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HISTORICAL LAND-USE DYNAMICS AND THE GEOGRAPHICAL DRIVERS OF BUILT-UP EXPANSION IN THE CZECH REPUBLIC, 1842–2019: A SPATIOTEMPORAL ANALYSIS

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ABSTRACT

Built-up expansion is a major indicator of long-term landscape transformation, yet its historical trajectories and socio-environmental drivers remain insufficiently integrated over extended time periods. This study examined built-up-area dynamics in the Czech Republic from 1842 to 1950 to 2019 using a GIS-derived retrospective spatiotemporal design. The analysis included 43,386 spatial units across 67 geographical locations, representing 655.48 ha. Built-up presence, dynamic categories, settlement context, protection status, population, elevation, slope, temperature, precipitation, wind, and landscape type were evaluated using descriptive statistics, area-weighted comparisons, chi-square tests, Cramér's V, weighted logistic regression, and five-fold cross-validation. Built-up area increased from 93.63 ha in 1842 to 406.02 ha in 1950 and 609.60 ha in 2019, representing a 551.07% increase. Recent development accounted for 84.71% of the mapped area and was highest in urban settings. Urban locations had higher odds of recent development than peri-urban areas, whereas rural settings had lower odds. Protection status was not independently significant after adjustment. Population, elevation, temperature, wind, slope, and landscape type remained associated with recent development. Predictive performance was limited, indicating that additional spatial, policy, accessibility, and economic variables are required for stronger classification. The findings demonstrate spatially uneven expansion shaped by interacting social and environmental factors and support more context-sensitive land-use planning across Czech urban, peri-urban, rural, and protected landscapes.

Keyboard: Built-up expansion, Czech Republic, GIS, Land-use change, Spatiotemporal analysis

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1. Introduction

The most evident forms of long-term landscape modification are the expansion of built-up areas. It is the result of a combination of population change, economic growth, industrialisation, transport expansion, planning developments and changes in the way urban and rural space is organised. These processes have taken place in a Central European landscape, which has been formed by pre-industrial landscapes of settlement, industrialisation in the nineteenth century, political restructuring in the twentieth century, and post-socialist development. The contemporary settlement structure in Czechia is highly informative for the analysis of such transformations due to the traces of several periods, as well as significant regional variations in the level of urbanisation, agricultural transformation, forest transition, suburbanisation and infrastructure development. The broad-scale structural changes in landscapes as well as the uneven spatial changes in land use represent the characteristic of long-term landscape change in the Czech Republic, which shows that the recent development trends are not sufficient to explain the historical landscape trajectories (Kupková et al., 2021).

Built-up-area dynamics are not only about a continuous growth of urban areas. They encompass historically established settlements, recent built-up areas, and abandoned sites (as well as their disappearance), temporary development, and redevelopment after periods of abandonment. These categories demonstrate a sequence of reorganisation of landscapes that is not necessarily unidirectional. The research conducted by the authors and their colleagues on the dynamics of functional urban areas in Czechia, Slovakia and Poland revealed that the dynamics of land use change differ significantly depending on the urban hierarchy, the influence of the urban area and the development pattern of national territories (Wnęk et al., 2021). In addition, the intensity and direction of land-cover flows in Czechia have been impacted by the post-communist transformation, which has been associated with economic restructuring, agricultural adjustment, demographic redistribution and changes in land-management practices (Grešlová et al., 2023). The recent mapping of landscape transformation in the Czech Republic has also shown that there is significant variation at the regional and local levels, which could mask the national trends (Kupková & Boudný, 2025).

Urbanisation is a key driver of the transformation of natural, agricultural and semi-natural land to urban areas. Planning systems, infrastructure, land markets, accessibility, and the connection between central cities and surrounding settlements (Nuissl & Siedentop, 2020) are all responsible for its spatial expression. Population and economic growth are often assumed to be the key forces behind urban expansion, but vary from city to city and between the different development contexts (Mahtta et al., 2022). Land systems can also be defined by feedbacks, path dependence, cross-scale interactions, and competing social and environmental demands, and involve historical, spatial, and institutional aspects that need to be considered (Meyfroidt et al., 2022). The characteristics are particularly relevant in Czechia, where urban and peri-urban development has been different from rural development, under the various political and economic regimes.

