ORIGINAL ARTICLE

Spatial inequalities in child mortality due to poverty related diseases and material deprivation in Argentina, 2017–2022

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Abstract

Objectives: to analyze socio-territorial inequalities in child mortality due to poverty-related diseases in Argentina (2017–2022) and their association with household material deprivation (IPMH, 2022 Census), identifying critical territories through spatial analysis.

Methods: subnational ecological study (n=527 departments/districts). MONEP rates in children under 5 years were calculated as the annual average of deaths from poverty-associated causes per 100,000 population aged 0–4 years. Thematic maps, global spatial autocorrelation (Moran's I), local clusters (univariate and bivariate LISA), and spatial regression models (OLS/SAR/SEM/SDM) were estimated.

Results: significant positive spatial autocorrelation was observed for both MONEP (I=0.568; p<0.001) and IPMH (I=0.824; p<0.001). Bivariate LISA identified high–high (HH) clusters in 40 departments (7.6%), as well as discordant HL (3.4%) and LH (8.7%) patterns. Spatial models substantially improved model fit compared with OLS; the SAR model was selected as the principal specification (AIC=4049.3) based on parsimony and spatial diagnostic tests. In this model, IPMH remained positively and significantly associated with MONEP (β=0.060; p=0.022), while strong spatial dependence was also detected (ρ=0.732; p<0.001). Decomposition of spatial effects revealed an indirect spillover effect of 0.151, more than double the direct effect (0.072).

Conclusions: structural poverty is associated with higher child mortality from deprivation-related diseases, with territorially concentrated critical clusters. These findings support targeted interventions in HH areas and highlight the usefulness of subnational spatial analysis for evidence-based health planning.

Key words *Child mortality, Poverty, Spatial analysis, Social determinants of health, Argentina*

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Introduction

Inequalities in child health are one of the most persistent and unfair manifestations of social inequality. Although child mortality has declined steadily in Latin America over the past few decades, national averages tend to mask deep subnational disparities that stem from historically entrenched structural determinants, such as poverty, territorial fragmentation, and unequal access to essential goods and services.[1,2] Understanding these inequalities requires going beyond statistical descriptions and developing theoretical frameworks that account for the mechanisms that produce, reproduce, and concentrate them in specific territories.

The conceptual starting point of this study is the perspective on the social determinants of health systematized by the WHO Commission, according to which health inequities are the preventable result of historically produced and unequally distributed social conditions.[1] However, this general framework needs to be enriched with medium-range theories that specify the concrete mechanisms through which social structure translates into health inequalities. To that end, this study brings together two complementary analytical perspectives. The first is based on Link and Phelan's [3] theory of the "fundamental cause," which posits that socioeconomic status acts as a "cause of causes" and argues that its effect on health persists over time and across different diseases because those with greater material, symbolic, and social resources always find ways to protect themselves from emerging risks, whatever their nature may be at any given historical moment.[3] This theory has a crucial methodological implication, since the analysis of diseases specifically linked to deprivation, the so-called "diseases of poverty", allows for a more precise capture of the effect of socioeconomic status on mortality.

The second tradition is critical health geography, which conceptualizes territory not as a neutral container of social phenomena, but as a social product that in turn produces differential conditions of life and death.[4] Along these lines, Harvey argues that capitalism actively produces unequal geographies; the accumulation of capital and differential investment in infrastructure, services, and public goods generate territories with radically different opportunities for social and biological reproduction.[5] From this perspective, the departments in Argentina with accumulated structural deficits are not simply lagging areas on a development continuum, but rather territories whose current configuration reflects historical processes of unequal investment and differential allocation of public resources that have shaped their health, housing, and educational infrastructure. From this perspective, the spatial patterns of infant mortality and poverty reflect cumulative territorial processes that shape differential exposures to health risks.

This study analyzes socio-territorial inequalities in child mortality from poverty-related diseases in Argentina for the period 2017–2022, examining their association with the departmental incidence of the *Índice de Privación Material de los Hogares* (IPMH) (Household Material Deprivation Index), measured using data from the 2022 the *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census). Using a subnational approach and spatial autocorrelation techniques, the study seeks to identify critical areas where material deprivation and poverty-related child mortality are spatially concentrated. Unlike previous studies, this research integrates recent data with census indicators from the 2022 Census, combining bivariate LISA analysis and multivariate spatial modeling at the departmental/district level, using an approach that integrates the perspective of the social determinants of health, root cause theory, and territorial analysis of inequalities.

Based on this background and the adopted conceptual framework, two main hypotheses were proposed. First, it is expected that the departments/districts with the highest incidence of material deprivation will have higher rates of child mortality from poverty-related diseases, in line with the perspective of the social determinants of health and the theory of the fundamental cause. Second, it is hypothesized that this association will exhibit significant spatial dependence, consistent with the territorially structured nature of socio-health inequalities and with the existence of shared regional dynamics that transcend local administrative boundaries.

Background

At the regional level, the literature on subnational inequalities in child health in Latin America documents persistent patterns of territorial concentration that do not disappear as national averages decline. Various studies have shown that the gaps between central and peripheral regions in child mortality and malnutrition persist over time, associated with gradients of structural poverty, unequal access to health services, and poor environmental and housing conditions.[1,2] PAHO notes that, despite regional progress, subnational inequities in child mortality continue to reflect historical trajectories of unequal development, especially in rural and peripheral areas with lower levels of economic and health integration.[2]

In the specific field of spatial analysis of child health, studies conducted in Brazil, Mexico, and Colombia have incorporated spatial autocorrelation techniques and georeferenced modeling to identify clusters of child mortality and their association with subnational

socioeconomic determinants.[6,7,8] These studies agree that spatial dependence is a structural feature of the distribution of child mortality in contexts of high regional inequality, and that failing to account for it produces biased estimates of the association between poverty and health outcomes. The incorporation of spatial models -SEM (Spatial Error Model) and SAR (Spatial Autoregressive Model) -has demonstrated consistent improvements in model fit compared to ordinary regression models in this type of subnational ecological study.

