BMC Public Health

RESEARCH

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Structural factors of disability and ageing: spatial patterns in Mexico

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Abstract

Background Mexico is undergoing rapid population ageing, but its pace and intensity vary markedly across regions. This process unfolds amid deep social and economic inequalities, particularly in rural and marginalized areas where limited access to healthcare and social protection increases the risk of chronic disease, disability, and dependence.

Objective To examine how demographic ageing, socioeconomic, and health conditions relate to disability prevalence among older adults at the municipal level, emphasizing the structural and territorial factors that constrain healthy ageing.

Methods Using data from the 2020 Population and Housing Census and 2015–2019 mortality records, a municipal composite ageing index was developed to capture both the magnitude and structure of ageing. Spatial analytical techniques—Moran's I, Local Indicators of Spatial Association (LISA), and Geographically Weighted Regression (GWR)—were applied to identify spatial dependence and local variation.

Results Bivariate Moran's I indicated limited global autocorrelation between ageing and disability, but LISA revealed pronounced local clusters. Ageing was more advanced in northern and central Mexico, whereas disability concentrated in the south and southeast. Lower educational attainment, reduced social protection coverage, and greater socioeconomic disadvantage were linked to highter disability prevalence.

Conclusions The findings show that ageing and disability are spatially patterned outcomes shaped by long-standing territorial inequalities. Recognizing these spatial dynamics is key to designing regionally differentiated, place-based public health and social policy responses that promote equitable ageing in Mexico.

Keywords Demographic ageing, Disability, Spatial analysis, municipality, Social inequalities

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Background

Latin America is undergoing one of the fastest populations ageing processes globally, driven by declining fertility rates and increasing life expectancy [1]. However, the pace, timing, and consequences of this transition are uneven, reflecting persistent socioeconomic inequalities, institutional fragmentation, and contrasting demographic histories across countries. These regional asymmetries have important implications for health systems, long-term care, and social policy, particularly in contexts where ageing occurs alongside limited welfare protection and high levels of structural vulnerability [2, 3].

Mexico, one of the largest and most unequal countries in the region, is no exception; population ageing is progressing at a moderately accelerated rate—like Peru, Colombia, and Ecuador, where fertility has declined to fewer than 2.5 children per woman and the proportion of older adults ranges between 10 and 14% [1]. According to the 2020 census, the national population reached 126 million inhabitants, of whom 12% (15 million) were aged 60 or older, and projections estimate that by 2070 this will reach 34.2% (48.4 million) [4, 5]. Although life expectancy has increased and individuals are expected to live an additional 21.8 years, yet only 16.1 of those years are likely to be lived in good health [6]. This gap is partly explained by cumulative social and economic disadvantages across the life course, including the high prevalence of obesity, chronic disease, and limited access to prevention and timely healthcare, which manifest in premature mortality, disability, and functional dependence [7–10]. Ageing in Mexico therefore unfolds within a context of deep socioeconomic and territorial inequality particularly among older adults in marginalized settings [10–12]. These disparities reinforce the need for spatially oriented approaches to study ageing and disability.

Previous research has shown that mortality and morbidity in Mexico follow clear spatial patterns strongly associated with social disadvantage. Southern states, for example, show persistent place-based marginalization and excess mortality [13, 14]. Inequalities in access to healthcare and social security are likewise spatially concentrated in municipalities with greater structural disadvantage [14]. The fragmentation of the Mexican healthcare system exacerbates these territorial disparities: although most older adults are nominally covered by some form of public or social security insurance, catastrophic out-of-pocket expenditures remain common (Salinas-Escudero et al., 2019). In 2020, 37.9% of adults aged 65 and over lived in poverty, more than half (55.7%) relied exclusively on non-contributory pensions, and only one-third (33.1%) received contributory pension benefits [15].

Spatial studies in related areas—i.e. analyses of mortality, service distribution, and social exclusion—have demonstrated the analytical value of territorial approaches for identifying clustering and structural inequality [16]. However, research explicitly examining the spatial patterns of disability among older adults in Mexico is limited, and when available, it seldom incorporates sociodemographic correlates (e–g-education, social security, Indigenous status) or links disability with broader structural determinants. These gaps constrain the understanding of how disability patterns intersect with place-based disadvantages and limit the development of targeted social and health policies [13, 14, 17, 18].

This study addresses these gaps by providing the first nationwide spatially disaggregated analysis of ageing and disability among older adults across Mexican municipalities. Empirically, it generates new evidence on the geography and magnitude of disability, showing how demographic, socioeconomic, and institutional contexts shape diverse ageing experiences. Conceptually, it highlights ageing as a spatial and relational process shaped by place-based inequalities, offering a framework for integrating place-based equity into ageing and disability research and for informing regionally differentiated public health and social policy strategies.

By adopting a spatial approach, the study uncovers patterns of concentration and distribution of disability among older adults and examines how structural factors—such as social marginalization, healthcare fragmentation, and demographic dynamics—vary across municipalities [17–20]. Accordingly, the study analyzes how population ageing, together with socioeconomic and health conditions, relates to disability prevalence among older adults at the municipal level in Mexico, and examines the structural factors that constrain healthy ageing.

Methods

Sources

For this analysis, we used data from the 2020 Population and Housing Census, including both the basic and extended questionnaires. The basic questionnaire was administered to all households in Mexico, while the extended questionnaire was applied to a nationally representative sample stratified by federal entity, municipality, and for all localities with 50,000 or more inhabitants. The unit of analysis was the municipality; therefore, data were aggregated for the 2,469 municipalities in Mexico in 2020. In addition, open data from Registry of Deaths (2015–2019) from the National Institute of Statistics and Geography (INEGI, by its Spanish acronym) were used to construct mortality indicators associated with disability. The final analytic sample consisted of 2,469 municipalities with complete information for all variables included

in the spatial and regression analyses. No municipalities were excluded due to missing data.

Variables

Disability measurement

Disability was measured at the municipal level using data from the 2020 Mexican Population and Housing Census, which included a battery of questions based on the Washington Group Short Set (WG-SS) and the International Classification of Functioning, Disability and Health (ICF) framework [21, 22]. Following international standards, we operationalized disability among older adults as the percentage of individuals aged 60 years and over who reported having great difficulty or being unable to perform at least one of the following activities: seeing, hearing, walking, remembering or concentrating, bathing, dressing or eating, and speaking or communicating [23]. This indicator captures functional decline directly associated with dependency in old age and allows for comparability across populations. To account for potential life-course effects and accumulated disadvantages, we also included as an explanatory variable the prevalence of disability among individuals under age 20. This measure reflects early-onset functional limitations and serves as a proxy for contextual and structural factors that may contribute to higher disability prevalence in older ages [24]. The inclusion of this variable allows testing whether municipalities with higher rates of disability in youth also exhibit higher disability among older adults, thus capturing intergenerational and structural dimensions of health inequality.

