailments and thus free up scarce medical resources - note that Amebiasis is practically unheard of in Canada, the U.K., Singapore and other countries with universal access to high-quality water services. For the affected, a case of IID typically requires two days of rest with the associated loss of productivity, income and other opportunities this implies. Reducing morbidity would therefore have a positive impact on people's welfare in general. Beyond providing evidence in favor of the public health and welfare case for improving residential water services, this study offers a concrete example of how inequality of opportunity (access to residential water services) translates into inequality of outcome (health). As such it ties into a current and broader policy discussion about inequality where the traditional focus on income distribution has evolved to include equality of opportunity [11].

Clearly residential water services represent an essential input for hygiene and cleanliness in homes and thus public health. Improving the quality of residential water services however may not be sufficient for eradicating IID in the Mexican context, where millions of people have never experienced reliable, indoor-plumbing piped water and thus may not have formed the habits (such as frequent hand washing) that are necessary for hygiene and disease prevention. Taking this cautionary note into account, public education focused on informing people on how to best take advantage of their water services could therefore prove an important component of the solution to the present public health problem. The water services-health-public education nexus deserves attention and presents opportunities for research that could enrich the design of public policy interventions.

Conflict of Interest

The authors declare they have no conflicts of interest in this article.

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