In Argentina, the most directly relevant prior research comes from the line of work by Longhi and colleagues. Longhi, Bolsi, and Paolasso documented socioterritorial fragmentation and living conditions at the subnational level, identifying regions in the North- NOA and NEA -as those with the greatest accumulation of structural disadvantages.[9] Longhi *et al*.[10] analyzed the territorial distribution of child malnutrition at the regional, provincial, and departmental levels, revealing marked disparities between the North and South of the country that overlap with poverty indicators.[10] Longhi and Salazar Burgos[11] extended this analysis to the 2019–2020 period, confirming the persistence of critical patterns where nutritional deprivation and structural poverty converge.[11] However, these studies did not incorporate explicit spatial analysis at the departmental level nor did they use the 2022 Census's IPMH as an exposure indicator.

The present study aims to fill this gap. It analyzes socio-territorial inequalities in child mortality from poverty-related diseases in Argentina for the 2017–2022 period, examining their association with the departmental incidence of the IPMH (2022 Census) using bivariate LISA analysis and multivariate spatial modeling at the departmental/district level.

Methods

A subnational ecological study was conducted using a quantitative approach and a demographic-territorial perspective. The results were reported in accordance with the recommendations of the STROBE guidelines for observational studies.[12] From an epistemological perspective, the ecological design is not a limitation to be tolerated, but rather a methodological choice consistent with the premise that health inequalities are collective phenomena produced by social and territorial structures that cannot be reduced to individual attributes.[13] Consequently, the research question is explicitly territorial and population-based, focusing on the spatial distribution of deprivation and infant mortality rather than on the individual experience of each child.

Within this framework, the so-called "ecological fallacy", that is, the risk of inferring individual associations from aggregated data,must be rigorously distinguished from the analytical objective of the study, which focuses on socio-territorial patterns rather than on individual causal relationships.[14] This distinction is essential for properly interpreting the scope of the findings and their relevance to the analysis of structural health inequalities.[13,14]

The concept of "diseases of poverty," systematized by McKeown, refers to conditions historically linked to material deprivation, respiratory and diarrheal infections and malnutrition—and is distinct from the "diseases of wealth" that emerged with industrialization.[15] Within this framework, poverty does not act as a direct cause of death, but rather as a structural condition that shapes environments of differential exposure to risk.

In operational terms, following the International Classification of Diseases, Tenth Revision (ICD-10), MONEP included intestinal and diarrheal infectious diseases (A00–A09), acute respiratory infections (J00–J22), and the group of nutritional deficiencies and malnutrition (E40–E46, E50–E56, E58–E61, E63–E64), which are considered in the epidemiological literature to be causes historically associated with contexts of material deprivation and socio-environmental vulnerability. Aggregated microdata on mortality by underlying cause, age, and department/district of residence were obtained from the vital statistics databases of the *Programa Nacional de Estadísticas de Salud* (*Ministerio de Salud de la Nación*)(National Health Statistics Program (Ministry of Health of Argentina)), covering the period 2017–2022.

No reclassification or imputation was performed for deaths classified under ill-defined causes or nonspecific codes ("garbage codes"). The analysis included exclusively deaths of children under five years of age whose underlying cause of death was coded according to ICD-10 and was consistent with MONEP operational definition adopted in the study. Consequently, deaths recorded under categories of ill-defined symptoms, signs, and conditions were excluded from the numerator to preserve the epidemiological specificity of the indicator under analysis.

The spatial unit of analysis was the department/district (n=527). The mortality analysis period was 2017–2022, defined based on the availability and consistency of vital statistics in recent years. Aggregated, publicly available secondary sources were used. Deaths by cause and age were obtained from official vital statistics of the *Programa Nacional de Estadísticas de Salud* (National Health Statistics Program). The age structure of the population and indicators of material deprivation were obtained from the 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

However, subnational spatial analysis using administrative units has inherent limitations stemming from

the so-called Modifiable Areal Unit Problem (MAUP), which has been widely discussed in the literature on spatial epidemiology and quantitative geography.[16] In the case of Argentina, the departments/districts exhibit marked heterogeneity in population size, density, and area, which can affect the stability of rates and the identification of spatial patterns, especially in sparsely populated areas. Consequently, the results should be interpreted as territorial configurations observed at the administrative scale used and not as invariant patterns independent of the spatial aggregation unit.

The dependent variable was defined as the child mortality rate from poverty-related diseases (MONEP), operationalized as a subnational rate for children under five years of age, calculated as the ratio of the annual average number of deaths among children aged 0 to 4 from causes associated with poverty, respiratory, infectious, and malnutrition-related causes, during the 2017–2022 period, and the census population aged 0 to 4 years from the 2022 Census, expressed per 100,000 children. The use of annual averages reduced the random variability inherent in infrequent events in small areas; furthermore, the census denominator provides a stable basis for subnational calculations of the population exposed to risk for the reasons mentioned above.

To assess the robustness of the estimates in the face of potential temporal inconsistency between the numerator and denominator, a sensitivity analysis was conducted using an alternative specification of the population denominator based on an intercensal interpolation of the population aged 0–4 years for the 2019–2020 period. The rates obtained using both specifications were compared through descriptive and correlational analyses.

Furthermore, as mentioned earlier, the potential instability of the rates in small áreas, resulting from low event frequency and population differences between departments/districts, was taken into account. To reduce random variability, MONEP was estimated using annual mortality averages for the 2017–2022 period rather than individual annual values. Although empirical Bayesian smoothing or spatial smoothing procedures were not applied, these strategies represent a relevant methodological approach for future studies aimed to improve the stability of estimates in low-population areas.[17]

Given that the analyzed period includes the years of the COVID-19 pandemic (2020–2021), an additional sensitivity analysis was conducted by excluding those years from the mortality numerator and recalculating MONEP using only deaths from 2017–2019 and 2022. The estimates obtained were compared with the main specification using descriptive, correlational, and spatial analyses to assess the stability of the observed territorial patterns in the face of possible alterations in registration and health dynamics associated with the pandemic context.

The incidence of the *índice de privación material de los hogares* (IPMH)(Household Material Deprivation Index) was used as the independent variable; this is an indicator of structural poverty at the departmental/district level, operationalized as the percentage of households experiencing any type of material deprivation out of the total number of households in the department/district, according to the 2022 Census. The choice of IPMH over the monetary poverty line or the NBI is based on theoretical and operational reasons. IPMH captures structural material deprivations in households linked to housing conditions, sanitation, and access to basic services, dimensions closely related to differential exposure to respiratory, infectious, and nutritional diseases. Furthermore, because it is derived from the 2022 Census, it ensures comprehensive coverage and comparability at the departmental/district level. Unlike monetary poverty, which is more sensitive to short-term fluctuations in income, IPMH reflects persistent material conditions that are potentially relevant to the territorial distribution of MONEP.