To facilitate descriptive territorial comparisons and identify structural gradients in the distribution of disability, municipalities were classified into quintiles according to the percentage of the population aged 60 years and older with disabilities. Each quintile represents approximately 20% of municipalities, from the lowest to the highest disability prevalence. This descriptive grouping enables the examination of demographic, socioeconomic, and epidemiological profiles across different levels of disability, providing an empirical basis for understanding the heterogeneity of ageing and health conditions in Mexico. The use of quintiles, rather than absolute thresholds, was justified by the absence of standardized benchmarks for disability prevalence and the significant variability in population size and age structure among municipalities.

Demographic variables: composite ageing index

A Principal Component Analysis (PCA) was applied to construct a Composite Ageing Index from two standardized variables: the natural logarithm of the absolute number of people aged 60 and over, and the ageing ratio (population aged 60 + divided by the population aged 0–14). The first principal component accounted for 65.1% of the total variance, effectively capturing both the magnitude and structural dimension of demographic ageing at the municipal level. The correlation between the two variables was –0.2862, indicating a moderate and complementary relationship between the absolute concentration of older persons and their relative proportion within the population. This composite index offers a nuanced and spatially consistent representation of territorial variations in ageing and demographic dependency [25]. The composite ageing index was designed to integrate both the magnitude and the structural dimension of population ageing across municipalities. While the ageing ratio (population aged 60 + to population aged 0–14) captures the relative ageing of the population, it does not reflect the absolute concentration of older persons residing in each area—an important factor for understanding the potential scale of social and health care needs. The inclusion of the natural logarithm of the absolute number of people aged 60 and over enables differentiation between municipalities with similar ageing ratios but very different population sizes, which may face distinct challenges regarding infrastructure, service provision, and demographic dependency. Rather than merely controlling population size, this approach provides a synthetic measure that integrates demographic intensity and structure, offering a more nuanced and spatially coherent understanding of ageing patterns across the territory. The PCA-based index was strongly correlated with a simple unstandardized composite index (log60 + + ageing ratio)/2) ($r = 0.77$), indicating that both measures capture a similar underlying ageing dimension, confirming its robustness and interpretative consistency.

Sociodemographic, socioeconomic, and health variables

Regarding the characteristics of the older population, we considered several indicators that capture demographic vulnerability and social protection. These included the percentage of individuals aged 60 and over living alone, a condition associated with reduced access to informal care networks and greater risk of social isolation and functional decline [26, 27]. To assess formal access to healthcare, we included the percentage of older adults affiliated with social security institutions, such as the Mexican Social Security Institute (IMSS), the Institute for Social Security and Services for State Workers (ISSSTE), Petróleos Mexicanos (Pemex), the Secretariat of National Defence (Sedena), and the Secretariat of the Navy (Semar). Social security affiliation has been shown to mitigate health vulnerability and reduce mortality risk among older adults in Mexico [14, 28]. Educational attainment was represented by the percentage of older adults without schooling, given the consistent association between low education and increased disability, dependency, and cognitive decline [29]. To capture the degree

of social protection, we incorporated the percentage of households with at least one older adult receiving government support and the percentage reporting pension or retirement income. These indicators reflect the coverage of income-transfer and social protection programs that buffer economic vulnerability and care deficits in later life [10].

At the socioeconomic level, we included the labor force participation rate among individuals aged 12 years and over, as an indicator of local economic activity and productive inclusion [30]. We also considered the proportion of the population aged three years and over who speak an Indigenous language, as a proxy for sociocultural diversity and structural disadvantage, given the persistent inequities faced by Indigenous groups in health and ageing outcomes [31]. The municipal marginalization index, developed by the National Population Council [32], was also included (The marginalization index was standardized so that higher values correspond to less marginalization*)*. These variables capture structural and cultural dimensions of inequality that shape the environments in which older adults age. Additionally, we incorporated the inter-municipal internal immigration rate, which reflects territorial mobility and demographic renewal processes that influence both the composition of local populations and the distribution of social and health resources. This indicator was derived from the 2020 Population and Housing Census, which explicitly defines internal migration based on residence change within the five years prior to the census for individuals aged five years and older. This variable captures demographic dynamics that can affect local ageing structures, social support systems, and the spatial allocation of public services [20, 26].

To integrate an epidemiological dimension, we included mortality-related indicators spanning the life course. Specifically, we considered the percentage of deaths among adults aged 20 years and over and among those aged 60 years and over that were attributable to conditions strongly associated with disability [8]. Due to instability in the estimates for small municipalities, mortality rates were not computed at the municipal level [33]. These included diabetes mellitus [E100–E140], ischemic heart disease [I200–I250], chronic kidney disease [N170–N190], Alzheimer's disease and dementias [F01, F03X, G300], cerebrovascular diseases [I600–I690] and chronic obstructive pulmonary disease [J400–J440], among others classified under the ICD-10 framework. Mortality indicators were calculated as the five-year average (2015–2019) to minimize annual variability and ensure greater stability in municipal estimates [8].

All data processing and indicator construction were conducted using Stata version 18 and GeoDa. Taken together, this set of variables integrates demographic, socioeconomic, and epidemiological dimensions to capture the multifaceted contexts in which older adults live, situating disability within the broader territorial and structural inequalities that shape ageing in Mexico.

Data analysis

The analytical strategy was designed to capture the spatial heterogeneity of ageing and disability across Mexican municipalities and to identify the contextual factors that shape these patterns. The dependent variable was the prevalence of disability among adults aged 60 years and older, while explanatory variables included the demographic, socioeconomic, and health indicators described above. All analyses were conducted at the municipal level, and findings are interpreted as contextual associations, not individual-level inferences.

Spatial dependence and clustering

We first examined the spatial structure of the data to assess the extent of geographic dependence between municipalities. To evaluate the overall spatial association of each variable, we calculated Global Moran's I, which measures whether similar values cluster in space. Although some variables showed modest global autocorrelation, this does not preclude the existence of meaningful local clusters. Therefore, we used Local Indicators of Spatial Association (LISA) to identify statistically significant groupings of municipalities with similar or contrasting values.