With the new possibilities of geospatial analysis, it is now possible to reconstruct and compare built-up patterns over long historical periods. The capacity of observing urban growth and land-cover dynamics over broad areas promptly has been extended by satellite big-data approaches, but their time depth is frequently restricted to the modern remote-sensing era (Kuang et al., 2021). Time-series techniques could uncover the degree, duration, and trend of built-up growth, which is more detailed than the information provided by any comparison of a single date (Yan & Wang, 2021). In Czechia, remote-sensing classifications have proven to be valuable for classification of land-use and land-cover categories and for detecting spatial change, with the use of machine-learning techniques (Svoboda et al., 2022). GIS-based analyses have also been demonstrated in Central European cities, providing insights into the rate and nature of urban and suburban change; the addition of historical maps to remotely sensed imagery and GIS analysis can help to illuminate these changes (Wiatkowska et al., 2021).

Determinants of built-up expansion are seldom consistent. The location of development is influenced by population concentration, settlement type, environmental protection, elevation, slope, climate and landscape type, either individually or combined. Multiple factors, however, must be assessed in a statistical manner to discriminate between general associations and simple description. Through the analysis of the detector, Liu et al. (2020) found that built-up expansion can be formed by various socioeconomic and environmental factors rather than a single factor. The viewpoint is applicable for the case of Czechia, which is characterized by the diversity of its protected landscapes, topography, climatic gradients, and urban–rural settings, which can affect the historical development in a different way.

Although there is much research on recent changes in land use, less research has incorporated built-up information from the nineteenth century, the mid-twentieth century, and the twenty-first century with a large suite of socio-environmental predictors of land cover change. There has also been little attention paid to redeveloped, temporal, and extinct built-up spaces as well as recent and continuous development. This study aimed to analyze built-up area dynamics in the Czech Republic for 1842, 1950, and 2019, and to determine their relationships with settlement types, population size, protected area status, elevation, slope, climatic characteristics (temperature, precipitation, wind), and landscape types. The goal was to measure the change in long-term built-up area and to find out which socio-environmental factors are associated with the recent development separately in a GIS-based spatial and temporal context.

Objectives of the study:

1. To quantify historical built-up-area changes in the Czech Republic from 1842 to 2019.
2. To compare built-up-area dynamics across urban, peri-urban, rural, protected, and non-protected settings.
3. To identify socio-environmental factors independently associated with recent built-up development.

2.Methodology

2.1Study Design and Data Source

The Czech Republic was selected to analyse the built-up-area dynamics and their socio-environmental drivers since 1842 via the use of a GIS-derived spatiotemporal design, which is a type of retrospective observational study. Secondary data was derived from the publicly available dataset: Mapping Socio-Ecological Factors, Built-Up Expansion and Land Use Change: Spatial Analysis and Insights for Planning and Restoration_A_2 (Prados, 2026), which is available under a Creative Commons Attribution 4.0 licence. The primary analytical file was chosen as this had the most comprehensive integration of historical built-up presence and socio-environmental attributes. It contained 43,386 spatial units derived from GIS data from 67 geographical locations, 31 variables, and a total mapped area of 655.48 ha, of which built-up was observed 3 times, in 1842, 1950, and 2019.

2.2Study Variables and Operational Definitions

Every observation was a spatial unit created by the GIS through spatial joining, spatial intersection, spatial overlay, or other spatial operations. The main outcome was dynamic (recent, continuous, extinct, temporal, redeveloped) based on the presence or absence of built-up structures over the three historical years. This classification has been confirmed with the CERRT variable. The area_ha was used to measure built-up area. The most important factors were the geographical location, population category, settlement category, the presence or absence of protected areas, built-up unit size, elevation, slope, temperature, precipitation, wind conditions, and landscape type. Factors that are independently associated with recent built-up development after the other factors included were specified as socio-environmental drivers.

2.3Data Preparation and Quality Assessment

All variables were examined for missing values, duplication, impossible values, inconsistent coding, and variables showing no analytical variation. There were no missing values in the primary outcome, and agreement was checked for dynamic and CERRT before analysis. Categorical variables were redefined as consistent groups for statistical analysis, and area was adjusted to hectares. Direct spatial modelling was not possible in the case of the coordinate fields due to the lack of geographical variation. Sparse temporal categories were kept, and redeveloped categories were kept for descriptive analysis and bivariate analysis, and an adjusted regression outcome was dichotomized as recent vs all other categories of dynamic categories. All 43,386 original spatial units have been preserved, and repeated observations with the same predictor and outcome profile have been aggregated, retaining the frequency weights from the original observations.