Furthermore, IPMH captures deprivations that directly limit the ability to lead a healthy life; overcrowding restricts the ability to isolate oneself from infections; the lack of running water and sewage systems increases the burden of enteric diseases; and precarious housing conditions amplify exposure to climatic variations that contribute to respiratory diseases.

The analysis was conducted in four stages: (a) descriptive and cartographic analysis of the spatial distribution of MONEP and IPMH; (b) global spatial autocorrelation (Moran's I) to assess whether the distribution differs from a random pattern; (c) identification of local clusters using univariate and bivariate local indicators of spatial association (Local Indicators of Spatial Association - LISA), using univariate and bivariate measures, following the methodology proposed by Anselin[18] to detect territories with spatially clustered high or low values and to delineate critical areas; and (d) multivariate statistical modeling to assess the association between MONEP and IPMH, incorporating spatial models based on the results of the residual autocorrelation analysis.

To quantify the territorial scope of the IPMH effect on the MONEP, the direct, indirect, and total effects derived from the selected SAR model were estimated, following the decomposition proposed by LeSage and Pace.[19] The direct effect captures the impact of an increase in the IPMH incidence on MONEP of the department itself; the indirect effect, or spatial spillover, quantifies the impact on MONEP from neighboring departments, as a result of the spatial dependency structure captured by the parameter ρ; and the total effect represents the sum of both dimensions. The effects were estimated using a simulation with 1,000 replicates based on the model's

variance-covariance matrix, yielding 95% confidence intervals using the percentile method of the simulated distribution. This procedure allows us to assess whether the territorial impact of material deprivation on child mortality is limited to the units where it occurs or whether, on the contrary, it spreads to adjacent territories, with substantial implications for a multiscale understanding of health inequalities and for the design of territorially informed public policy interventions.

Since the model includes only IPMH as a covariate, without adjusting for potential confounders such as access to health services, rurality, or geographic region, the estimated direct, indirect, and total effects should be interpreted as unadjusted associations within the framework of spatial econometrics, and not as causal effects in the strict sense.

The spatial structure was defined using a row-standardized "queen" contiguity matrix. The LISA analyses were estimated using the "spdep" package in R and were exploratorily replicated in GeoDa using Monte Carlo permutations (999 simulations), revealing consistent patterns.

After estimating the linear regression model using ordinary least squares (OLS), the presence of spatial autocorrelation in the residuals was assessed using Moran's I statistic. Since significant spatial dependence was identified, alternative spatial models were estimated to account for the spatial structure, assess the spatial dependence of the analyzed process, and avoid inefficient estimates resulting from spatial autocorrelation.[18]

Spatial autoregressive (SAR), spatial error (SEM), and spatial Durbin (SDM) models were estimated using the same row-standardized "queen" contiguity matrix employed in the exploratory analyses. Model selection was performed by comparing Akaike Information Criteria (AIC), Rao's Score/Lagrange Multiplier tests, and evaluating the significance of the spatial parameters. All analyses were conducted in R using the "spdep" and "spatialreg" packages.

This study uses exclusively publicly available aggregated secondary data from official vital statistics and the 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census), with no possibility of identifying individuals. In accordance with current regulations governing health research in Argentina, this type of study is considered exempt from review by a Research Ethics Committee. The author declares that the ethical principles established in the Declaration of Helsinki were respected.

Results

The territorial distribution of MONEP showed marked subnational heterogeneity, with areas of relatively higher concentration contrasting with extensive zones of low or near-zero values (Figure 1). The incidence of structural poverty exhibited a strongly regionalized territorial pattern, with clear spatial differences between departments/districts (Figure 2). MONEP had a median of 3.60 and an average of 7.94 per 100,000 children aged 0–4; the incidence of structural poverty had a median of 38.6% and an average of 42.4%, indicating asymmetric distributions and high subnational dispersion.

The sensitivity analysis showed high structural consistency between the main specification and the alternative population denominator specification. The rates obtained using the 2022 Census had a slightly higher mean value than those obtained using the interpolated population (7.94 vs. 7.28 per 100,000). Despite this shift in absolute magnitude, a nearly perfect territorial correlation was maintained between the two specifications (Pearson=0.997). Changes in the departmental classification were marginal, confirming the robustness of the observed spatial patterns regardless of the demographic denominator used.

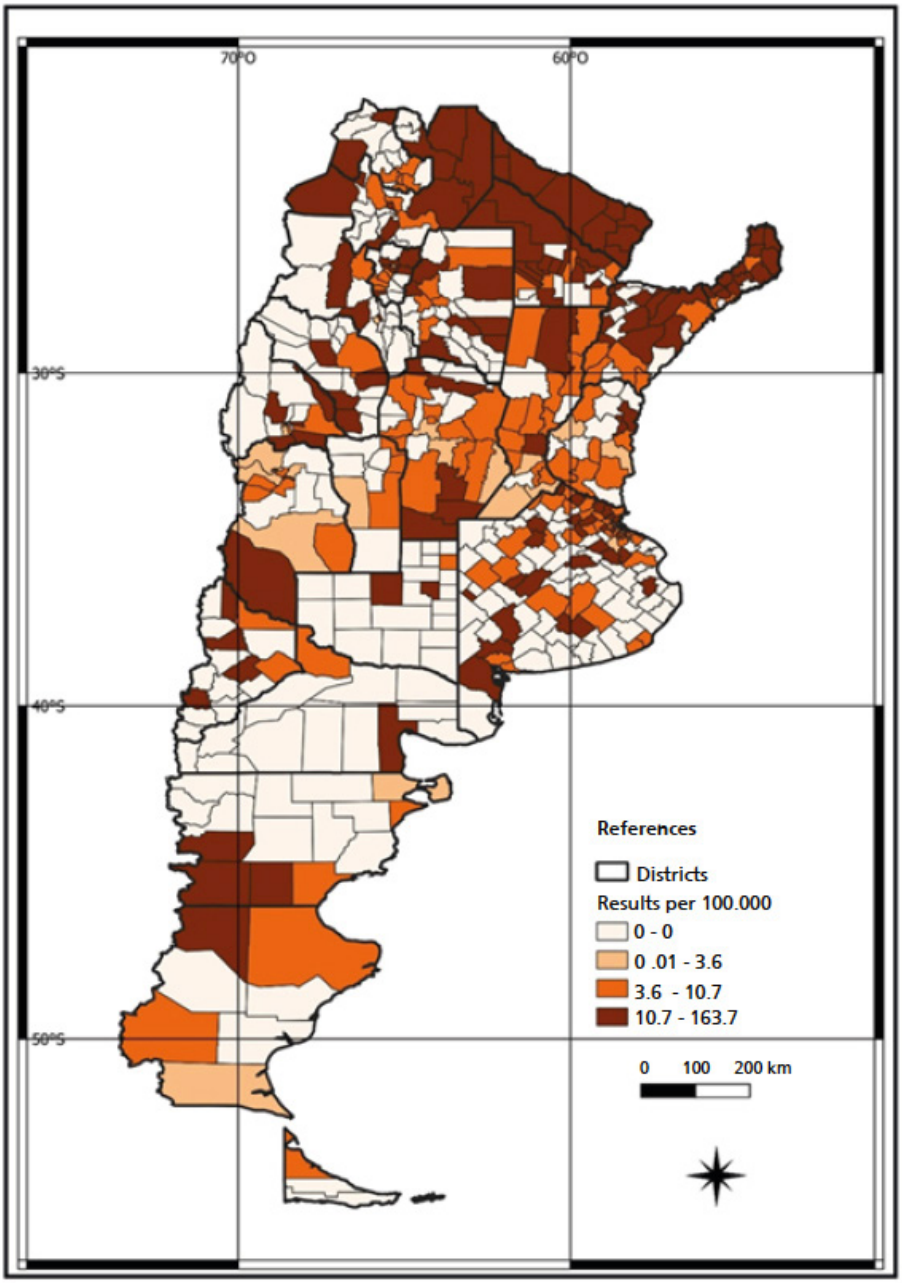
The sensitivity analysis excluding the pandemic years showed an increase in the average magnitude of the MONEP rate (9.92 vs. 7.94 per 100,000), consistent with a lower recorded frequency of deaths from these causes during 2020–2021. However, the territorial structure of the rates remained high and positively correlated with the main specification (Pearson=0.975), suggesting that the observed spatial patterns are robust to the exclusion of the pandemic years.

