

The Paradox of Progress: Persistent Spatial Health Traps in Czechia after Two Decades of Transition

Dana Hübelová

Mendel University in Brno

Beatrice-Elena Chromková Manea

Mendel University in Brno

Jan Caha

Technical University of Ostrava

Alice Kozumplíková

alice.kozumplikova@mendelu.cz

Mendel University in Brno

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Abstract

Background

Health inequalities represent a persistent challenge for public health policy, yet longitudinal evidence covering the full spectrum of their determinants remains scarce. Despite two decades of significant macro-economic growth and European integration, it remains unclear whether systemic progress in Czechia has mitigated or reinforced existing geographical health divides. This study examines the stability of spatial health inequalities in Czechia – a country that has undergone profound post-socialist socio-economic transformation – over a twenty-year period (2001–2021).

Methods

Spatial differentiation of health determinants and outcomes was assessed at the LAU 1 level (77 units). Using a holistic framework, 57 indicators were integrated across seven categories of contextual determinants (Index A) and a composite index of population health outcomes (Index B). All indicators underwent min-max normalisation before aggregation via the Weighted Sum Approach. To identify spatial clustering and its temporal dynamics, Global Moran's I and Local Indicators of Spatial Association (LISA) were applied at three time points coinciding with national censuses (2001, 2011, 2021). Regional inequality was quantified using the Theil Index, and temporal significance was assessed via the Wilcoxon Signed-Rank Test.

Results

Findings reveal a significant decoupling of trends. Economic and educational determinants showed regional convergence between 2001 and 2011, but progress has since stagnated. Disparities in healthcare accessibility (A.7) and environmental status (A.4) intensified in peripheral regions during the second decade. Spatial autocorrelation analysis confirmed the presence of structural health traps – persistently entrenched Low-Low clusters in the northwestern and northeastern border peripheries that resist national economic improvement. The contrast between shifting determinant dynamics and the rigid spatial clustering of health outcomes (Moran's I: 0.55, 0.44, 0.54) indicates a significant spatial-temporal lag between socioeconomic change and population health.

Conclusions

Macro-economic prosperity does not automatically translate into health equity. Without targeted, place-based interventions, peripheral areas face a compounding spatial penalty of cumulative disadvantage. This study offers a replicable methodological model for monitoring health equity in transitional

economies and underscores the need for territorial cohesion policies that address the structural determinants – not merely the symptoms – of health injustice.

Background

Health equity remains a foundational pillar of just societies, yet profound disparities in health status continue to persist across population groups and regions. These inequalities are not merely random geographic variations; rather, they represent unjust, systemically produced disparities [1] driven by a complex interplay of socioeconomic, environmental, and behavioural determinants [2]. In the Czech context, these spatial patterns reflect deep-seated structural injustices rooted in historically unequal distributions of political power and public investment, which have forged specific territorial trajectories of disadvantage.

The nexus between health outcomes and broader social gradients is well-established [3–5], with the social gradient remaining one of the most reliable indicators of systemic inequality [6]. Evidence consistently shows that these disparities are remediable yet persistent, cutting across all levels of the social hierarchy and manifesting at multiple scales – from national divides to intra-neighbourhood variations [7–12]. While European and North American studies document life expectancy gaps of up to 15 years between the most and least advantaged [13, 14], recent trends suggest that in many developed economies these health inequalities are actually deepening [15, 16].

Despite the abundance of literature on the links between poverty, income inequality, and mortality [17–19], a significant gap in knowledge persists. Most existing research remains fragmented, focusing either on isolated determinants or limited timeframes, thereby failing to capture the long-term, multi-dimensional evolution of regional disparities. This is particularly true for post-socialist transitional economies, where the legacy of centrally planned spatial investment, rapid market liberalisation, and European integration creates a distinctive and understudied configuration of health determinants.

This study addresses this gap by providing a two-decade longitudinal analysis (2001–2021) of spatial health inequalities in Czechia, integrating 57 indicators into a holistic framework that spans seven categories of health determinants and a composite health outcomes index. Testing the stability of these inequalities is particularly compelling given Czechia's rapid macro-economic growth and deep integration into European structures. It remains a critical question whether this systemic progress has mitigated or reinforced existing geographical divides.

This research builds upon the foundational holistic model for assessing health inequalities developed in Czechia ([20, 21], which operationalised the Dahlgren-Whitehead framework [22] into a modular, scalable system and provided a static baseline classification of determinants and outcomes. The present study makes three distinct and original contributions. First, it introduces a dynamic assessment by evaluating the same framework at three census time points (2001, 2011, 2021), enabling the detection of structural change rather than mere cross-sectional description. Second, it applies Local Indicators of Spatial Association (LISA) category transition analysis to identify and classify the temporal evolution of spatial

clusters — moving beyond the question of where inequalities exist to how and whether they are changing. Third, by situating the Czech findings within the international discourse on left behind places and spatial traps, this study repositions a national case study as an analytically tractable model for comparable post-socialist transitional economies across Central Europe.

To explore these questions, we adopt a place-based approach, which is essential for identifying at risk regions and understanding how differential exposure, sensitivity, and resilience shape population health [23–25]. We move beyond simple social causation versus health selection frameworks [26] to examine how material resources, environmental exposures, and institutional capacities constitute a shared structure of vulnerability [27–29].

In Czechia, these disparities are articulated through residential segregation and the concentration of deprivation, particularly in urbanised outer peripheries and border districts — areas often marked by structural unemployment and the historical legacy of post-WWII resettlement [30, 31]. The uneven allocation of public infrastructure further exacerbates these patterns, as rapid suburbanisation often outpaces the provision of essential services [21].

A central interpretive question guiding this analysis is whether the changes observed over two decades represent a true structural transformation of regional health trajectories, or merely the persistent spatial penalty of historically disadvantaged regions temporarily masked by national economic growth. Specifically, this study aims to:

1. Identify spatial patterns of health inequalities and their concentration areas at three census time points.
2. Compare regional profiles to determine how specific categories of determinants — such as education (A.2) or healthcare accessibility (A.7) — drive these disparities over time.
3. Classify and measure the temporal development of regional inequalities to detect the emergence and persistence of structural spatial traps.

Materials and methods

Study Area and Data Sources

Spatial differentiation of health determinants and outcomes was assessed at the LAU 1 level (Local Administrative Units) in Czechia, comprising 76 districts and the capital city of Prague. The LAU 1 scale was selected as the optimal pragmatic unit, providing a more granular resolution than the geographically and economically fragmented NUTS 2 or NUTS 3 regions while ensuring data availability for all 57 monitored indicators.

The analysis focuses on three temporal cross-sections—2001, 2011, and 2021—coinciding with the national population censuses to ensure maximum data consistency. Where census-year data were unavailable for specific indicators, the closest available proxy year was used. Table in Appendix A

documents the exact reference year for each indicator at each time point. In total, 44 indicators required a proxy year substitution, with the maximum temporal displacement being 7 years from the target census year. Sensitivity to this substitution was assessed by examining whether proxy-year indicators showed statistically significant inter-annual volatility in the periods surrounding the target year; no indicator exhibited trends that would materially alter its normalised value at the census time point. Indicators for which regional-level data were unavailable at the LAU 1 scale were assigned the value of the corresponding NUTS 3 region, as noted in Appendix A. This approach is consistent with standard practice in composite index construction at sub-national scale and introduces only marginal measurement uncertainty relative to the overall index. Data were triangulated from several authoritative sources: the Czech Statistical Office (CZSO), the Institute of Health Information and Statistics (IHIS), the Ministry of Labour and Social Affairs (MoLSA), and the Czech Hydrometeorological Institute (CHMI).

Constructing the Holistic Model

The methodology follows a modular framework developed in previous research [20, 21], integrating 57 indicators into two principal composite indices:

- Index A.1-A7. (Determinants): Comprising 33 indicators grouped into seven categories (A.1–A.7: Economy, Education, Demography, Environment, Social Environment, Housing, and Healthcare Accessibility).
- Index B (Health Outcomes): Comprising 24 indicators representing mortality, morbidity, and reproductive health.

To ensure comparability between heterogeneous variables, all sub-indicators underwent min-max normalisation to a dimensionless scale (0–100), where 100 represents the most favourable outcome. The original units of individual indicators are listed in Appendix A and serve as source inputs for standardisation.

Data Aggregation

Following normalisation, sub-indicators were aggregated using the Weighted Sum Approach (WSA). Equal weights were assigned to all components to maintain the holistic integrity of the model and to avoid the subjective bias inherent in a priori theoretical hierarchies. In the absence of empirical consensus on the relative contribution of heterogeneous determinants — ranging from environmental pollutants to educational attainment — equal weighting provides a transparent and reproducible baseline for longitudinal comparison. The robustness of this assumption was previously validated by comparing equal-weight composite index rankings against an expert panel-derived weighting scheme, with results showing no substantive difference in regional classifications or overall findings [21]. The present study adopts equal weighting on this established basis, ensuring methodological continuity and longitudinal comparability across the three time points.