2.4Historical and Descriptive Analysis

Python was used to calculate frequencies and percentages for settlement category, protection status, and built-up dynamic category. Observation-based distributions were presented as "counts" and percentages, and area-weighted distributions were generated by dividing the values of the area_ha attribute by the numbers in the original observed distribution to normalize the distribution for the different sizes of the spatial units. Built-up presence was summarized for 1842, 1950, and 2019. Absolute change was the actual change from the first period to the last period of the graph, while relative change was presented as a percent of the first period. Estimated annualized change was calculated using the compound annual growth rate method for 1842–1950, 1950–2019, and 1842–2019. Python was also used to produce area-weighted cross-tabulations that compared the dynamic categories to the urban/peri-urban/rural/protected/non-protected categories.

2.5Bivariate and Multivariable Statistical Analysis

Categorical socio-environmental variables were correlated with built-up-area dynamics with Pearson's chi-square test, and the strength of association was measured with Cramér's V. The following geographical variables were evaluated: geographical location, population, settlement category, protection status, temperature, precipitation, wind, elevation, slope, built-up unit size, and landscape type. Using a weighted binary logistic regression model, independent factors associated with recent development (coded 1) versus all other dynamic categories (coded 0) were identified. These variables were used in the model: settlement category, protected status, population, elevation, slope, temperature, precipitation, wind, and landscape type. Peri-urban settlement was the reference category, and the adjusted odds ratios (AORs) with 95% confidence intervals (CIs) and two-sided p-values were presented. A p-value of less than 0.05 was considered to be statistically significant.

2.6Model Validation, Software, and Ethical Considerations

A multi-category predictive model was created to study the capacity of the variables in the model to separate the five built-up dynamics. 2141 aggregated predictor profiles and five-fold cross-validation were used in the analysis. The categories of the outcome were highly imbalanced, and this is why balanced accuracy was chosen. Balanced accuracy was calculated, and the standard deviation of balanced accuracy across the five folds was computed. Analytical packages were used in Python to clean, analyze, model by regression, validate, and prepare figures. This study was based on an openly available secondary dataset that did not include any personal or identifiable information, so permission and informed consent were not required, and the data were analysed under the conditions set by the data repository licence.

3.Results

3.1Dataset Characteristics and Analytical Sample

The final dataset included 43,386 spatial units of built-up area from the GIS, which were distributed across 67 geographical locations in the Czech Republic, including 31 variables and 655.48 ha of mapped area, with no missing values for the primary outcome variable; 40.39% of the spatial units were urban, 27.20% peri-urban, and 32.41% rural, while 8.60% were in protected areas and 91.40% were outside protected areas. Here are the properties of the analytical data from the GIS (Table 1).

Table 1. Characteristics of the GIS-derived analytical dataset

Characteristic	n	% or value
Total spatial units	43,386	100.00
Total variables	31	—
Geographical locations	67	—
Total mapped area, ha	—	655.48
Historical reference years	3	—
Missing primary-outcome values	0	0.00
Urban spatial units	17,523	40.39
Peri-urban spatial units	11,799	27.20
Rural spatial units	14,064	32.41
Protected-area spatial units	3,730	8.60
Non-protected spatial units	39,656	91.40

3.2Historical Change in Built-Up Area

Built-up-area presence increased markedly across the three reference years, rising from 93.63 ha (8,817 units) in 1842 to 406.02 ha (31,544 units) in 1950 and 609.60 ha (38,452 units) in 2019, corresponding to a net increase of 515.97 ha (551.07%) over the full study period, with the largest relative growth occurring between 1842 and 1950 (333.65%) compared to 1950–2019 (50.14%). The amount of built-up area has changed between 1842 and 2019, as shown in Figure 1. Table 2 presents changes in the presence of built-up areas in the past (1842–2019).