The global analysis revealed significant positive spatial autocorrelation for both MONEP (Moran's I=0.568; $p< 0.001$) and the IPMH incidence (I=0.824; $p<0.001$), indicating that both variables exhibit non-random spatial patterns. The difference in the magnitude of the índices, considerably higher for IPMH, suggests that the regionalization of structural poverty is substantially more intense than that of child mortality, which is consistent with the hypothesis that various mediating factors operate between deprivation and health outcomes, introducing local heterogeneity.

At the local level, the univariate LISA analysis for MONEP identified significant Low-Low (3.4%), High-High (2.5%), and High-Low (1.5%) clusters, with a predominance of non-significant areas (92.6%). The Low-High quadrant did not contain any significant units (0.0%), indicating the absence of departments with low mortality surrounded by high mortality on the scale analyzed (Figure 3). For the IPMH, Low-Low (20.3%) and High-High (16.3%) clusters were observed, with a smaller proportion of non-significant areas (63.2%), confirming the greater spatial regionalization of structural poverty compared to child mortality.

Figure 1

Geographic distribution of child mortality rate from poverty-related diseases (MONEP) in Argentina, 2017–2022.



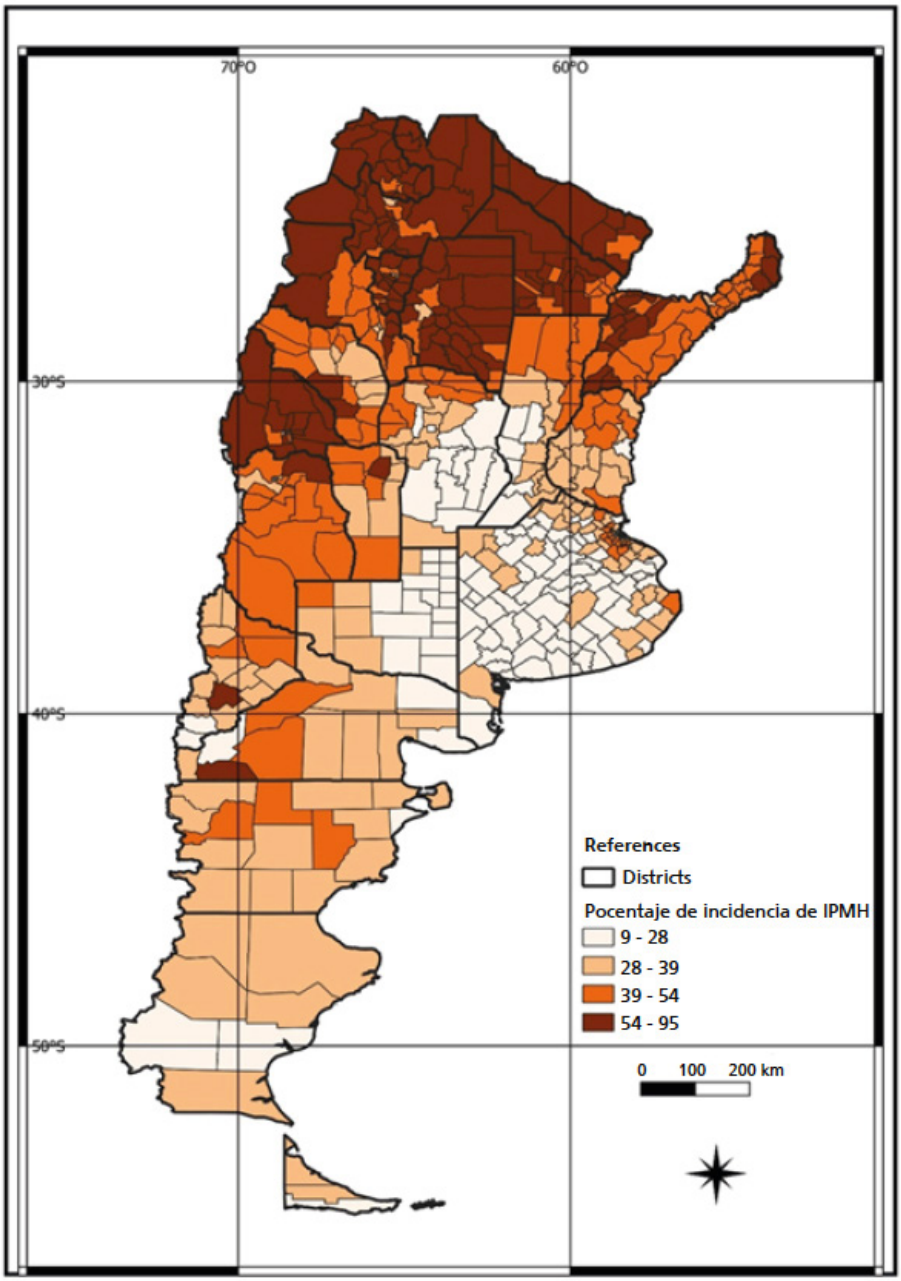
Source: *Programa Nacional de Estadísticas de Salud* (National Health Statistics Program) and 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