The resulting composite indices (A.1–A.7 and B) express a relative value within the interval 0–1 (or 0–100 for descriptive presentation), facilitating longitudinal and cross-regional comparisons. The decision to apply equal weighting to all 57 indicators was adopted to maintain the holistic integrity of the model and to avoid the subjective bias inherent in a priori theoretical hierarchies. In the absence of a consensus on the relative impact of heterogeneous determinants—ranging from environmental pollutants to educational attainment—equal weighting provides a transparent and robust baseline for longitudinal comparison [21].

Spatial Statistical Analysis

To identify regional clusters and territorial disparities, we employed a suite of spatial analytical tools using ArcGIS Pro (v.3.6).

1. Global Moran’s I: Used to assess the presence of global spatial autocorrelation, indicating whether health determinants and outcomes are spatially clustered, dispersed, or random across Czechia.
2. Local Indicators of Spatial Association (LISA): To pinpoint specific local clusters, the local version of Moran’s I was applied [32]. Regions were classified into four categories:
 - High-High (HH): high values surrounded by high values – positive cluster
 - Low-Low (LL): low values surrounded by low values – negative cluster
 - High-Low (HL): high values surrounded by low values – spatial outlier
 - Low-High (LH): low values surrounded by high values – spatial outlier
1. LISA Category Transitions: Recognising that numerical changes in local Moran’s I are context-dependent, we analysed shifts in category classification (e.g., a unit moving from HH to INS) between periods. This typology of changes (summarised in Table 1) allows for a robust interpretation of the dynamics of spatial patterns.
2. Moran Scatterplots: Provided as diagnostic visualisations to illustrate the relationship between a unit's value and the weighted mean of its neighbours. Quadrants correspond to HH/LL/HL/LH configurations, and points highlighted by significance level indicate units that contribute most strongly to spatial autocorrelation. These plots provide a diagnostic visualisation to accompany LISA maps.

Table 1 Typology of changes in LISA categories

Table 1 Typology of changes in LISA categories

Category at time t	Category at time t + 1	Evaluation of change
High	High	No Change
High	Insignificant	Decrease
High	Low	Significant decrease
Insignificant	Insignificant	No Change
Insignificant	Low	Decrease
Insignificant	High	Increase
Low	Low	No Change
Low	Insignificant	Increase
Low	High	Significant increase

Temporal Significance and Inequality Measurement

To rigorously evaluate changes across the two decades, two distinct statistical measures were applied:

1. Wilcoxon Signed-Rank Test: A non-parametric test for paired data was used to identify statistically significant shifts between 2001–2011, 2011–2021, and the full 2001–2021 period. Both two-tailed (general difference) and one-tailed (directional improvement or deterioration) tests were performed at the $p < 0.05$ significance level.
2. Theil Index: To quantify the magnitude of regional disparities, the Theil Index was employed. This measure captures both absolute differences and relative deviations from the mean [33], providing a nuanced view of whether regional health inequality is converging or diverging over time.

Results

This section synthesises the descriptive and spatial trajectories of the composite indices across the observed periods (2001, 2011, and 2021). All analyses utilise dimensionless indices (0.0–1.0), where higher values represent more favourable conditions for health equity. Detailed descriptive statistics (mean, median, interquartile range, and standard deviation) are complemented by visualisations of inter-year shifts (Appendix B) and value distributions (Appendix C).

The longitudinal data reveal a distinctive temporal pattern: a predominant improvement across most determinant categories between 2001 and 2011, followed by a phase of stagnation or relative decline between 2011 and 2021.

1. Drivers of Improvement: The Education Index (A.2) exhibited consistent long-term growth, while Individual Living Status (A.5) saw its most significant gains in the latter decade. Economic and

Social Conditions (A.1) followed a U-shaped trajectory, rebounding after 2011 to surpass 2001 levels.

2. Categories of Concern: After an initial period of progress, Environmental Conditions (A.4) and Healthcare Accessibility (A.7) experienced a marked decline by 2021. Similarly, the Demographic Situation Index (A.3) showed signs of regression in the final period.
3. Stability of Outcomes: The Health Condition Index (B) remained remarkably stable over time, exhibiting only marginal improvement. Correspondingly, the aggregate composite index of determinants (A.1–A.7) plateaued after 2011, indicating that the potential for broad, systemic improvement in health equity under the current policy framework has likely been exhausted.

Statistical dispersion, measured by standard deviation for Index A.1–A.7, peaked in 2011 (0.048) before slightly contracting by 2021 (0.042), suggesting a stabilisation of regional disparities rather than a fundamental spatial shift. In contrast, Index B (Health Outcomes) showed a renewed increase in variability in 2021 (0.114) after a temporary contraction in 2011. The accompanying boxplots highlight significant outliers, particularly in Education (A.2), and reveal a narrowing interquartile range for socioeconomic categories (A.1, A.2, A.3, A.5). However, the widening distribution in Healthcare (A.7) and Health Outcomes (B) in 2021 signals a potential resurgence of regional health disparities.

Spatial Dynamics of Composite Index (A.1-A.7) and Health Outcomes (B)

Spatial autocorrelation analysis confirms that health determinants and outcomes are not randomly distributed but follow distinct regional patterns (see Fig. 1, Fig. 2, Fig. 3). Moran's I for the aggregate determinants progressed from 0.26 (2001) to 0.51 (2011), before settling at 0.39 in 2021. This indicates a consolidation of spatial clustering in the first decade, followed by a slight weakening of these patterns. The spatial patterns identified in the northwestern and northeastern border peripheries demonstrate remarkable spatial inertia. By maintaining a stable LL classification across the entire twenty-year span, these regions function as structural health traps where the spatial penalty remains resistant to national macroeconomic improvements. Conversely, HH clusters of favourable determinants are concentrated in Central and Southern Bohemia, the latter becoming increasingly prominent by 2021.

Fig. 1 Variable A.1–A.7 for the year 2001

Fig. 2 Variable A.1–A.7 for the year 2011

Fig. 3 Variable A.1–A.7 for the year 2021

Spatial patterns for health outcomes (B) remained highly stable and robust, with Moran's I values of 0.55 (2001), 0.44 (2011), and 0.54 (2021). This high level of autocorrelation underscores the structural rigidity of regional health disparities (see Fig. 4, Fig. 5, Fig. 6).

- LL clusters: Areas of poor health outcomes are consistently anchored in the northwestern border periphery, showing little change over twenty years.
- HH clusters: Favourable outcomes were initially identified in Southeastern Moravia and the Bohemian-Moravian border zone (2001). Over time, these positive clusters expanded to include the Prague metropolitan region and its hinterland (2011), as well as parts of Eastern Bohemia (2021).

The contrast between the shifting spatial autocorrelation of determinants (Index A.1-A.7) and the entrenched clustering of health outcomes (Index B) suggests a significant spatial-temporal lag, where historical disadvantages in health status resist contemporary socioeconomic improvements.

Fig. 4 Variable B for the year 2001

Fig. 5 Variable B for the year 2011

Fig. 6 Variable B for the year 2021

Diverging Spatial Trends: From Economic Growth to Infrastructural Stagnation

The longitudinal analysis (2001–2021) reveals a fundamental decoupling between macro-economic growth and the localised stability of health determinants. Rather than a uniform trajectory of improvement, the results delineate two antithetical dynamics that define the Czech post-transformational landscape.

These categories represent the primary drivers of positive development over the two-decade period. Table 2 illustrates the trends in the indicator values between 2001 and 2021. Meanwhile, Table 3 demonstrates the dynamic changes in the determinants of health inequalities between 2001 and 2011, as well as between 2011 and 2021. Indicators pertaining to economic conditions (A.1) and educational attainment (A.2) exhibited the most statistically significant improvements.

Table 2 Trend in the index values during the period 2001–2021

Indicator	Left-sided test (improvement over time)	Right-sided test (deterioration over time)	Description
A.1	✓		Improved
A.2	✓		Improved
A.3		✓	Deteriorated
A.4		✓	Deteriorated
A.5	✓		Improved
A.6			Stable, no trend
A.7		✓	Deteriorated

Table 3 Dynamic changes in health inequality determinants

Variable	Change between 2001 and 2011	Change between 2011 and 2021
A.1	$p < .001$	$p < .001$
A.2	$p = .02$	$p = .07$
A.3	$p < .001$	$p = .03$
A.4	$p < .001$	$p = .01$
A.5	$p = .05$	$p < .001$
A.6	$p = .36$	$p = .98$
A.7	$p < .001$	$p < .001$

However, this progress was spatially heterogeneous. While low educational levels were more pervasive in 2001, the 2021 data illustrate a sharp polarisation between metropolitan hubs (Prague, Brno) and structurally disadvantaged regions (North-west Bohemia). This suggests a process of human capital centralisation, whereby economic prosperity increasingly clusters in urban cores, leaving peripheral regions vulnerable to demographic and social stagnation.