A queen contiguity spatial weight matrix of first order was applied, defining municipalities as neighbors when they share a border [34]. Both univariate and bivariate LISAs were estimated. The univariate LISA identified spatial clusters of high and low disability prevalence, while the bivariate LISA explored the co-location between disability and selected explanatory variables, such as the composite ageing index, the marginalization index, and the proportion of older adults covered by social security. This approach allowed us to visualize spatial interdependencies and reveal how disability prevalence is embedded within broader territorial structures rather than random spatial distribution.

Spatial regression modeling

In the second stage, we implemented a set of spatial regression models to examine how demographic, socioeconomic, and health factors are associated with disability prevalence across the territory. Three complementary models were used:

1. Ordinary Least Squares (OLS) – a baseline model assuming spatial independence.
2. Spatial Error Model (SEM) – which accounts for spatial autocorrelation in residuals, correcting

potential bias when neighboring municipalities share unobserved characteristics.

3. Geographically Weighted Regression (GWR) – which captures spatial non-stationarity, allowing the strength and direction of associations to vary locally across municipalities.

Model selection was based on a set of diagnostic statistics, including the Akaike Information Criterion corrected (AICc), Lagrange Multiplier (LM) tests, residual Moran's I, and Variance Inflation Factors (VIFs) to assess multicollinearity. The spatial models improved the explanatory power and model fit compared with the global OLS regression, underscoring the relevance of spatial processes in explaining municipal variation in disability.

Model specification

The general specification of the regression model is expressed as follows:

$$\begin{aligned}\text{Disability60+}_i = \beta_0 &+ \beta_1(\text{Composite Ageing Index})_i \\ &+ \beta_2(\text{Socioeconomic Indicators})_i \\ &+ \beta_3(\text{Health Indicators})_i + \varepsilon_i\end{aligned}$$

where i denotes the municipality, and ε_i represents the spatially correlated error term.

In the GWR model, the coefficients $\beta_k(u_i, v_i)$ vary by geographic location (u_i, v_i), reflecting the longitude and latitude of each municipality. This formulation captures local heterogeneity by estimating how the strength and direction of associations differ across space rather than assuming uniform effects throughout the country.

The results from the OLS, SEM, and GWR models were compared to examine both global and local associations. GWR outputs were mapped to visualize the spatial variation of coefficients and local R^2 values, highlighting regions where the explanatory variables had greater or lesser influence. Interpretation focused on spatial associations rather than causal relationships. For example, municipalities with higher disability prevalence frequently coincided with areas characterized by low social security coverage, high marginalization, and larger proportions of Indigenous populations. These findings reflect structural and contextual inequalities embedded in the Mexican territory, emphasizing the importance of considering space as a key analytical dimension in ageing and disability research.

Results

The analysis of 2,469 municipalities revealed consistent territorial gradients in ageing and vulnerability (Table 1). Municipalities with higher disability prevalence among adults aged 60 and older were smaller, less urbanized, and more demographically aged (16.7% vs. 13.0% in the lowest quintile). Educational and social disparities intensified along this gradient: the proportion of older adults without schooling increased from 25.9% to 34.9%, while social security coverage declined from 31.2% to 14.9%. Dependence on public support programs rose sharply (49.1% to 68.8%), reflecting a shift from contributory to non-contributory protection mechanisms. Labor force participation decreased (55.2% to 48.4%), and higher disability prevalence coincided with greater Indigenous presence and higher marginalization. A strong association between disability in youth and in older ages suggests intergenerational accumulation of structural disadvantages. Mortality indicators showed minimal variation across municipalities. This limited variability may be partly explained by the aggregation of mortality into broad age categories and by survival selection processes, in which individuals with more severe chronic conditions may not survive to older ages at equal rates across regions. This suggests that late-life disability is shaped less by current mortality patterns and more by cumulative social and structural inequities over the life course (Table 1).

Spatial distribution of population ageing and disability in older adults in Mexico

The descriptive analysis revealed marked spatial heterogeneity in demographic ageing and disability among older adults across Mexican municipalities. As shown in Fig. 1A, the Composite Ageing Index highlights higher concentrations of older persons in northern and central regions, as well as in specific areas of the south such as Chiapas, Yucatán, Campeche and Quintana Roo. In contrast, disability prevalence shows a distinct territorial configuration, with the highest levels concentrated in the south and southeast—particularly in Guerrero, Chiapas, and Oaxaca (Fig. 1B). These patterns indicate that ageing and disability do not necessarily progress in parallel and may reflect different underlying structural and territorial conditions rather than purely demographic processes (Fig. 1).

Global and local spatial association

To assess the extent of spatial dependence, univariate Moran's I statistics were calculated for all variables. All indicators showed positive and statistically significant spatial autocorrelation, indicating a tendency for similar values to cluster geographically rather than being randomly distributed. The bivariate Moran's I coefficients (Table 2) revealed generally low global correlations between disability prevalence and explanatory variables (values close to zero). This does not imply

Table 1 Municipal indicators grouped by quintile disability prevalence among adults aged 60 and over