The bivariate LISA analysis revealed that 64.3% of the departments/districts showed no statistically significant local associations between MONEP and IPMH. Among the significant units, Low-Low clusters predominated (84 departments, 15.9%), areas with low MONEP in settings of low deprivation, and Low-High clusters (46 departments, 8.7%), representing areas with low relative mortality surrounded by high structural poverty. The High-High clusters—where high deprivation and high MONEP converge, forming critical territories where structural disadvantages and adverse health outcomes accumulate, comprise 40 departments (7.6%). The High-Low clusters accounted for 3.4% of the units (18 departments) (Figure 4, Table 1).

Dissonant patterns of non-negligible frequency were also observed: 18 departments with a High-Low pattern (3.4%)- high MONEP in contexts of lower relative poverty - and 46 with a Low-High pattern (8.7%)- low MONEP despite high structural deprivation. Far from being isolated cases, these patterns suggest the presence of moderating territorial factors not captured by the IPMH, the identification of which constitutes a relevant line of inquiry for future studies.

Figure 2

Geographic distribution of the incidence of the *Índice de Privación Material de los Hogares* (IPMH) (Household Material Deprivation Index) in Argentina, according to the 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

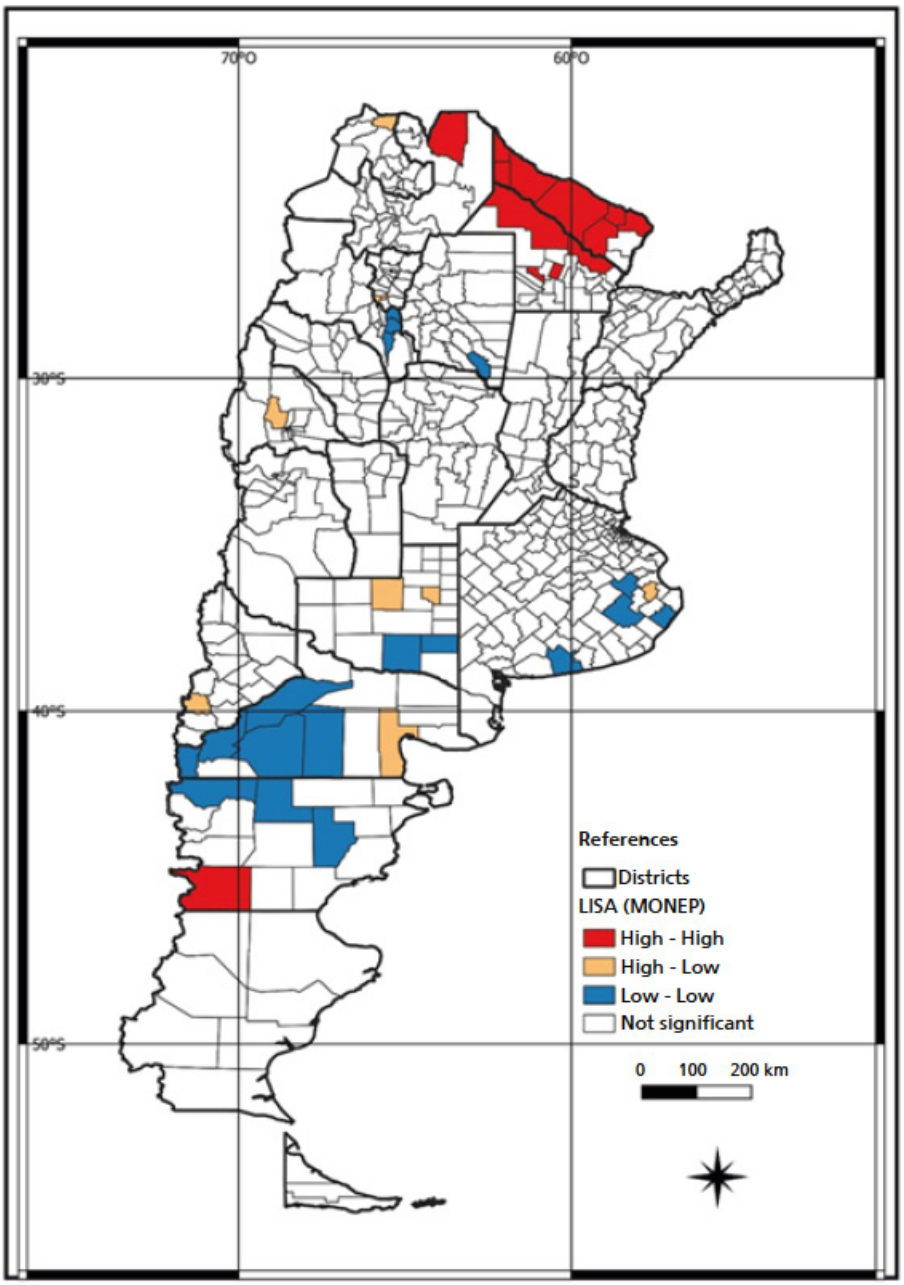


Source: 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

The OLS model revealed positive and statistically significant spatial residual autocorrelation (Moran's I = 0.528; $p< 0.001$), which justified the estimation of spatial models. Rao Score tests confirmed the relevance of the spatial lag model (RSlag significant; adjRSerr not significant, p=0.938), guiding the selection toward SAR. The AIC comparison indicated a slightly better fit for SDM (AIC=4048.4), followed closely by SAR (AIC=4049.3) and SEM (AIC=4053.7) All performed substantially better than the OLS model (AIC=4,327.8). Given that the difference between SDM and SAR models is only one AIC point and that the LM tests indicate the lag process as a source of spatial dependence, the SAR model was selected as the primary model due to its greater parsimony. In the SAR model, the incidence of IPMH maintained a positive and statistically significant association with MONEP (β =0.060; p=0.022), while the spatial dependence parameter was high and significant (ρ =0.732; $p< 0.001$), indicating a marked territorial concentration of child mortality beyond what is explained by structural poverty.