In stark contrast to broader economic gains, the indices for the physical environment (A.4) and healthcare accessibility (A.7) highlight systemic failures in regional equity.

- **Healthcare Accessibility (A.7):** This index demonstrates the most concerning trend. Despite overall technological advancement, healthcare access in peripheral districts has undergone relative deterioration. LISA analysis identifies stable cold spots in border regions, suggesting that the centralisation of specialised care into regional centres has created spatial barriers to entry that are not mitigated by improvements in general population mobility.

- The Physical Environment (A.4): The persistence of environmental burdens in traditional industrial agglomerations (Ústí nad Labem) confirms a hypothesis of environmental injustice. The historical legacy of heavy industry remains a dominant, immovable determinant of health outcomes, resisting two decades of remediation efforts.

The aggregate index of determinants (A.1–A.7) follows a non-linear trajectory. While a nationwide improvement was observed between 2001 and 2011, the subsequent decade (2011–2021) is characterised by structural rigidity and stagnation (see Fig. 7, Fig. 8). This plateau indicates that standard, market-driven development policies have reached their limit; further reductions in health inequalities will require targeted, place-based interventions rather than blanket national strategies.

Fig. 7 Change in A.1–A.7 between the years 2001–2011

Fig. 8 Change in A.1–A.7 between the years 2011–2021

Structural Persistence and the Post-2011 Paradox: A Synthesis of Health Equity Dynamics

The temporal analysis uncovers three primary mechanisms that sustain spatial health inequalities in Czechia, offering broader lessons for other post-socialist transitional economies.

- The 2011 Inflection Point and the Limits of Growth: The most striking finding is the cessation of progressive development in health determinants after 2011. This phenomenon may be interpreted as a saturation phase, where macro-economic indicators (GDP, unemployment rates) cease to correlate with tangible improvements in regional health conditions. Whilst the national economy continued to expand, indices A.4 and A.7 stagnated or declined. This suggests that health equity in Czechia is no longer driven by market transition, but is increasingly hindered by systemic bottlenecks, such as healthcare workforce shortages in the periphery and unaddressed environmental legacies.
- The Geographical Trap of Left-Behind Places: The Theil index results reveal pronounced and evolving regional inequalities, with education (A.2) consistently representing the most unequal and structurally persistent category over the entire period (see Table 4).

Table 4 Differences in the degree of regional inequalities (Theil index)

2001	A.1 Ec- soc	A.2 Edu	A.3 Demo	A.4 Envi	A.5 Indiv	A.6 Safety	A.7 Care	B Health Condit	INDEX A.1-A.7
	2.12	9.98	2.22	1.96	3.80	1.06	3.87	1.25	0.31
2011	3.01	9.09	0.84	0.37	5.65	0.53	2.75	0.45	0.42
2021	1.08	8.47	0.58	3.30	2.64	0.76	5.52	1.49	0.32

Between 2001 and 2011, inequalities declined across several domains—including demography, environmental conditions, safety, and healthcare accessibility—while economic conditions and individual characteristics exhibited moderate increases. However, this trend partially reversed between 2011 and 2021, when inequalities intensified markedly in healthcare accessibility and environmental conditions, alongside a renewed increase in health outcome disparities (B), despite improvements in selected socio-economic categories. These patterns closely align with the concept of the geographical trap of left-behind places, as LISA analysis repeatedly identifies the same disadvantaged clusters—particularly in North-west Bohemia and the Moravian-Silesian borderlands. This enduring spatial concentration of disadvantage points to deeply rooted structural traps, where improvements in individual-level determinants fail to translate into broader territorial progress due to rigid, path-dependent contextual conditions. The findings thus underscore that, in the absence of targeted place-based interventions, spatial health inequalities are likely to persist and self-reproduce regardless of overall economic growth.

- **Cumulative Exposure and the Temporal Lag Effect:** A comparison between the evolution of determinants (Index A.1-A.7) and health outcomes (Index B) suggests a significant temporal lag. The economic improvements of the early 2000s have only partially translated into better health outcomes by 2021. The stable prevalence of chronic conditions and mortality in disadvantaged regions underscores that spatial health is a cumulative process. Consequently, the current stagnation in healthcare access and environmental quality (A.7, A.4) represents a issue for future health equity.

These findings challenge the efficacy of EU cohesion policies in Central Europe. The data suggest that while investments have successfully bolstered economic capital (A.1), they have largely failed to strengthen health capital in the internal and external peripheries. Moving forward, structural funds must prioritise health equity as a specific territorial goal to prevent further social and spatial fragmentation.

The Convergence of Outcomes: Persistent Health Disparities (Index B)

The final synthesis of population health outcomes (Index B) reveals the cumulative impact of the determinants. Unlike the socioeconomic indices, which showed signs of national improvement, Index B is characterised by stark geographical rigidity.

- The Health Divide: Despite two decades of economic transition, the spatial distribution of health outcomes (B) has remained remarkably stable (see Fig. 9, Fig. 10). LISA analysis identifies a persistent low-health cluster in the industrialised North-west and the Moravian-Silesian regions. These areas demonstrate a compounding effect, where poor environmental quality (A.4) and declining healthcare accessibility (A.7) intersect with historical socioeconomic deprivation, resulting in significantly higher rates of premature mortality and morbidity.

Fig. 9 Change in B between the years 2001–2011

1. Change in B between the years 2011–2021

- Metropolitan Advantage vs. Peripheral Penalty: A significant divergence is observed between the capital, Prague, and the rest of the country. Prague and its hinterland represent a stable high-health cluster, benefiting from what can be termed a triple dividend: superior economic conditions (A.1), high educational attainment (A.2), and concentrated healthcare infrastructure (A.7).
- Statistical Stagnation: The Wilcoxon signed-rank test for Index B demonstrates much lower rates of change compared to Index A.1-A.7 (see Table 5). This indicates that while the conditions for health (determinants) have fluctuated, the actual health status of the population is deeply entrenched in the regional structure. This decoupling of determinant improvement from health outcomes suggests a significant time lag and points to the necessity of long-term, generational health strategies.

Table 5 Dynamic changes in health inequality determinants

Variable	Change between 2001 and 2011	Change between 2011 and 2021
A.1–A.7	$p < .001$	$p = .52$
B	$p < .001$	$p = .04$

Discussion

The spatial health inequalities identified in Czechia reflect a sophisticated interplay between historical path-dependencies, economic transitions, and social stratification. While the analysis of aggregated ecological data does not permit direct causal inference, the statistically significant temporal shifts observed constitute critical signals that warrant interpretation through established frameworks — specifically the layered determinants model [22] and the theory of differential vulnerability [25]. Taken together, the findings indicate that despite two decades of significant macro-economic growth, health inequalities remain structurally entrenched and spatially rigid at the LAU 1 level, with Moran's I for health outcomes (Index B) remaining consistently high across all three time points (0.55, 0.44, 0.54 in 2001, 2011, and 2021 respectively).

Structural Rigidity and the Left Behind Places Narrative

The persistent Low-Low clusters of health outcomes identified in North-West Bohemia and the Moravian-Silesian region — stable across all three census time points — align with the international discourse on ‘left-behind places’ [34].

Much like the post-industrial North of England, these Czech regions exhibit a specific ‘geography of discontent’ where structural economic decline is strongly associated with adverse health outcomes. The LISA transition analysis indicates that these areas have not merely been navigating a temporary transition; rather, their spatial classification has remained unchanged over twenty years, suggesting a long-term decoupling from national prosperity. This pattern is consistent with the observation that where globalisation and transition-era investments fail to take root, health equity remains elusive regardless of national healthcare quality [34].

This geographic rigidity is also consistent with the concept of term vulnerability amplification [29], which refers to the dynamic interaction between compositional factors (population characteristics) and contextual factors, such as institutional capacity and access to preventive care. In regions with lower educational attainment and weak public infrastructure, adverse health outcomes are likely amplified by macro-political and macro-economic forces [35], though the aggregate nature of our data precludes direct individual-level verification of this mechanism.