Characteristics		Level Population 60 + with disability					
		Total	1 st Quintile (0–18.2%)	2nd Quintile (18.2- 21.5%)	3rd Quintile (21.5–25.0%)	4th Quintile (25.0–29.5%)	5th Quintile (29.5–77.7%)
Number of municipalities	**N**	**2469**	**494**	**494**	**494**	**494**	**493**
Municipal demographic indicators							
Population Total	Mean (s)	51,038 (146,991)	94,401 (215,566)	78,321 (206,598)	46,128 (106,429)	24,888 (48,422)	11,375 (20,684)
	(min, max)	(81, 1,922,523)	(81, 1,692,181)	(356, 1,922,523)	(296, 1,173,351)	(229, 779,566)	(113, 190,885)
Population 60 + (absolute)	Mean (s)	6133 (18,423)	11,641 (29,439)	8,847 (22,865)	5,586 (14,050)	3076 (6108)	1507 (2454)
	(min, max)	(26, 262,064)	(26, 238,500)	(75, 262,064)	(71, 203,469)	(48, 107,218)	(28, 21,087)
Population 60 + (%)	Mean (s)	14.3 (5.0)	13.0 (4.9)	13.3 (4.4)	13.8 (4.1)	14.5 (4.7)	16.7 (5.7)
	(min, max)	(0.7, 38.2)	(0.7, 38.2)	(3.1, 34.4)	(3, 36.7)	(3.9, 32.8)	(6.1, 37)
Population 0–14(%)	Mean (s)	27.5 (4.4)	26.8 (5.2)	27.6 (4.3)	27.7 (3.9)	27.9 (4.3)	27.7 (4.3)
	(min, max)	(2.3, 48.4)	(2.3, 46.3)	(16.3, 45.2)	(17.2, 44.3)	(14.5, 48.4)	(14.4, 42.8)
Composite ageing index	Mean (s)	0 (1.0)	0.2 (1.1)	0.3 (0.9)	0.2 (0.8)	0.9 (0.0)	−0.6 (1.1)
	(min, max)	(−5.9, 1.6)	(−5.9, 2.1)	(−3.7, 2.4)	(−4.0, 2.2)	(−5.0, 1.7)	(−5.9, 1.6)
Internal migration rate	Mean (s)	21.9 (18.6)	21.7 (22.1)	19.8 (17.3)	21.9 (20.3)	21.0 (15.0)	25.0 (17.0)
	(min, max)	(0,266.9)	(0,196.9)	(0.4, 143.2)	(0.7, 266.9)	(0.0,122.0)	(0.8,121.1)
Indicators related to the older adult population (60 +)							
Living alone (%)	Mean (s)	13.8 (4.0)	12.8 (5.0)	13.3 (3.7)	13.5 (3.4)	14.0 (3.4)	15.2 (4.1)
	(min, max)	(2.4, 44.2)	(2.7, 44.2)	(4.5, 27.5)	(4.5, 27.6)	(4.3, 28.8)	(2.4, 32.3)
With social secury (%)	Mean (s)	24.8 (21.2)	31.2 (23.1)	30.4 (22.4)	26.6 (20.9)	21.1 (18.9)	14.9 (15.5)
	(min, max)	(0, 87.3)	(0, 87.3)	(0, 86.3)	(0, 83.2)	(0, 84.3)	(0, 80.5)
Without schooling (%)	Mean (s)	30.1 (18.6)	25.9 (20.7)	27.3 (17.7)	29.3 (17.3)	33.2 (17.6)	34.9 (17.8)
	(min, max)	(0, 95.7)	(0, 95.7)	(0, 88.9)	(3.2, 91.9)	(1.9, 93.1)	(3, 90.5)
Receive support (%)	Mean (s)	58.2 (14.8)	49.1 (16.7)	54 (13.7)	57.3 (12.3)	61.7 (11.6)	68.8 (10.7)
	(min, max)	(0, 93.8)	(0, 93.8)	(21.9, 91.9)	(18.4, 88.5)	(28.6, 93)	(34.8, 93.4)
Municipal socioeconomic indicators							
Labor participation Rate 12 + (%)	Mean (s)	53.3 (9.7)	55.2 (10.1)	55.5 (8.4)	54.5 (9)	53.1 (9.5)	48.4 (9.8)
	(min, max)	(13.1, 77.5)	(14.4, 77.5)	(24.6, 74.5)	(13.1, 73.7)	(18.9, 72.8)	(17, 73.1)
Marginalization Index	Mean (s)	53.9 (3.9)	55.3 (4.2)	54.7 (3.9)	54.1 (3.8)	53.2 (3.6)	52.2 (3.1)
	(min, max)	(21.4, 62.4)	(32.2, 62.4)	(21.4, 61.1)	(28.2, 60.1)	(37.8, 59.9)	(31.3, 58.4)
Population speaking an Indigenous language (%)	Mean (s)	42 (3.0)	4.5 (3.8)	4.0 (2.9)	4.2 (3.3)	4.0 (2.3)	4.5 (2.4)
	(min, max)	(0, 35.6)	(0, 28.6)	(0.1,19.6)	(0.3, 35.6)	(0.5, 23.3)	(0.4, 21.1)
Health, disability, and mortality indicators							
Population 0–20 with disability (%)	Mean (s)	6.1 (2.2)	4.7 (1.8)	5.5 (1.7)	6.0 (1.7)	6.4 (1.9)	7.8 (2.6)
	(min, max)	(0, 21.7)	(0, 11.9)	(1.6, 13.1)	(1.5, 12.8)	(2, 19.7)	(2.8, 21.7)
Causes of death 60 + associated with disability (%)	Mean (s)	38.7 (10.2)	38.5 (9.8)	39.4 (9.0)	39.2 (9.0)	39.4 (9.6)	37.1 (12.9)
	(min, max)	(0, 85.7)	(0, 70)	(0, 71.4)	(0, 66.7)	(0, 66.7)	(0, 85.7)
Causes of death 20 + associated with disability (%)	Mean (s)	34.4 (8.9)	33.8 (8.3)	34.7 (7.7)	34.7 (7.8)	34.9 (8.6)	33.8 (11.7)
	(min, max)	(0, 87.5)	(0, 66.7)	(10, 64.3)	(0, 60.5)	(0, 61.9)	(0, 87.5)

Source: Authors' elaboration using Population and Housing Census 2020 and mortality records 2015–2019 (INEGI)

spatial randomness but rather suggests that global averages mask local heterogeneity.

The univariate LISA maps (Fig. 2A–B) identified significant clusters of municipalities with high values of ageing surrounded by others with similar characteristics (high–high), concentrated in central and southern Mexico and in specific parts of the north. Conversely, low–low clusters were predominant in the northern and southern regions, reflecting younger demographic structures. Regarding disability (Fig. 2B), high–high clusters were concentrated in Oaxaca and Guerrero, while low–low clusters were observed in northern and central states, consistent with their lower disability prevalence.

When exploring bivariate LISA associations, the results revealed distinct regional configurations. The ageing–disability relationship showed clusters of municipalities with high disability and advanced ageing across the north, center, and south—indicating that disability is