Figure 3

Local spatial clusters (univariate LISA) of child mortality from poverty-related diseases (MONEP) in Argentina (α=0.05).



Source: *Programa Nacional de Estadísticas de Salud* (National Health Statistics Program) and 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

Table 1

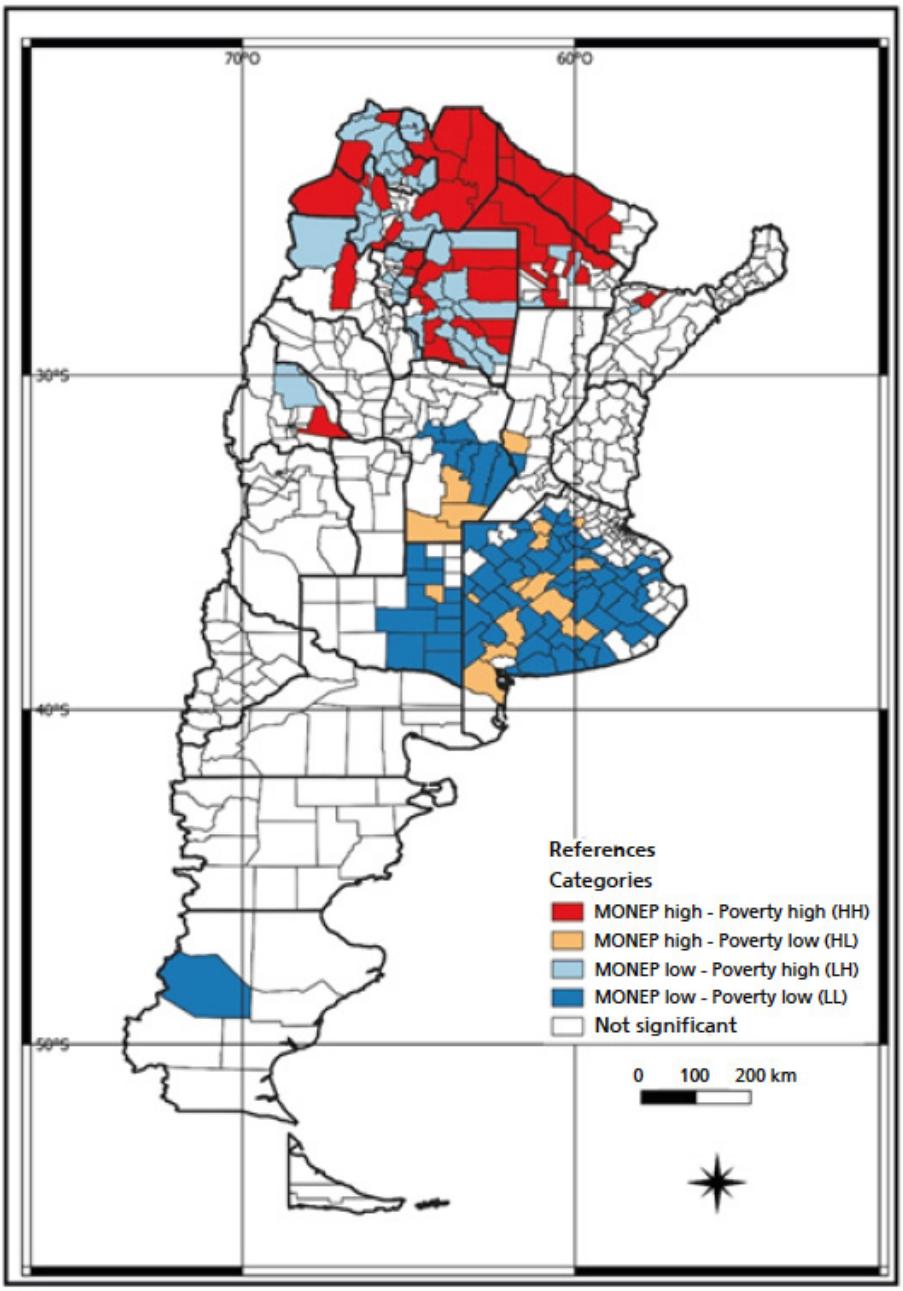
Bivariate LISA clusters between MONEP and IPMH incidence (α=0.05).

Cluster	N (departmental units)	% of departments	% of households 2022*
MONEP high - Poverty high (HH)	40	7.6	4.06
MONEP high - Poverty low (HL)	18	3.4	2.37
MONEP low - Poverty high (LH)	46	8.7	2.69
MONEP low - Poverty low (LL)	84	15.9	17.30
Not significant	339	64.3	73.58

IPMH = Household Material Deprivation Index.
*% of households in 2022: percentage of private households in the country corresponding to the departments/districts in each category, calculated based on the total number of households surveyed by the 2022 National Population, Household, and Housing Census (total n = 15,932,302 households).
Source: *Programa Nacional de Estadísticas de Salud* (National Health Statistics Program); 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

Figure 4

Local bivariate spatial clusters (LISA) between child mortality from poverty-related diseases (MONEP) and the incidence of the *Índice de Privación Material de los Hogares* (IPMH) (Household Material Deprivation Index) in Argentina (α=0.05).



Source: *Programa Nacional de Estadísticas de Salud* (National Health Statistics Program) and 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census).

Table 2

Direct, indirect, and total effects of IPMH on MONEP — SAR Model

Effect	Estimate	Standard Error	95%CI	*p*
Direct	0.072	0.031	0.011 – 0.131	0.018
Indirect	0.151	0.067	0.027 – 0.289	0.023
Total	0.222	0.096	0.037 – 0.413	0.019

IPMH = Household Material Deprivation Index.
* Note: Effects estimated using simulation with 1,000 replicates; CI = confidence interval based on percentiles of the simulated distribution.
Source: *Programa Nacional de Estadísticas de Salud* (National Health Statistics Program); 2022 *Censo Nacional de Población, Hogares y Viviendas* (National Population, Household, and Housing Census)

Decomposition of the spatial effects of the SAR model revealed that the impact of material deprivation on child mortality considerably exceeds the direct local effect. The direct effect of the IPMH on MONEP was 0.072 (95%CI=0.011–0.131; p=0.018), indicating that a one-percentage-point increase in the incidence of material deprivation is associated with an increase of 0.072 cases per 100,000 children within the department itself. The indirect or spatial spillover effect amounted to 0.151 (95%CI=0.027–0.289; p=0.023), more than double the direct effect, demonstrating that structural deprivation in one department also impacts mortality in neighboring departments. The total effect, which combines both dimensions, was 0.222 (95%CI=0.037–0.413; p=0.019). All three effects were statistically significant, with 95% confidence intervals that do not include zero (Table 2).