The Failure of Territorial Cohesion and Spatial Traps

The stagnation observed in Czechia's rural borderlands and internal peripheries serves as a critical case study for Territorial Cohesion policy within the European Union. While EU structural funds aim to reduce regional disparities, our data — specifically the expansion of Low-Low clusters in healthcare accessibility (A.7) between 2011 and 2021, confirmed by statistically significant deterioration ($p < .001$) — point to a persistent failure to bridge the gap between metropolitan centres and inner peripheries. This mirrors trends observed in the French ‘empty diagonal’ or parts of Poland, where geographic centrality does not guarantee social or health integration [36–38].

Without targeted, place-based interventions, these regions risk consolidating into spatial traps, where ageing populations face a compounding burden of social isolation and systemic barriers to care. This trajectory is consistent with the unexpected increases in mortality observed in districts previously classified as low-risk, a pattern of vulnerability that was further exposed during the covid-19 pandemic [29, 39].

The Socioeconomic Gradient and the Role of Education

Spatial clustering intensified markedly in the first decade, as reflected in the increase in Moran's I for the aggregate determinants index from 0.26 (2001) to 0.51 (2011), before partially receding to 0.39 in 2021. The most pronounced and persistent disparities appear in economic status (A.1) and educational attainment (A.2), corroborating the well-established association between territorial socioeconomic profiles and population health [40, 41]. The widening divergence in Index A.1 between the metropolitan

core and the North-West periphery suggests that current horizontal redistribution mechanisms have been insufficient to offset the market-driven concentration of capital.

Education (A.2) emerges as the most robust compositional determinant and the only index showing statistically significant improvement across both observed decades ($p = .02$ for 2001–2011; $p = .07$ for 2011–2021). Because formal education is typically completed in early adulthood — a life stage with lower health variability — it is largely resistant to reverse causality [26, 42]. Education shapes health through both economic pathways (income and employment) and psychosocial mechanisms [43–45]. Districts with persistently low educational attainment show a consistent association with higher rates of chronic disease and shorter life expectancy [41, 46], as well as higher exposure to environmental risks [47].

Policy Implications

The strong spatial correlation between determinants (Category A) and health outcomes (Category B) is consistent with a mechanism of cumulative disadvantage, whereby historical underinvestment in education and infrastructure has been associated with persistent trajectories of poor public health in specific territories. This pattern suggests that existing interventions have been insufficient, frequently failing to address the deeper structural conditions of affected regions [48].

Reducing health inequalities is not guaranteed even in highly developed nations — and in many cases disparities are in fact widening [15, 16]. The Czech experience demonstrates that effective responses must extend beyond clinical interventions toward locally specific structural reforms. The post-2011 stagnation in the composite determinants index (A.1–A.7), combined with the statistically significant deterioration in healthcare accessibility (A.7, $p < .001$) and environmental status (A.4, $p = .01$) in the second decade, indicates that aggregate, top-down economic growth has reached its limit in reducing regional health disparities. Consequently, mitigating long-term socio-economic marginalisation requires policies that prioritise regional territorial cohesion and address the specific needs of populations embedded in enduring spatial gradients of ill-health, with a clear emphasis on structural rather than purely fiscal interventions.

Strengths and Limitations of the Study

A primary strength of this research lies in its longitudinal consistency and methodological robustness. By utilising a stable database of 57 health determinants and outcomes [21, 49], this study provides a rare two-decade perspective on the evolution of health inequalities in a transitional economy. The reliance on established, publicly available databases ensure not only the transparency and reproducibility of our findings but also the continuity of data collection protocols over time. Furthermore, the application of advanced spatial statistics (LISA, Moran's I) alongside non-parametric temporal tests allowed for a sophisticated triangulation of spatial and temporal dynamics, moving beyond simple descriptive accounts.

However, several limitations must be acknowledged. Firstly, while the Weighted Sum Approach (WSA) ensures a holistic evaluation without arbitrary bias, we recognise that the equal weighting of all 57 indicators may mask the disproportionate influence of specific drivers in certain regions. The observed stagnation of the composite determinant index (A.1–A.7) between 2011 and 2021 raises important questions regarding instrument sensitivity. It is possible that as regional disparities become more nuanced, a linear index may lose its capacity to detect subtle, non-traditional shifts in inequality.

Secondly, the study is constrained by the ‘ecological fallacy’ inherent in aggregate territorial data. While our analysis identifies significant spatial clusters at the LAU 1 level, these patterns do not necessarily reflect the experience of every individual within those regions. Future research should aim to integrate micro-level longitudinal data to better understand the life-course trajectories behind these spatial gradients.

A further limitation concerns the composition of the Health Outcomes Index (B), which relies predominantly on mortality-based indicators. Broader dimensions of population health – including self-rated health, disability prevalence, and quality of life – are not captured in the current framework. This reflects a data availability constraint rather than a conceptual omission: indicators of this kind are typically derived from survey data, which were not available at the LAU 1 level for all three census time points examined here. It should be noted that a previous iteration of this framework, focused on a single cross-sectional year for which survey data were accessible, did incorporate self-reported health and disability indicators alongside the mortality-based measures [49]. The results of that analysis confirmed the validity of the mortality-based composite as a proxy for broader health status, as the spatial patterns produced by the extended indicator set were consistent with those generated by the mortality-only framework. Nevertheless, future longitudinal applications of this model should prioritise the integration of survey-based health indicators as they become available at sub-national level, to capture dimensions of population health that mortality data alone cannot reflect.

A limitation concerns the temporal coincidence of the 2021 data endpoint with the covid-19 pandemic. The pandemic disproportionately affected socioeconomically disadvantaged and peripheral regions across Central Europe, and it is plausible that some of the deterioration observed in health outcomes and healthcare accessibility indicators in the final period reflects acute pandemic effects rather than purely structural long-term trends. The current study was not designed to disentangle these two dynamics, and the 2021 composite indices should therefore be interpreted with this caveat in mind. Notably, the persistence of Low-Low spatial clusters across all three time points – including 2001 and 2011, well before the pandemic – provides strong evidence that the structural health traps identified here predate and are independent of covid-19. Nevertheless, future research should explicitly model the pandemic period as a potential confound, distinguishing between the structural spatial penalty documented in this study and the acute, if spatially uneven, shock introduced by the pandemic. This would allow a cleaner assessment of whether the post-2011 stagnation observed in health determinants has been further compounded or merely temporarily amplified by the pandemic.

Finally, the current model—though comprehensive—may need to evolve to incorporate emerging determinants of health equity. The post-2011 stagnation suggests that traditional socioeconomic indicators (e.g., unemployment, formal education) should be supplemented with variables reflecting contemporary vulnerabilities, such as digital exclusion, access to green infrastructure, and housing energy poverty. Addressing these factors will be essential for maintaining the model's diagnostic power in future assessment cycles.

Conclusions

This study set out to examine whether two decades of macro-economic growth and European integration in Czechia have translated into meaningful reductions in spatial health inequalities — or whether structural disparities have persisted despite national prosperity. The evidence points clearly to the latter. Regional health inequalities at the LAU 1 level remain spatially entrenched, with Low-Low clusters of poor health outcomes anchored in the northwestern and northeastern border peripheries across all three observed time points. The composite health outcomes index (B) showed only marginal improvement over twenty years, while disparities in healthcare accessibility (A.7) and environmental status (A.4) intensified in the second decade — precisely the period of greatest macro-economic stability.

The Czech case is analytically significant beyond its national context. While its local specificities — including the historical legacy of post-WWII resettlement and a relatively extensive internal periphery — shape the precise geography of disadvantage, the underlying dynamic is characteristic of post-socialist Central Europe more broadly. The Czech case is analytically significant beyond its national context. While its local specificities — including the historical legacy of post-WWII resettlement and a relatively extensive internal periphery — shape the precise geography of disadvantage, the underlying dynamic is characteristic of post-socialist Central Europe more broadly. Analogous processes of peripheral marginalisation are documented in Poland, where peripheral regions show persistent divergence between economic growth and healthcare access [50], in Hungary, where post-industrial deindustrialisation has generated structurally embedded regional health inequalities that continue to manifest decades after the socialist transition [51], and in Slovakia, where socioeconomic composition of urban neighbourhoods is significantly associated with early mortality, pointing to deeply embedded spatial gradients of health disadvantage within cities [52]. The methodological framework employed here is therefore directly transferable for comparative research across the V4 region, where shared historical trajectories and comparable data infrastructures make systematic cross-national monitoring both feasible and necessary.