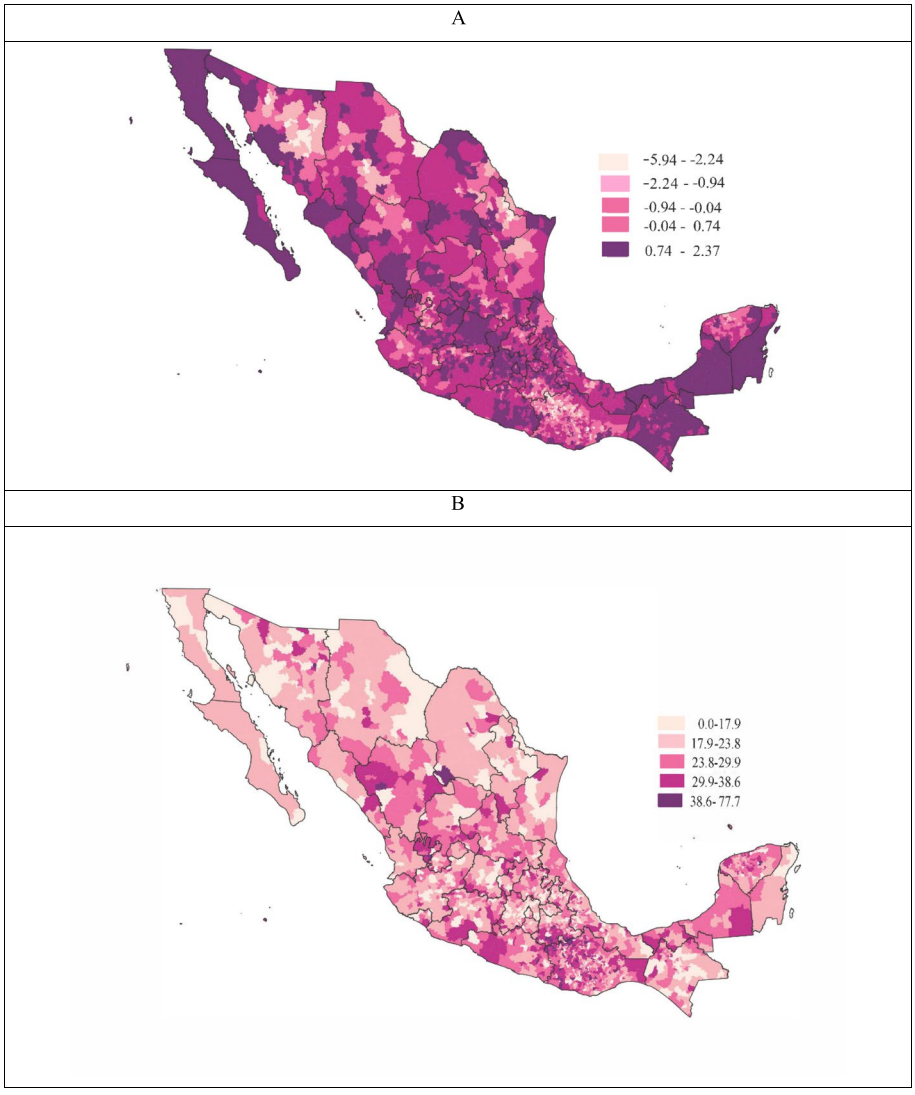


Fig. 1 Composite Ageing Index (**A**) and Percentage of Older Adults with Disability (**B**) among municipalities of Mexico, 2020. Source: Authors' elaboration using Population and Housing Census 2020 (INEGI)

not exclusively concentrated in older regions, but also where socioeconomic disparities persist (Fig. 3A). Conversely, municipalities with incipient ageing but high disability were concentrated in the southeast, suggesting that disability in those areas may arise from early-life disadvantage rather than demographic ageing. The disability–marginalization relationship showed high–high clusters mainly in southern Mexico, where deprivation and disability coexist, while low–low clusters dominated the more prosperous northern corridor (Fig. 3B). These results confirm that structural inequalities shape spatial clustering, rather than individual mobility or migration between neighboring municipalities. The identified clusters reflect shared historical and institutional conditions within states and regions.

Spatial regression models

To further examine these spatial relationships, we estimated three regression models: OLS, SEM, and GWR (Table 3). The OLS model provided baseline, while the SEM corrected for residual spatial dependence, and the GWR captured local variability in coefficients. Model diagnostics supported the inclusion of spatial effects. The AICc value decreased substantially from OLS to SEM and GWR, and the adjusted R^2 increased from 0.41 to 0.46, indicating improved fit. Residual Moran's I confirmed that spatial autocorrelation was successfully mitigated in the SEM and GWR models. Across models, several consistent patterns emerged: 1) The Composite Ageing Index exhibited a weak negative association in the global model, though local estimates in the GWR indicated positive associations in some municipalities; 2) The percentage of individuals under 20 with disability displayed

Table 2 Exploration of spatial relationship between Percentage of Older Adults with Disability and explanatory variables

Variables	Moran´s I Univariate	Moran´s I Bivariate (p60 + with disability)
Composite Ageing Index	0.567	−0.186
Pob. < 20 with disability (%)	0.248	0.175
Pob. 60 + who live alone (%)	0.532	0.158
Pob. 60 + with social security (%)	0.617	−0.221
Pob. 60 + without schooling (%)	0.678	0.153
Household where pob. 60 + with receive support (%)	0.694	0.296
Total Labor Participation Rate	0.209	−0.204
Indigenous population (%)	0.709	0.091
Marginalization Index	0.647	−0.217
Inter-municipal Immigration (rate)	0.381	−0.096
Causes of death 60 + associated with disability (%)	0.228	−0.047
% Causes of death 20 + associated with disability (%)	0.223	−0.023

Source: Authors' elaboration using Population and Housing Census 2020 and mortality records 2015–2019 (INEGI)

a strong and positive relationship with disability in older ages ($\beta = 1.46$, $p < 0.001$ in OLS), confirming the intergenerational transmission of structural disadvantage; 3) Higher proportions of older adults without schooling and of households receiving support were positively associated with disability, indicating that educational and economic vulnerability reinforce dependency risks; 4) Indigenous population share and marginalization index exhibited negative coefficients, which reflect that municipalities with higher marginalization values (i.e., lower socioeconomic conditions) correspond to greater disability prevalence—this inverse sign arises because the marginalization index was standardized such that lower values indicate worse living conditions; 5) Inter-municipal internal migration rate was positively associated with disability ($\beta \approx 0.04$, $p < 0.05$ in SEM), suggesting that areas experiencing population turnover may face service discontinuities that heighten vulnerability among older residents and 6) Mortality due to chronic diseases associated with disability displayed mixed effects, with disability among adults aged 20 + showing a small positive relationship and mortality among those 60 + a negative one, reflecting differences in survival and disease burden across age groups. Overall, the spatial models indicate that structural and demographic characteristics jointly explain spatial variation in disability, and that these associations are not spatially uniform.

Local model performance and spatial heterogeneity (GWR)

The GWR model revealed substantial spatial non-stationarity in the relationships between disability prevalence and its determinants. Local coefficients varied markedly across municipalities, delineating distinct spatial regimes. Stronger positive associations between the composite ageing index and the lack of formal education were observed in the central and northeastern regions, where advanced population ageing overlaps with long-standing socioeconomic disadvantages. Similarly, the positive effects of inter-municipal migration on disability prevalence were more pronounced in urbanized northern areas, likely reflecting transformations in demographic composition and care structures.