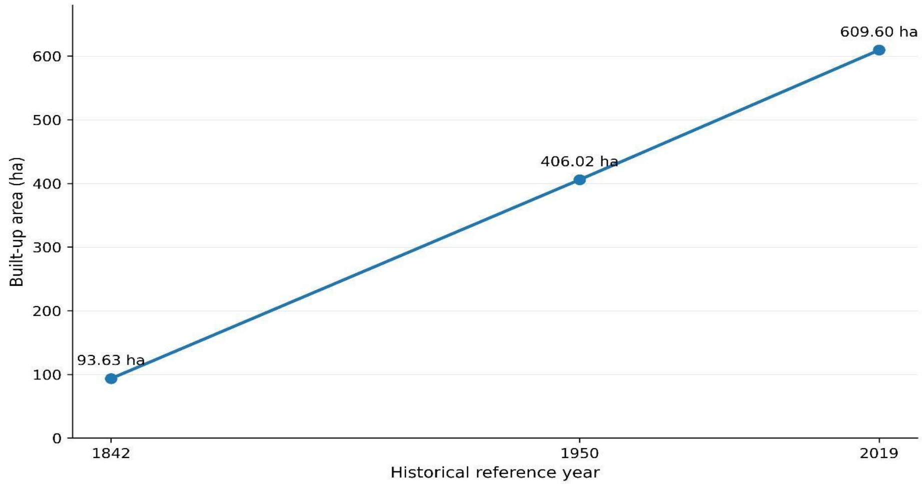

Figure 1. Historical Change in Built-Up Area in the Czech Republic, 1842–2019

Table 2. Historical change in built-up-area presence, 1842–2019

Measure	**1842**	**1950**	**2019**
Built-up spatial units, n	8,817	31,544	38,452
Built-up area, ha	93.63	406.02	609.60
Share of total mapped area, %	14.28	61.94	93.00

3.3Distribution of Historical Built-Up-Area Dynamics

The majority of observations, and most of the area mapped, was for the recent built-up class (79.15%), followed by continuous (9.24%; 8.10%) and extinct (10.84%; 5.99%) classes, with rare amounts of both observation-based and area-based cases for temporal (0.53%; 1.01%) and redeveloped (0.24%; 0.20%) classes, and there was a noticeable difference between the proportions of the observation-based and area-based results for recent built-up. The distribution of the historic built-up area dynamic categories is shown in Figure 2. Table 3 reports the frequency and the amount of built-up-area dynamic categories.

Table 3. Frequency and area of historical built-up-area dynamic categories

Dynamic category	**n**	**% of observations**	**Area, ha**	**% of mapped area**
Recent	34,339	79.15	555.26	84.71
Continuous	4,007	9.24	53.06	8.10
Extinct	4,704	10.84	39.29	5.99
Temporal	230	0.53	6.59	1.01
Redeveloped	106	0.24	1.28	0.20
Total	43,386	100.00	655.48	100.00

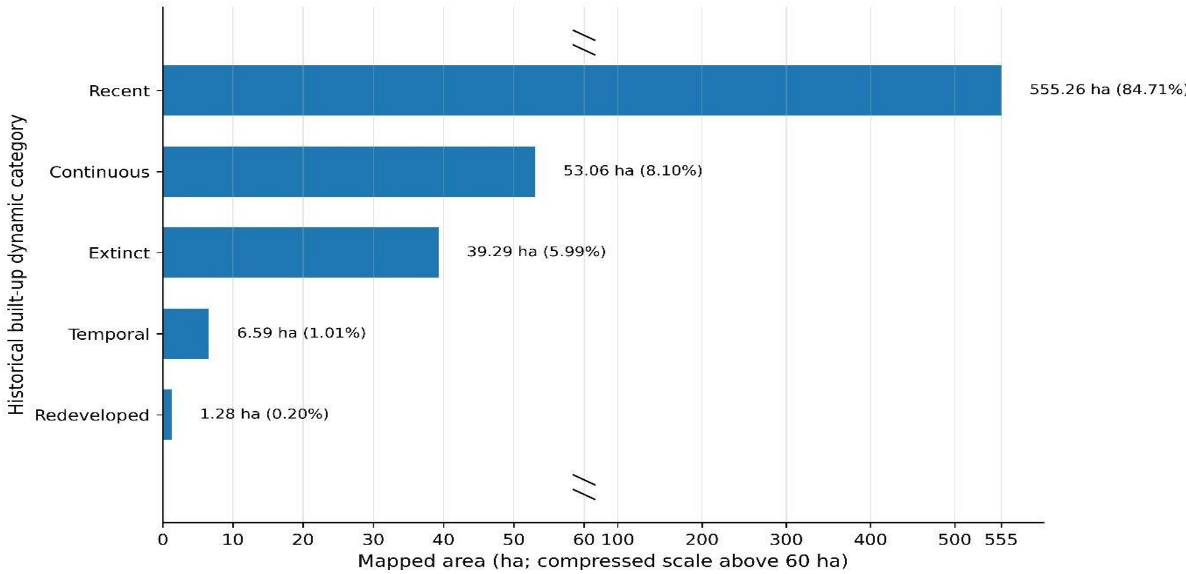

Figure 2. Distribution of Historical Built-Up-Area Dynamic Categories in the Czech Republic

3.4Built-Up-Area Dynamics Across Settlement and Protection Contexts

There was also significant difference in recent development by area-weighted distribution across settlement-type (94.35% recent development in urban areas vs 59.62% recent development in rural areas), and by area-weighted distribution across protection status (85.85% recent development in non-protected areas vs 64.58% recent development in protected areas), with continuous and extinct types increasing from urban to rural, and settlement and protection association both significant. The changes in built-up area status in urban, peri-urban and rural areas are shown in Figure 3. Table 4 displays the dynamics of built-up area within a settlement and a protection context.