Three concrete implications follow from these findings. First, healthcare policy must address the spatial dimension of access explicitly. The centralisation of specialised care into regional centres has created structural barriers in peripheral districts that general improvements in population mobility have not resolved; targeted investment in primary and preventive care infrastructure in Low-Low healthcare clusters is warranted. Second, environmental remediation in historically industrialised agglomerations

requires sustained, place-specific intervention rather than reliance on broader economic transition. The persistence of environmental burdens over twenty years of national development suggests that market mechanisms alone will not resolve this dimension of health injustice. Third, education policy should be understood as long-term health policy. Given that educational attainment is the most robust and causally prior compositional determinant identified in this study, investments in educational quality and attainment in structurally disadvantaged districts represent the most durable lever available for reducing future health disparities.

More broadly, this study argues that the holistic, multi-indicator monitoring framework employed here should be institutionalised as a standard tool within EU territorial cohesion policy. A composite model that tracks both determinants and outcomes at the sub-national level – evaluated at regular census intervals – would enable early identification of emerging spatial traps and allow cohesion funding to be targeted at regions before structural disadvantage becomes irreversible. Economic indicators alone are insufficient for this purpose, as the Czech evidence demonstrates: regions can participate in national economic growth while simultaneously deteriorating on health determinants that are invisible to GDP-based monitoring.

Future research should pursue three directions: integration of micro-level longitudinal data to move beyond the ecological level of analysis; incorporation of emerging determinants such as digital exclusion, housing energy poverty, and access to green infrastructure; and systematic comparative analysis across V4 countries using a harmonised version of this framework.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

DH conceptualized the study, developed the methodology, supervised the research, and contributed to writing the original draft as well as reviewing and editing the manuscript. B-EChM conceptualized the study, developed the methodology, and contributed to writing the original draft as well as reviewing and editing the manuscript. JC curated the data, performed the formal analysis, contributed to the methodology, validated the results, and prepared the visualizations. AK conducted the investigation, contributed to writing the original draft as well as reviewing and editing the manuscript, prepared the visualizations, and provided resources. All authors read and approved the final manuscript.

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Not applicable.

Data Availability

The raw indicator data underlying this study are drawn from publicly available sources, including the Czech Statistical Office (CZSO), the Institute of Health Information and Statistics of the Czech Republic (IHIS), the Ministry of Labour and Social Affairs (MoLSA), and the Czech Hydrometeorological Institute (CHMI), all of which are openly accessible. The composite indices and derived datasets generated during the current study are stored on an institutional server and are available from the corresponding author upon reasonable request.