Discussion

The results of this study provide empirical evidence on the territorialized nature of inequalities in child mortality in Argentina, showing that MONEP is not randomly distributed in space but is linked to spatial patterns of structural material deprivation. This finding is consistent with the tenets of CSDH, which holds that health inequities are the preventable result of historically produced conditions.[1] But beyond confirming the association between deprivation and mortality, the results allow us to examine the specific ways in which this association is territorialized, concentrated, and reproduced.

The difference in the magnitude of spatial autocorrelation between IPMH (I=0.824) and MONEP (I=0.568) warrants analysis from the perspective of the theory of the fundamental cause. If socioeconomic status were the only relevant determinant of child mortality, one would expect its spatial distribution to correspond proportionally to that of MONEP. The difference between the two coefficients suggests, however, that the regionalization of structural poverty is considerably more intense than that observed for MONEP. Although child mortality associated with poverty-related diseases exhibits significant territorial patterns, its spatial pattern is less compact and homogeneous than that of material deprivation, indicating the involvement of mediating and contextual factors that modulate the impact of poverty on health outcomes at the territorial level. According to Link and Phelan[3], these mediators are precisely the mechanisms through which the root cause operates, such that when available mediators improve, resource-rich groups find ways to take advantage of them sooner and more effectively, thereby reproducing the social gradient even when specific mechanisms change.

The identification of 40 departments in HH clusters - where high structural deprivation and high MONEP converge - is the study's most significant finding from a public health perspective. These territories are characterized by unfavorable material conditions associated with greater exposure to respiratory, infectious, and malnutrition-related diseases, including inadequate sanitation, overcrowding, and substandard housing. The spatial concentration of these disadvantages suggests that child mortality associated with poverty-related diseases is not solely attributable to individual or household characteristics, but also to persistent territorial patterns of inequality in infrastructure, access to services, and living conditions. According to Harvey, [5] these clusters are not accidental but rather the result of historical processes of differential investment in infrastructure, services, and public goods that have produced persistent territorial patterns of disadvantage. The evidence presented is consistent with the idea that the territorial concentration of material deprivation and its health consequences stems from long-term structural dynamics in the allocation of resources among regions.

Deviating patterns warrant a differentiated analysis. HL departments - high MONEP in contexts of lower relative poverty - could reflect heterogeneities in the statistical record, the presence of populations with specific epidemiological characteristics not captured by the IPMH (rural communities with differential exposure), or limitations in geographic access to health services. LH departments, those with low MONEP despite high deprivation, suggest the presence of territorial resilience factors, which could include primary care systems with greater problem-solving capacity or maternal and child health programs with effective coverage. Identifying these specific mechanisms constitutes a high-value agenda for qualitative and mixed-methods research, primarily because the territorial resilience mechanisms observed in these LH departments may offer policy lessons that can be replicated in HH departments.

The superiority of spatial models over OLS confirmed the presence of substantial spatial dependence in the territorial distribution of MONEP. Among the estimated specifications, the SAR model presented the best relative fit (AIC=4049.3), followed closely by SDM and SEM all of which were clearly superior to the classical linear model. The significance and magnitude of the rho parameter (ρ=0.732; p<0.001) indicate that a significant portion of the territorial variability in child mortality associated with poverty-related diseases is spatially structured. From the perspective of critical health geography, this substantial spatial dependence can be interpreted as evidence that the processes shaping child mortality from poverty-related diseases extend beyond departmental administrative boundaries and respond to broader regional dynamics. From the perspective of critical health geography, this

substantive spatial dependence can be interpreted as evidence that the processes shaping childhood mortality from poverty-related diseases transcend departmental administrative boundaries and are driven by broader regional dynamics linked to the unequal organization of health infrastructure, territorial accessibility, and the differential availability of resources and services. This territorial dimension of inequality is consistent with the social determinants of health framework regarding the importance of social and contextual structures in shaping health outcomes.

The decomposition of the spatial effects of the SAR model yields one of the study's most relevant findings from a public policy perspective. The indirect or spatial spillover effect (0.151; 95%CI=0.027–0.289) is more than double the direct effect (0.072; 95%CI=0.011–0.131), indicating that the impact of material deprivation on child mortality is not confined to the department where it occurs but spreads to neighboring territorial units. This finding is consistent with the relational and multiscale nature of the social determinants of health, where conditions of inadequate infrastructure, limited access to health services, and precarious housing do not respect formal administrative boundaries but rather create risk environments that transcend departmental borders and operate at the regional level. According to Harvey,[5] this spatial spread is not random but reflects the unequal territorial organization of resources and investments that has historically concentrated deprivation in peripheral regions, creating patterns of disadvantage that reinforce one another across contiguous territories. The total effect of IPMH on MONEP (0.222; 95%CI=0.037–0.413) is considerably greater than the point of the model estimate, a difference that is statistically significant and underscores the systematic underestimation resulting from analyzing the effects of poverty without considering its spatial dimension.

It should be noted that, as an unadjusted bivariate model, these estimates capture the crude association between material deprivation and child mortality in its direct and indirect spatial dimensions; quantifying causal effects would require adjustment for territorial confounders such as access to health services, rurality, and region, which constitutes a relevant analytical extension for future studies.

The results can also be interpreted in the context of national trends. Longhi *et al*.[9] documented persistent regional disparities in child malnutrition in Argentina, within the North regions - NOA and NEA - exhibiting the worst indicators; Longhi and Salazar Burgos[11] confirmed the persistence of these patterns during the 2019–2020 period. The household clusters identified in this study are consistent with this historical trajectory. We can therefore argue in this regard, that the territories experiencing structural deprivation are neither new nor emerging, but rather reflect long-standing processes of marginalization that are reproduced and consolidated through mechanisms operating simultaneously at the household level (material deprivation), the territorial level (deficient infrastructure), the regional level (peripheral economic dynamics), and the State level (differential institutional capacity). This multidimensional and multifunctional nature of inequalities reinforces the need for integrated interventions that simultaneously coordinate different policy levels.