In contrast, the share of the Indigenous population exhibited stronger negative associations in the southern states, where ethnicity often coincides with higher poverty levels but also with dense community networks that may mitigate some aspects of disability reporting. The local R^2 surface indicates that the model achieved the best fit in the central and northeastern regions and the weakest in the southern municipalities, suggesting that explanatory variables account for spatial variation unevenly across the territory. This pattern implies that additional contextual factors, including healthcare accessibility, environmental exposures, or local governance capacity, may play a greater role in shaping disability outcomes in the southern regions (Fig. 4).

Discussion

This study demonstrates that ageing and disability in Mexico are strongly influenced by socio-spatial inequalities. The coexistence of more advanced ageing in the northern and central regions, alongside higher disability prevalence in the south and southeast, indicates that place functions as a structural determinant of ageing and health outcomes. These territorial patterns are not the result of individual mobility or random variation, but instead reflect long-standing historical differences in economic development, health system capacity, and access to social protection and infrastructure. Similar findings have been reported in other Latin American contexts, where territorial inequalities amplify vulnerability in older age and reinforce disadvantage across generations [10, 13, 14].

These spatial patterns are consistent with findings from high-income settings. For example, Canadian research shows pronounced spatial clustering of older adult vulnerability, with significant hot and cold spots for low income, immigrant, and foreign-language 65 + populations, and concentrated pockets of 85 + residents requiring greater support [35].

The results challenge the notion that disability among older adults simply mirrors demographic ageing. Although the cross-sectional design does not allow causal inference or individual life-course tracking, the association between disability in youth and disability in

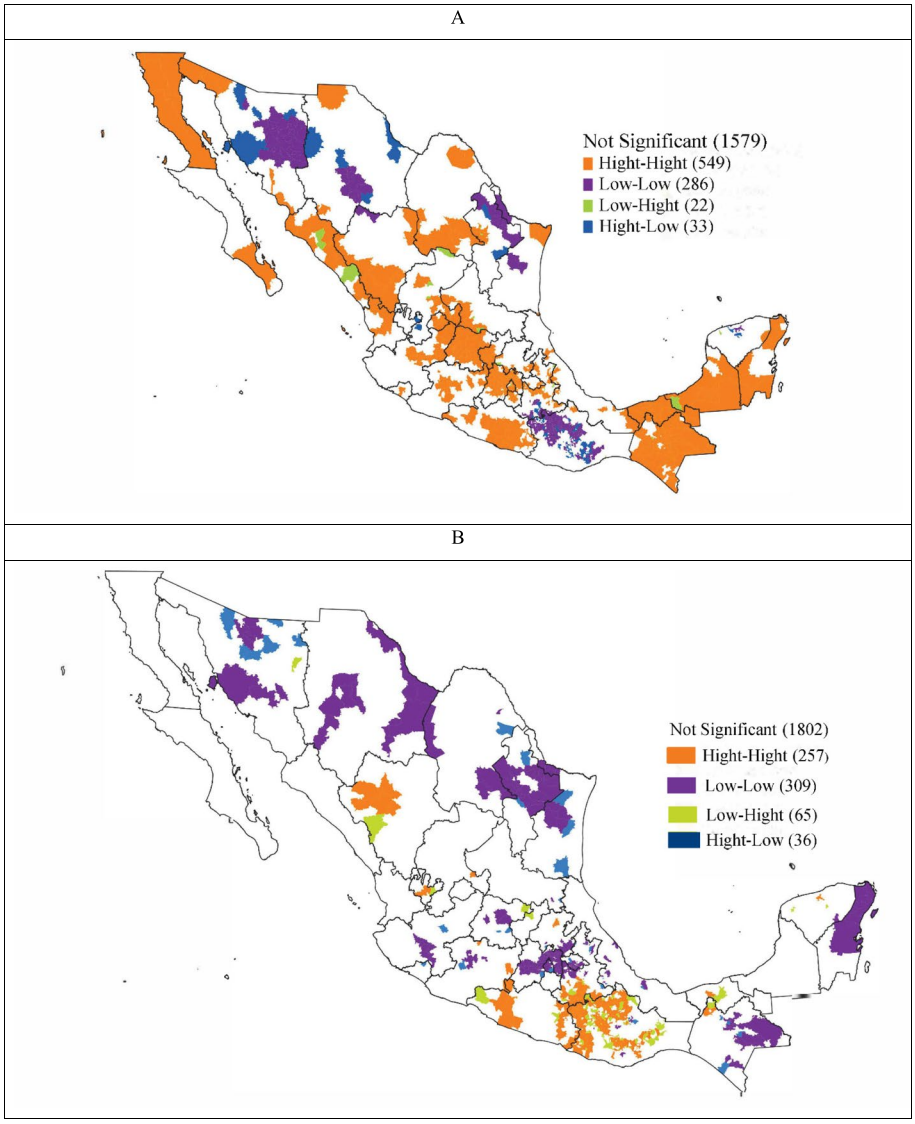


Fig. 2 Spatial Clusters of Composite Ageing Index (**A**) and Percentage of Older Adults with Disability (**B**) among municipalities of Mexico (Univariate LISA). Source: Authors' elaboration using Population and Housing Census 2020 (INEGI)

later life suggests that structural disadvantage may accumulate across generations [24].

Spatial analysis revealed low global but significant local autocorrelation, with clusters of high disability and deprivation concentrated in southern states and low-disability clusters in the north. These patterns do not indicate spatial diffusion; rather, they reflect shared structural and policy environments across neighboring municipalities, where institutional capacity and long-standing contextual factors produce spatially correlated outcomes. The GWR results further highlight regional heterogeneity in how ageing, education, labor participation, and indigeneity relate to disability. Positive associations between ageing and disability are strongest in the central and northeastern regions, where demographic ageing intersects with persistent socioeconomic inequality. In contrast, some southern municipalities show weaker or negative associations, possibly reflecting differences in disability reporting, cultural practices, or the buffering role of community-based support networks.