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Figures

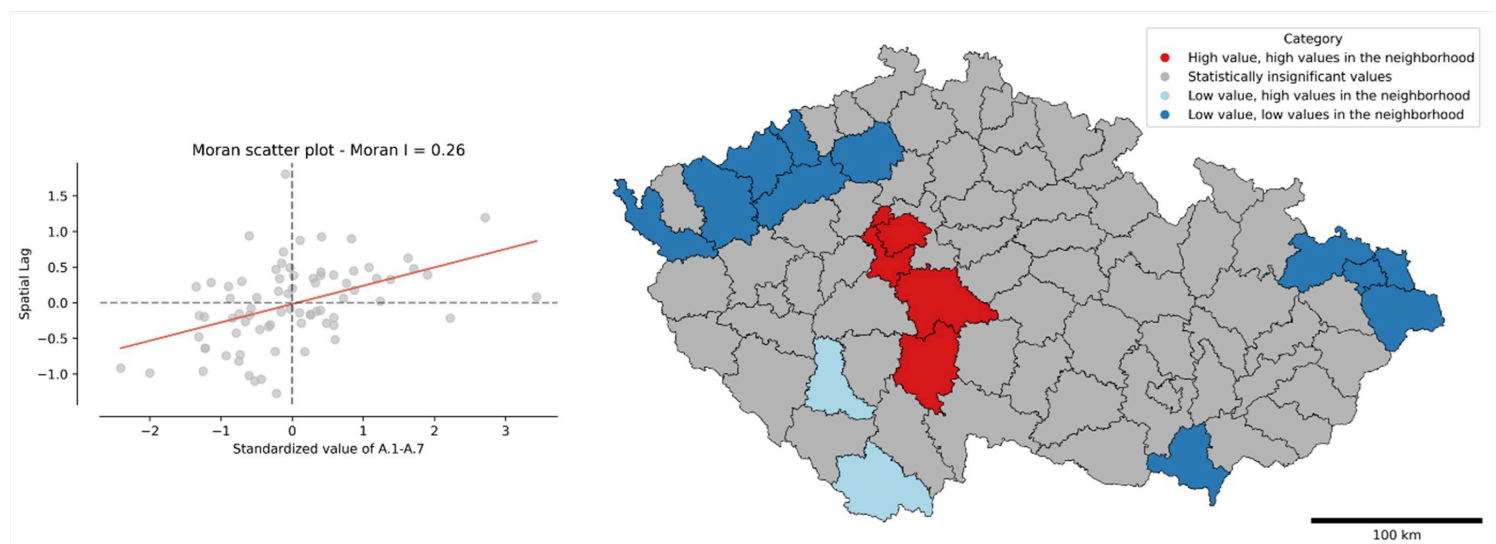


Figure 1

Variable A.1–A.7 for the year 2001

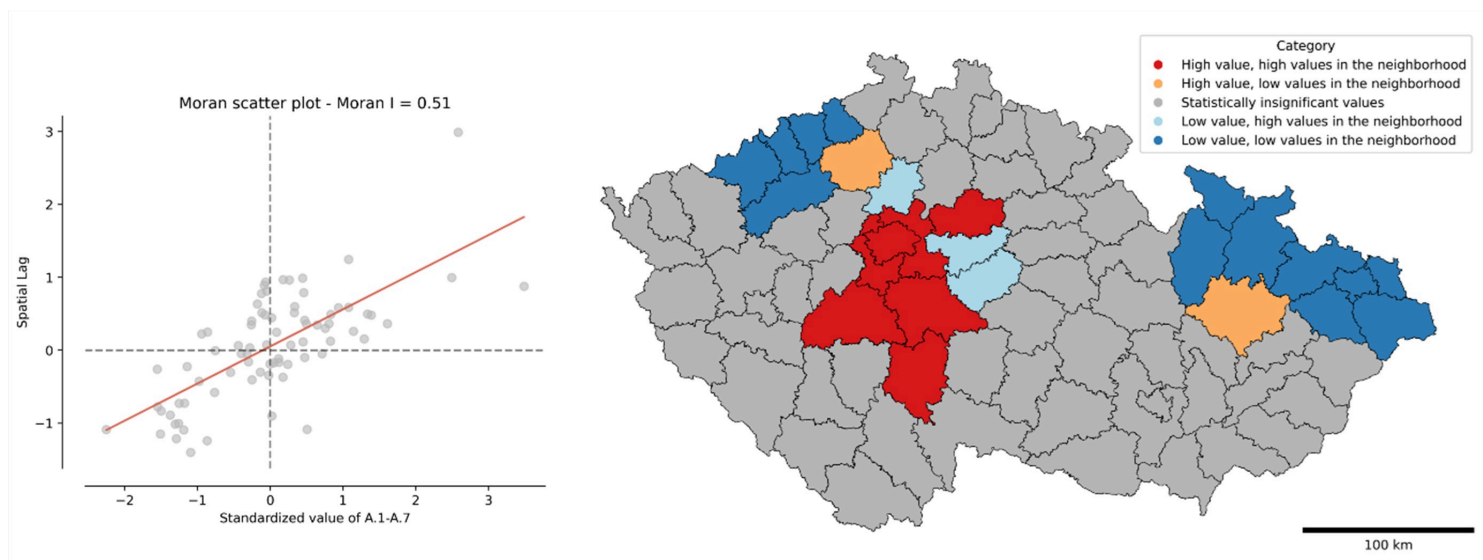


Figure 2

Variable A.1–A.7 for the year 2011

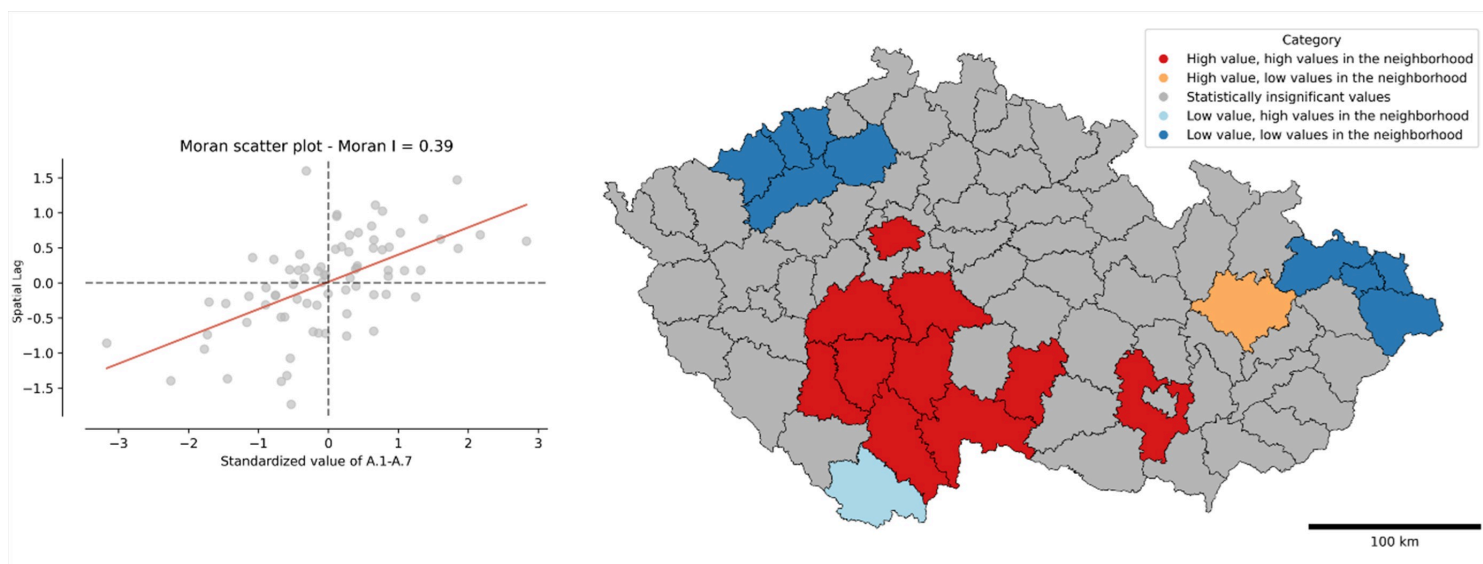


Figure 3

Variable A.1–A.7 for the year 2021