In terms of implications for public policy, the findings suggest that universal interventions, while necessary, are insufficient to reduce the identified territorial gaps unless they are complemented by strategies focused on HH clusters. These strategies should integrate improvements in sanitation and housing infrastructure, the strengthening of primary maternal and child healthcare, and social protection programs aimed at reducing food insecurity and material deprivation. It is clear, then, that incorporating spatial analysis tools into health information systems can help improve resource allocation and monitor the evolution of these gaps.

However, the study has limitations inherent to spatial ecological analysis. In particular, population and territorial heterogeneity among Argentine departments/districts may introduce differential variability in the stability of rates, especially in sparsely populated areas. Furthermore, the identified patterns are conditioned by the administrative scale used, in line with the methodological implications of MAUP described in literature on quantitative geography and spatial epidemiology. Although the use of annual averages and sensitivity analysis helped to partially mitigate these issues, future studies could incorporate Bayesian smoothing strategies and hierarchical spatial modeling to improve the robustness of subnational estimates.

It should also be noted that the analyzed period includes the years of the COVID-19 pandemic, during which there may have been changes in the dynamics of healthcare, geographic access to services, and the quality of death registration. Although sensitivity analyses showed high stability in the overall territorial patterns when the pandemic years were excluded, the existence of differential underreporting or changes in the classification of certain causes of death associated with respiratory, infectious, and nutritional diseases cannot be completely ruled out.

Overall, the findings of this study show that child mortality from poverty-related diseases in Argentina exhibits a clearly unequal and spatially structured territorial pattern. The identification of critical clusters where high material deprivation and higher levels of MONEP reinforces the importance of addressing health inequalities from a territorial and multiscale perspective,

recognizing that living conditions, social infrastructure, and differential access to resources and services shape unevenly distributed risk environments. In this regard, subnational spatial analysis not only allows for the identification of priority areas for health interventions but also contributes to evidence-based planning capable of integrating social, territorial, and epidemiological dimensions into the design of public policies aimed at reducing inequities in child health.

This study demonstrates that inequalities in child mortality from poverty-related diseases in Argentina exhibit a significant socio-territorial pattern, characterized by the coexistence of critical territories where high levels of material deprivation and increased health risk converge. Structural poverty exhibited strong spatial regionalization, while MONEP revealed more heterogeneous patterns, consistent with the idea that health outcomes emerge from the interaction between structural socioeconomic conditions, specific territorial dynamics, and contextual factors that mediate or moderate the impact of deprivation.

These inequalities are not the result of individual deficits or random distributions of risk, but rather reflect persistent territorial patterns of material deprivation and unequal access to health-protective resources. From the perspective of social determinants and root-cause theory, structural poverty operates as a persistent mechanism for producing health inequalities, the effects of which are territorially distributed in different ways depending on the contextual conditions of each region. The identified divergent patterns also suggest the possible existence of territorial factors of resilience or specific vulnerability that require further research. Moving toward equitable and sustainable improvements in child health in Argentina and the Region of the Americas requires recognizing the territorial and structurally produced dimension of these inequalities.

The decomposition of the spatial effects of the SAR model reveals that the impact of material deprivation on child mortality has a territorial dimension that extends far beyond the boundaries of the department where it is located. The indirect or spatial spillover effect is more than double the direct effect, so that the total effect of IPMH on MONEP is considerably greater than the coefficient derived from the point analysis. This finding has direct implications for policy design, since interventions focused exclusively on the departments with the worst indicators may underestimate the necessary scope of action if they do not take into account the regional dynamics that connect those territories to their surroundings. Reducing child mortality from poverty-related diseases therefore requires not only intervening in critical HH clusters but also in the broader territorial contexts that surround and perpetuating them.

These findings reinforce the idea that territory is not merely a geographical backdrop where health and disease processes occur, but an active dimension in the production and reproduction of health inequalities. The place where one is born, the material conditions in which childhood unfolds, and the territorial characteristics of the environment, infrastructure, access Access to healthcare, sanitation, connectivity, and housing conditions, differentially influence opportunities for survival, growth, and development from the earliest years of life. In this regard, the persistence of significant spatial patterns and the superiority of spatial models over classical specifications suggest that child mortality associated with poverty-related diseases cannot be understood solely in terms of isolated individual or family attributes, but rather as the result of complex, spatially structured territorial configurations. The ability of the SAR model, selected as the primary specification due to its parsimony and support from spatial diagnostic tests, and corroborated by alternative specifications (SEM, SDM), to capture spatial dependence and relationships between neighboring territories provides consistent evidence that socio-health inequalities have a relational and regional dimension that extends beyond formal administrative boundaries. Thus, spatial analysis is not only a sophisticated methodological tool but also a means of highlighting how social inequalities are territorially embedded and concretely shape processes of health and illness in childhood. Incorporating this perspective is essential for guiding public policies that are more responsive to territorial heterogeneity and for strengthening evidence-based health planning strategies in contexts of marked socio-spatial inequality.

Author's Contributions

Longhi F: Conceptualization; Methodology; Formal analysis; Research; Data curation; Writing—original draft; Writing—revision and editing; Visualization. The author declares no conflicts of interest.

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Data availability

The secondary data used in this study come from publicly available sources (National Health Statistics Program

and INDEC). The R processing script, the departmental database, the variable dictionary, the supplementary materials, and the results tables are deposited on Zenodo: https://doi.org/10.5281/zenodo.20626885

Use of artificial intelligence

The author declares that the conceptual, methodological, analytical, and interpretive decisions of the study were made entirely under his or her responsibility. During the manuscript preparation process, the artificial intelligence assistant Claude (Anthropic) was used as a support tool for the following instrumental tasks: debugging and documenting the R processing script, checking for consistency between the analysis results and the values reported in the text, assisting with the drafting and stylistic editing of sections of the manuscript, and assistance in searching for and cross-checking bibliographic references against their primary sources. The author expressly confirms that no scientific content—including citations, statistical values, and bibliographic references—was included in the manuscript without individual verification against the corresponding primary source. All substantive decisions regarding the formulation of hypotheses, theoretical framework, analysis design, interpretation of results, and development of scientific content were made by the author. This statement is made in accordance with COPE's updated recommendations on the use of AI tools in scientific production.

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