Together, these findings suggest the presence of distinct regional regimes of ageing and disability, challenging the effectiveness of uniform or standardized policy approaches. Conceptually, ageing must be understood as a spatially situated process shaped by distribution of resources, services, and opportunities [36]. Policy responses should therefore incorporate spatial equity into ageing and disability strategies. Northern and central areas with advanced ageing require strong investment in long-term care and social participation, whereas southern regions with high disability but younger demographic profiles may benefit more from early-life interventions

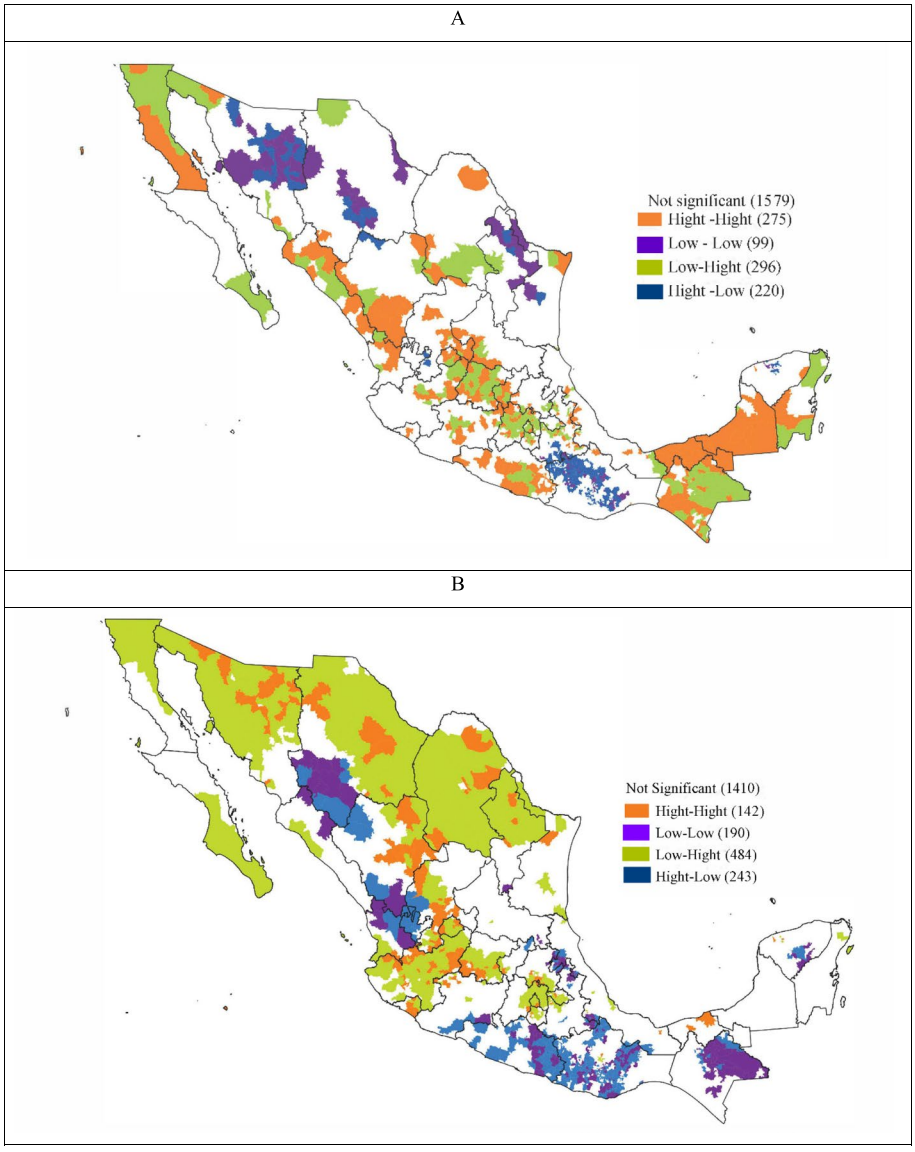


Fig. 3 Spatial overlap between percentage of older adults with disability and structural factors among municipalities of Mexico: Composite Ageing Index (**A**) and Marginalization Index (**B**). (Bivariate LISA). Source: Authors' elaboration using Population and Housing Census 2020 (INEGI)

targeting health, education, and employment. Recognizing territorial diversity is essential to building more equitable health and social care systems. This study uses nationally representative census data at the municipal level, allowing for a fine-grained assessment of spatial inequality. By integrating demographic, socioeconomic, and institutional variables with spatial analytical techniques (Moran's I, LISA, GWR) it provides robust empirical evidence of how structural conditions shape disability in later life. This multi-scalar approach strengthens the analytical contribution and enhances the relevance of the findings for place-based interventions and policy design.

Nonetheless, this study has limitations. Its cross-sectional design prevents causal interpretation, and the reliance on self-reported disability may introduce reporting heterogeneity across regions and cultural groups. Future studies should incorporate longitudinal and multilevel approaches to better connect individual characteristics with contextual determinants and to observe temporal changes in spatial inequalities. Despite these constraints, the findings demonstrate that space is an active dimension of inequality and is essential to understanding and addressing ageing and disability in Mexico.

Conclusion

This study makes three main contributions. Methodologically, it demonstrates the value of spatial analytical techniques for revealing local heterogeneity linked to structural determinants of health. Empirically, it provides the first municipal-level evidence on how ageing and

Table 3 Estimated results from the ordinary least square (OLS), spatial error model (SEM) and Geographically Weighted Regression (GWR) for percent of older adults with disability among municipalities of Mexico, 2020

	OLS		SEM		GWR	
Variables	**Coef**	**Sig**	**Global Coef**	**Sig**	**Local Coef**	**Sig**
Constant	25.8	0.000	0.000	0.000	0.018	0.237
Composite Ageing Index	−0.58	0.002	0.016	0.537	0.043	0.084
Pob. < 20 with disability (%)	1.46	0.000	0.353	0.000	0.377	0.108
Pob. 60 + who live alone (%)	0.03	0.360	0.024	0.213	0.043	0.081
Pob. 60 + with social security (%)	0.01	0.129	−0.010	0.669	−0.079	0.092
Pob. 60 + without schooling (%)	0.04	0.000	0.097	0.000	0.031	0.137
Household where pob. 60 + with receive support (%)	0.10	0.000	0.338	0.000	0.264	0.119
Total Labor Participation Rate	−0.02	0.281	−0.024	0.266	−0.036	0.064
Population speaking an Indigenous language (%)	−0.07	0.000	−0.262	0.000	−0.304	0.186
Marginalization Index	−0.27	0.000	−0.153	0.000	−0.187	0.173
Inter-municipal Immigration (rate)	0.10	0.028	0.040	0.030	0.045	0.077
Causes of death 60 + associated with disability (%)	−0.10	0.001	−0.085	0.041	−0.061	0.185
Causes of death 20 + associated with disability (%)	0.11	0.001	0.085	0.040	0.083	0.192
AIC	15,555.45		5904.395		5656.827	
Log-likelihood	−7764.727		−2939.197		−2649.920	
R-squared	0.408		0.367		0.499	

Source: Authors' elaboration using Population and Housing Census 2020 and mortality records 2015–2019 (INEGI)