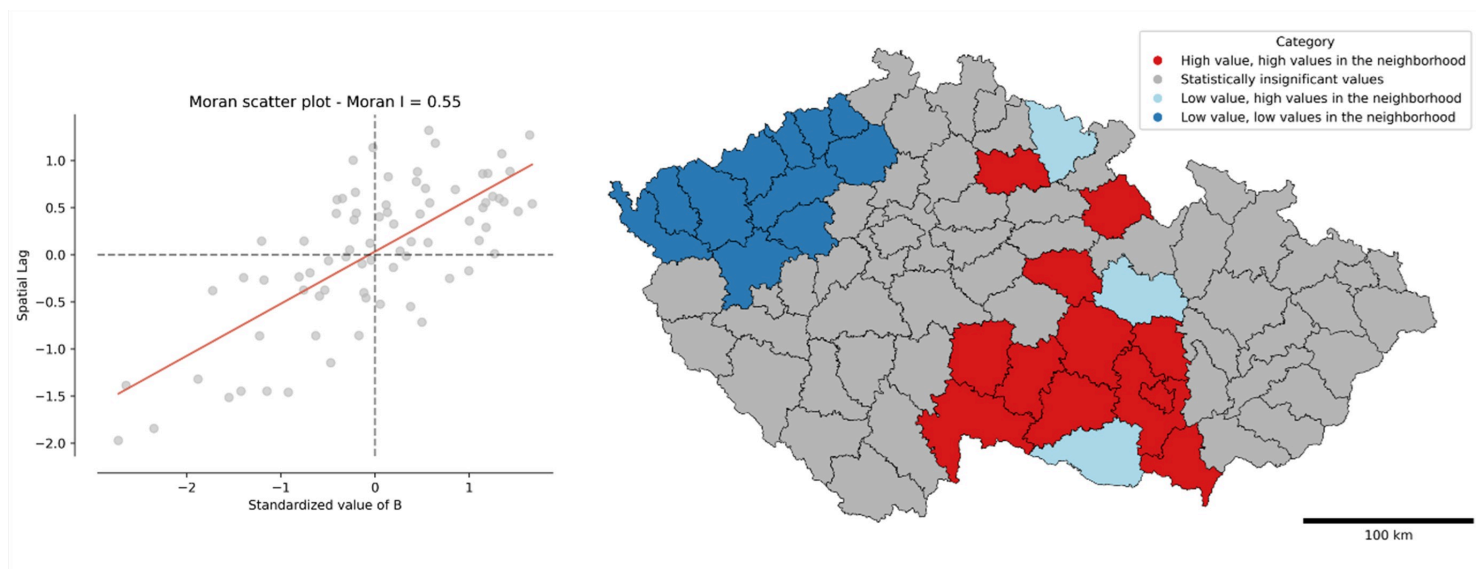


Figure 4

Variable B for the year 2001

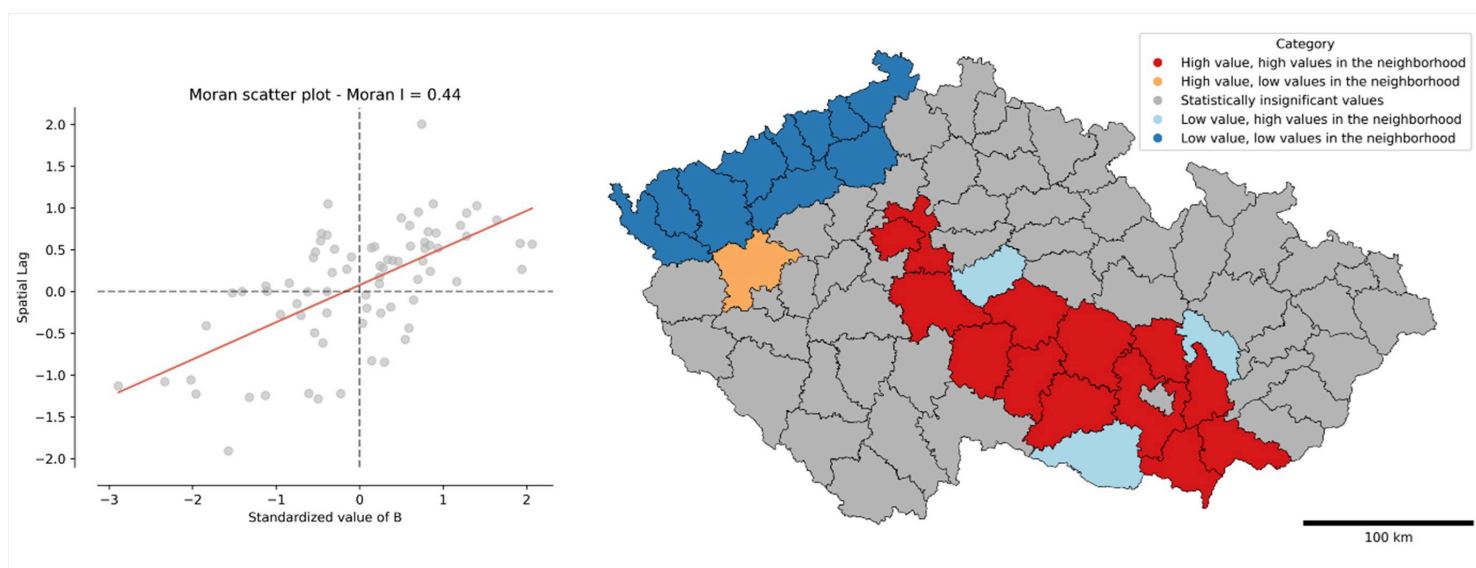


Figure 5

Variable B for the year 2011

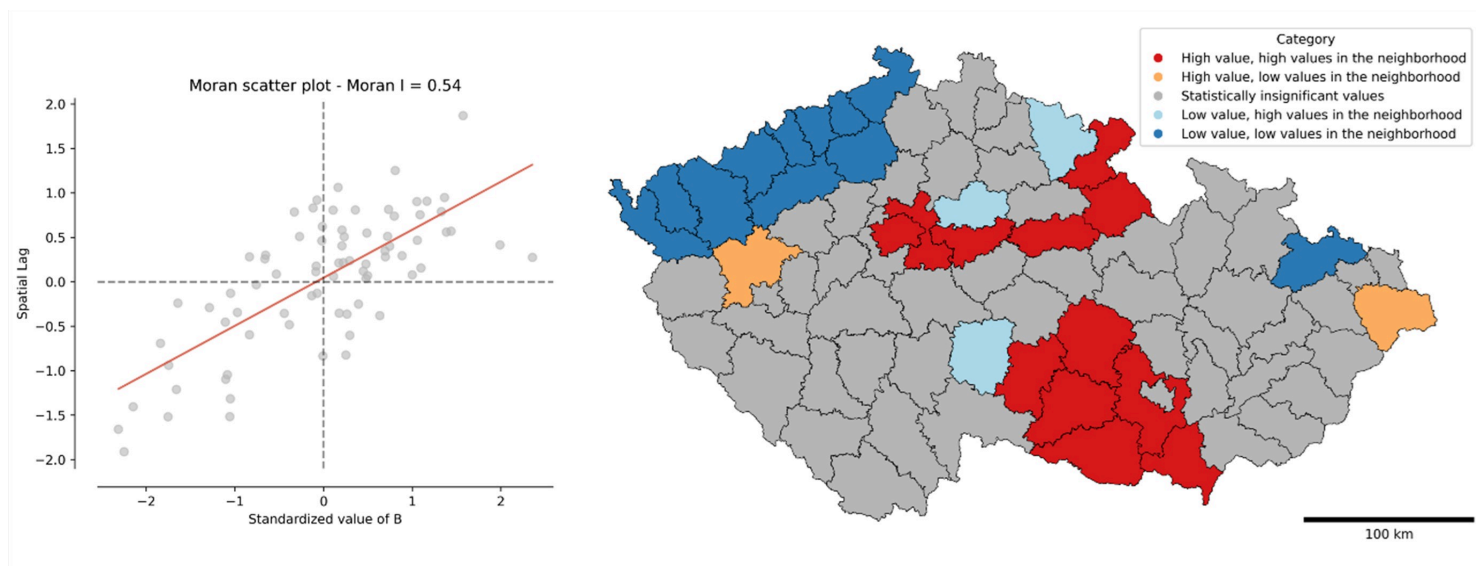


Figure 6

Variable B for the year 2021

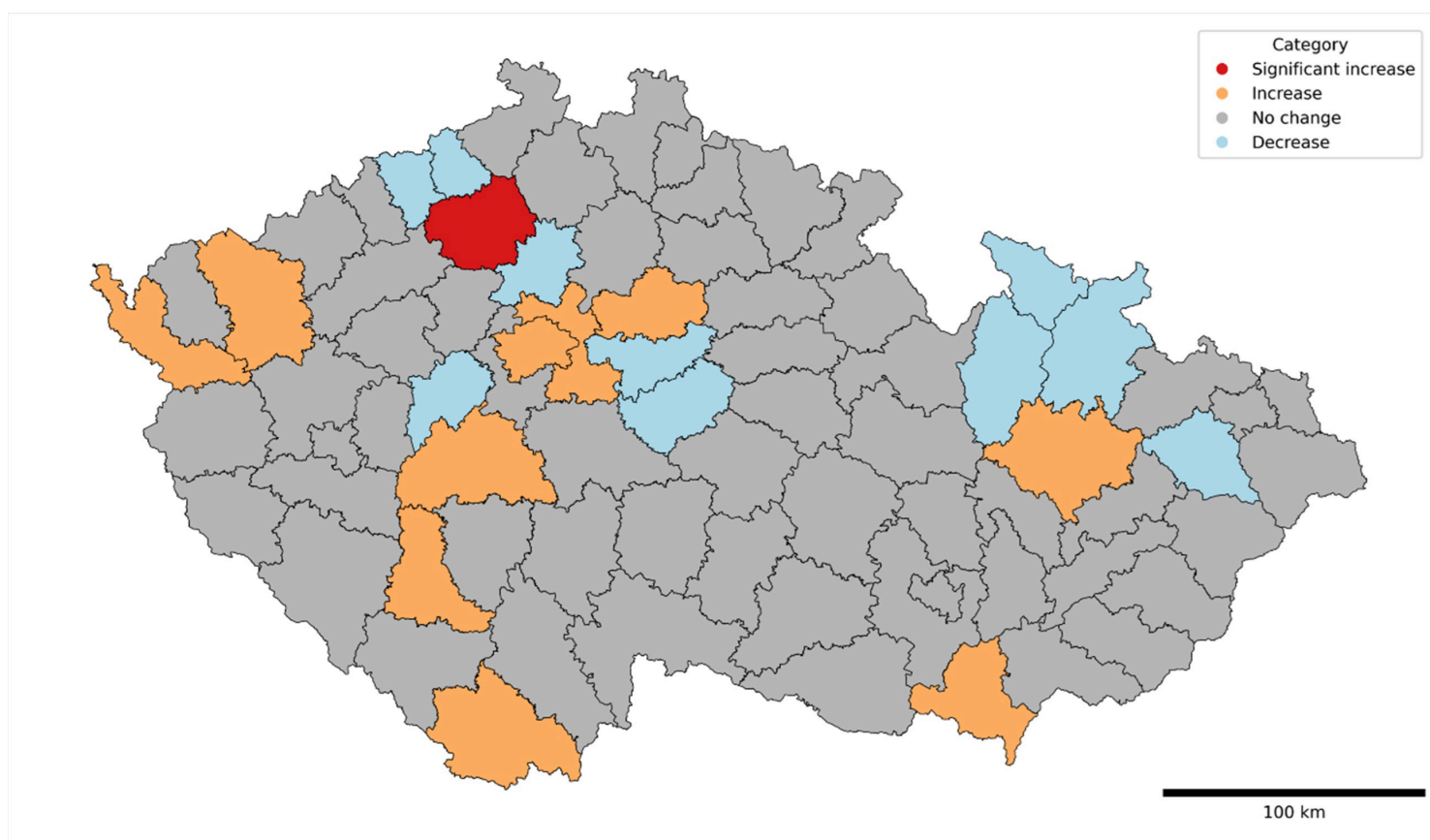


Figure 7

Change in A.1-A.7 between the years 2001-2011

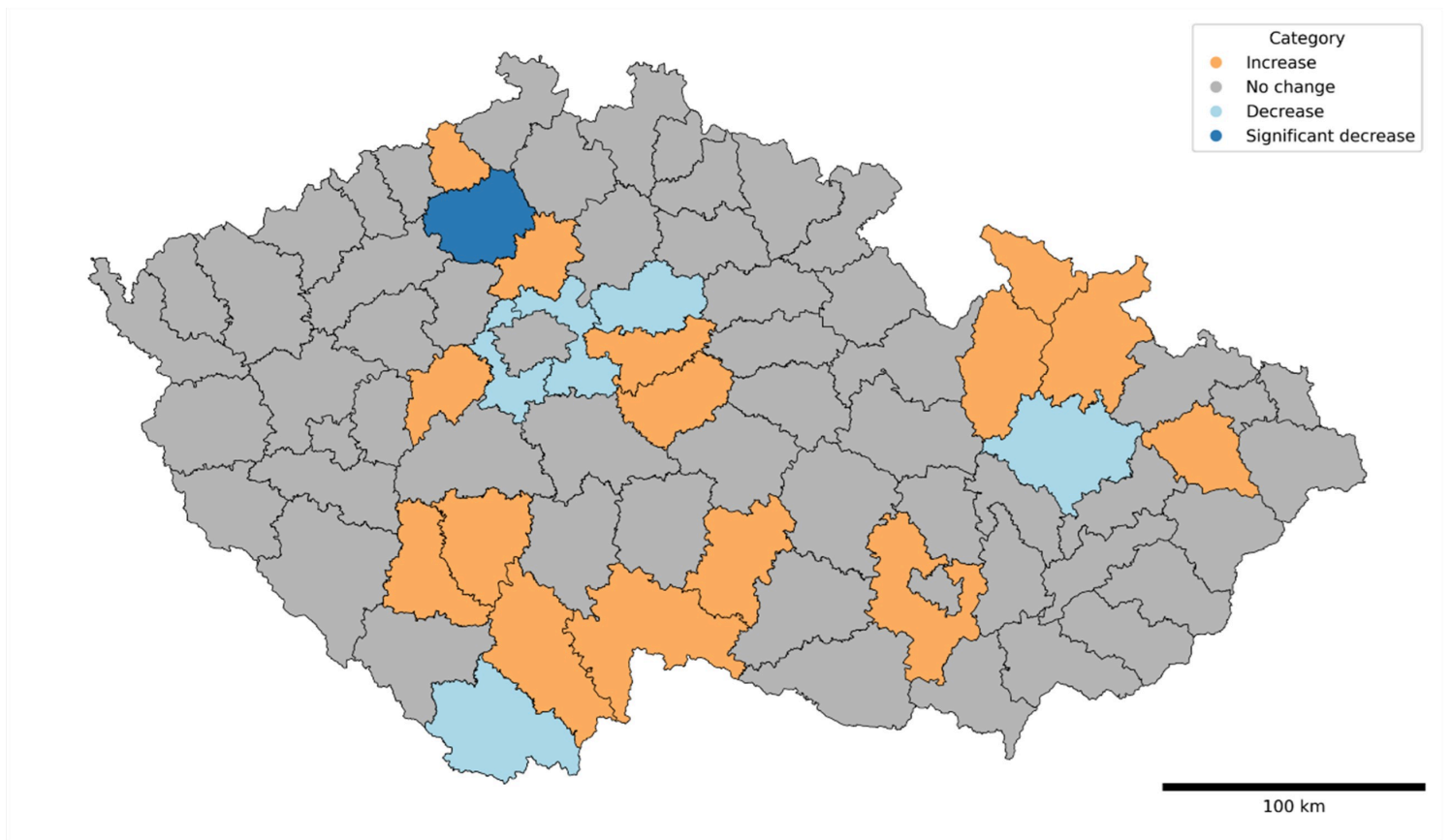


Figure 8

Change in A.1–A.7 between the years 2011–2021

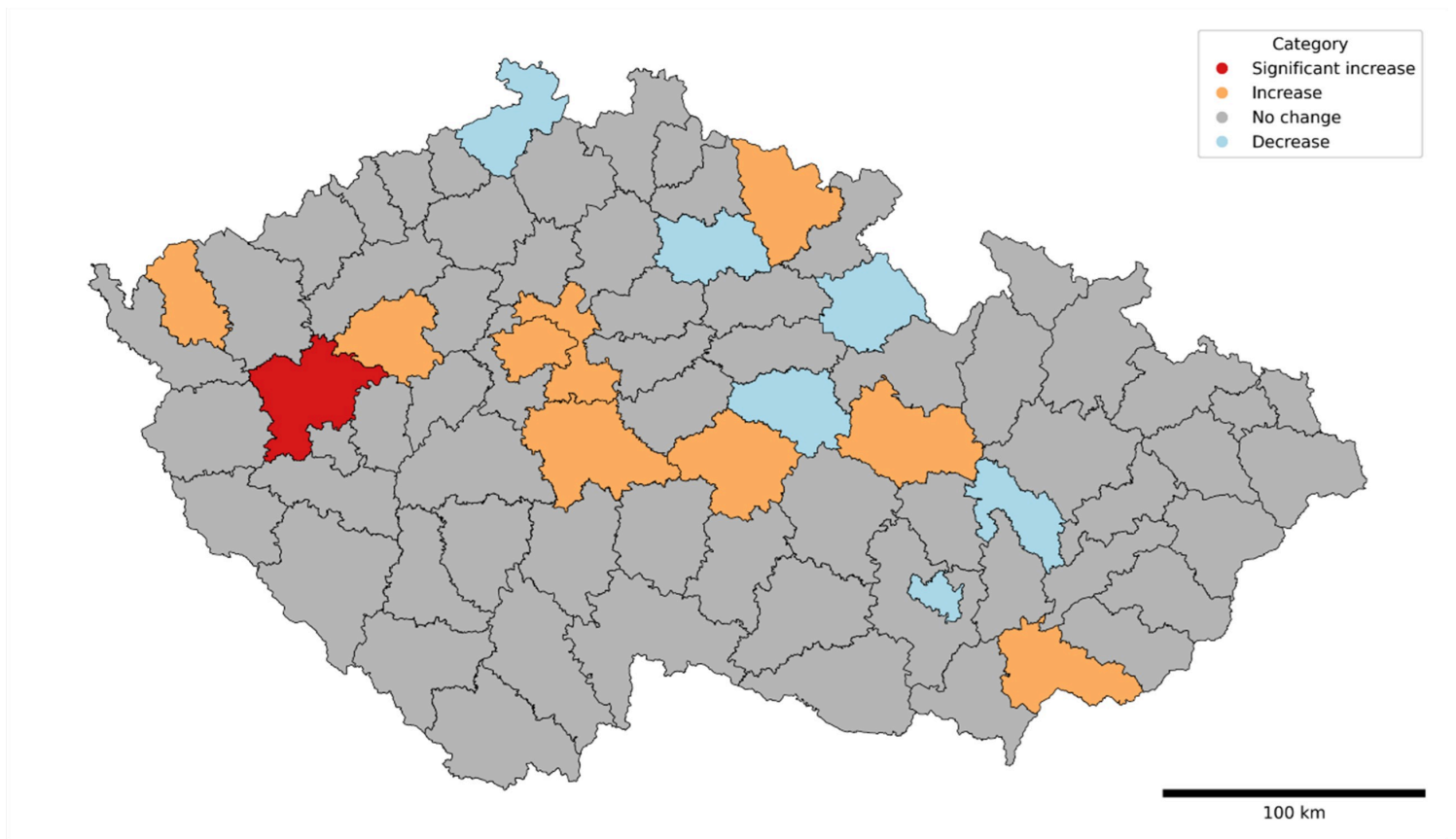


Figure 9

Change in B between the years 2001–2011

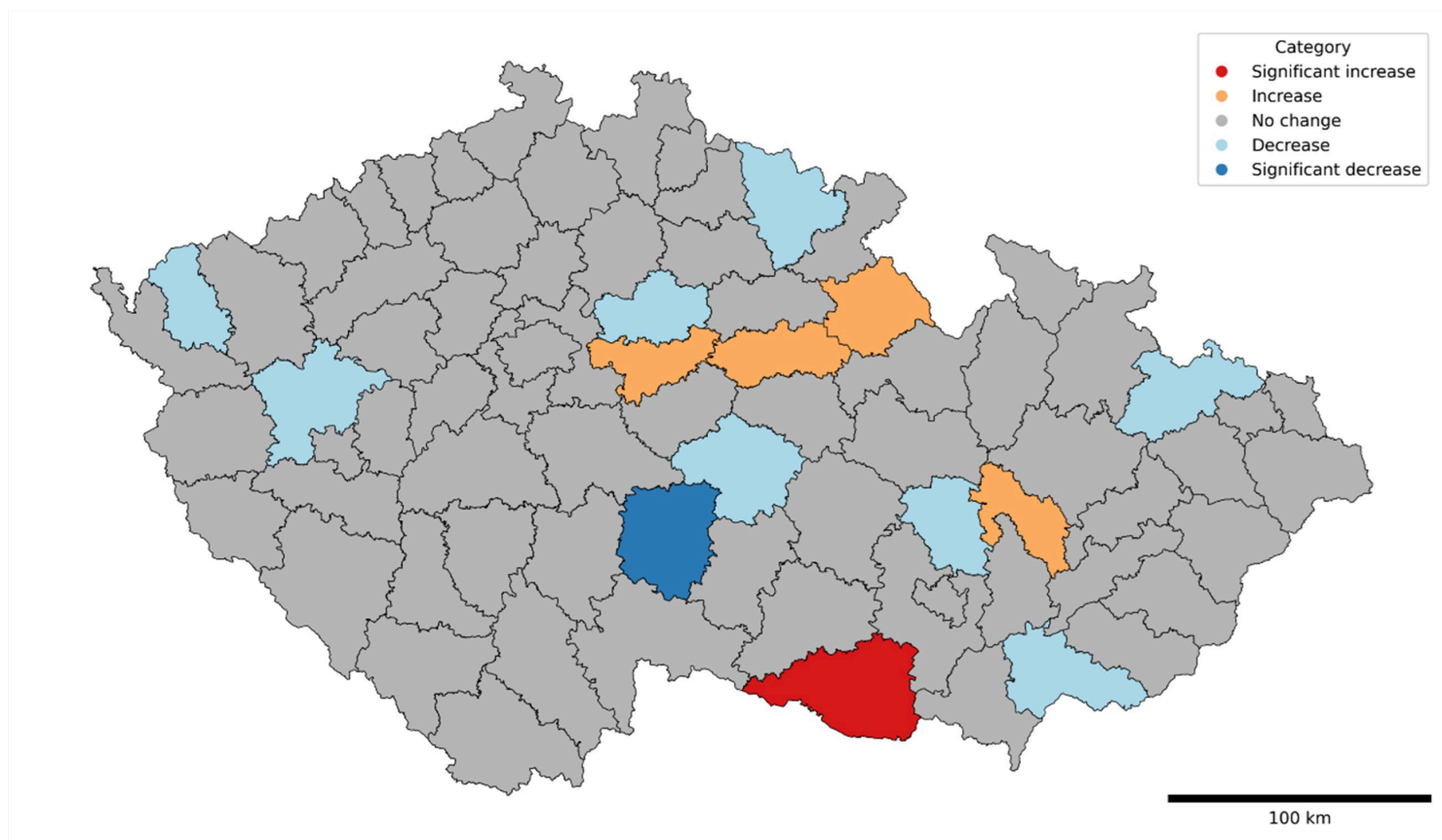


Figure 10

Change in B between the years 2011–2021

Supplementary Files

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