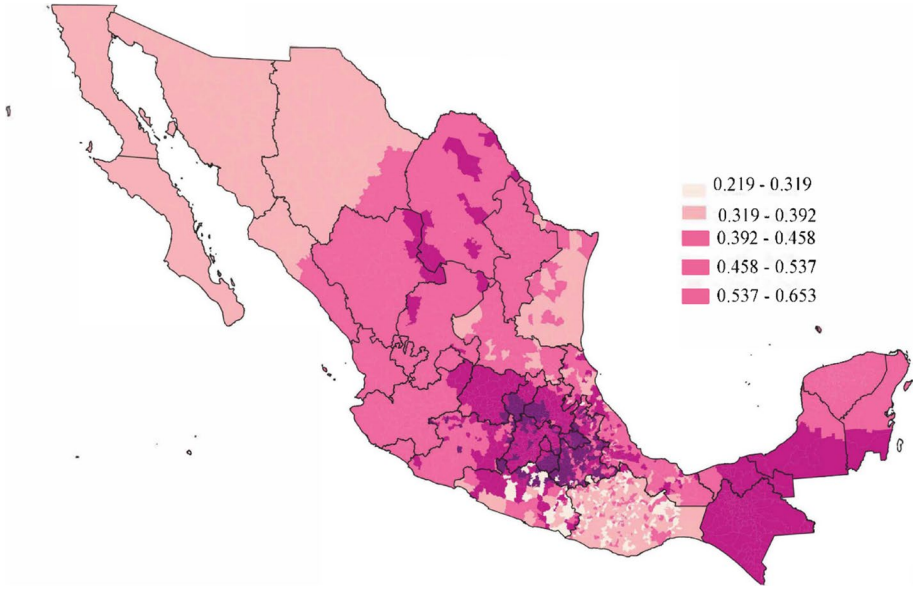


Fig. 4 Geographically Weighted Regression: Local Model Fit (Local R^2). Source: Authors' elaboration using Population and Housing Census 2020 and mortality records 2015–2019 (INEGI)

disability intersect among older adults in Mexico, uncovering regional regimes that national analyses overlook. Conceptually, it advances debates on the understanding of ageing as a spatial and relational process, offering a framework that can inform policy design across other similar contexts.

The findings have significant implications for policy. They call for greater place-based sensitivity in the design and implementation of public health, social welfare, and long-term care policies. National governments play a central role in enabling this by providing the legislative, financial, and institutional powers that allow regional and municipal authorities to act effectively. A coherent multilevel approach is therefore essential, in which national frameworks set the conditions for equity while local and regional policymakers and health systems translate these into place-based solutions. Regional and municipal actors, therefore, have a crucial role to play in developing and advocating for place-based strategies that strengthen local capacities, improve service accessibility, and promote equitable ageing trajectories. A spatially informed approach to ageing research and policy-design therefore

becomes not a constraint but an opportunity to better understand long-term inequalities and their effects in their context, appreciate diversity, and support adaptive local governance and health systems that foster social justice across the life course.

Ultimately, understanding that *space matters* opens the possibility for rethinking ageing not merely as a biological or demographic stage, but as a social and place-based process; a shared part of life that, if we are fortunate, we will all experience. For this reason, we must strive to make it a more equitable and enabling experience for everyone, regardless of where they live.

Abbreviations

AICc	Corrected Akaike Information Criterion
GWR	Geographically Weighted Regression
ICD-10	International Classification of Diseases, 10th Revision
INEGI	National Institute of Statistics and Geography
IMSS	Mexican Social Security Institute
ISSSTE	Institute for Social Security and Services for State Workers
LISA	Local Indicators of Spatial Association
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
Pemex	Petróleos Mexicanos (Mexican State-owned Petroleum Company)
Sedena	Secretariat of National Defense
Semar	Secretariat of the Navy
SEM	Spatial Error Model
WG-SS	Washington Group Short Set

Acknowledgements
Not applicable.

Authors' contributions
Research idea and study design: REGCH, DTP; data acquisition: REGCH, DTP; analysis/interpretation: REGCH, DTP, JVG, KR, CGP; statistical analysis: REGCH, DTP; manuscript drafting: REGCH, DTP, JVG, KR, CGP; supervision or mentorship: CGP. Each author contributed important intellectual content during manuscript drafting or revision and accepts accountability for the overall work by ensuring that questions pertaining to the accuracy or integrity of any portion of the work are appropriately investigated and resolved.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The publication of this article was supported by the National Institute of Geriatrics, Mexico.

Data availability
The microdata and index analyzed during the current study are publicly available from official sources: —**Sample expanded questionnaire of the 2020 Population and Housing Census (CCPV-2020)** — microdata available at [https://www.inegi.org.mx/programas/ccpv/2020/#microdatos](https://www.inegi.org.mx/programas/ccpv/2020)—**Death Registry (Estadística de Defunciones Registradas)** — microdata available at [https://www.inegi.org.mx/programas/edr/#microdatos](https://www.inegi.org.mx/programas/edr)—**2020 Marginalization Index (Índice de Marginación 2020)** produced by the National Population Council (CONAPO) — available at https://www.gob.mx/conapo/documentos/indices-de-marginacion-2020-284372 These datasets and indices can be accessed through the respective official platforms of INEGI and CONAPO.

Declarations

Ethics approval and consent to participate
Ethical approval was not required for this study as it is a secondary analysis of anonymized, publicly available microdata and derived indices from official statistical sources. This research is based on secondary analysis of microdata from the sample expanded questionnaire of the 2020 Population and Housing Census and the Death Registry (Estadística de Defunciones Registradas), both produced by the National Institute of Statistics and Geography (INEGI, Mexico), as well as the 2020 Marginalization Index produced by the National Population Council (CONAPO), which is derived from census information. Data collection for the census and death registers was conducted by INEGI in accordance with the National Standards of Ethics for members of the National System of Statistical and Geographic Information and the Law of the National System of Statistical and Geographic Information of Mexico, which safeguard the rights, freedoms, and inherent dignity of individuals throughout the processes of data collection, processing, and dissemination.
Informed consent was obtained by INEGI from all participants at the time of primary data collection, in accordance with Articles 20–22 of the Law on the Protection of Personal Data and Articles 12–20 of the Law of the National System of Statistical and Geographic Information.

Consent for publication
Not applicable. This study is based on anonymized secondary microdata and derives indicators from public statistical sources and does not include individual-level identifiable information.

Competing interests
The authors declare no competing interests.

Received: 1 July 2025 / Accepted: 22 December 2025
Published online: 03 January 2026

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