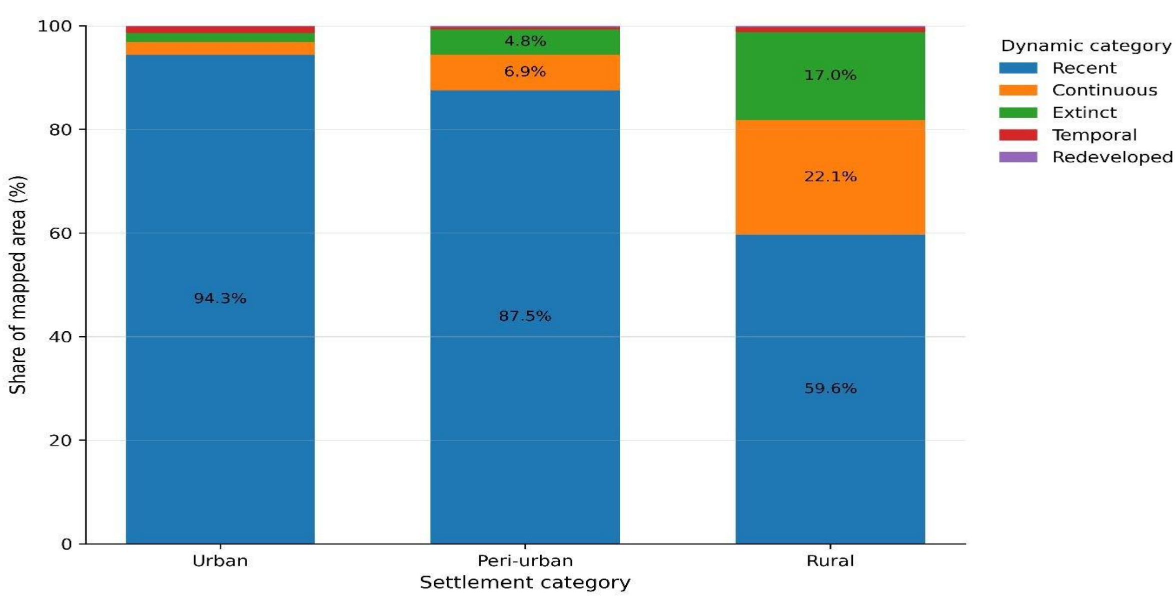

Figure 3. Built-Up-Area Dynamics Across Urban, Peri-Urban, and Rural Settings in the Czech Republic

Table 4. Area-weighted distribution of built-up-area dynamics by settlement and protection context

Context	Recent, %	Continuous, %	Extinct, %	Temporal, %	Redeveloped, %
Urban	94.35	2.49	1.71	1.33	0.12
Peri-urban	87.53	6.90	4.84	0.48	0.25
Rural	59.62	22.13	17.02	0.93	0.30
Non-protected	85.85	7.40	5.51	1.06	0.18
Protected	64.58	20.47	14.53	0.00	0.42

3.5Bivariate Socio-Environmental Associations

The strongest associations were found for the built-up-area dynamics and geographical location (Cramér's V = 0.250), settlement category (0.271), and population category (0.210); the moderate association was with the environmental variables (temperature, 0.140; wind, 0.134; precipitation, 0.114); and the weak association was with the slope (0.026); all tests were significant at $p < 0.001$. Associations between the socio-environmental variables and the built-up-area dynamics are presented in Table 5 in a bivariate way.

Table 5. Bivariate associations between socio-environmental variables and built-up-area dynamics

Variable	χ^2	Cramér’s V	p-value
Geographical location	10,828.72	0.250	<0.001
Population category	7,622.75	0.210	<0.001
Settlement category	6,371.68	0.271	<0.001
Temperature category	3,398.57	0.140	<0.001
Wind category	3,106.26	0.134	<0.001
Precipitation category	2,253.50	0.114	<0.001
Elevation category	1,741.82	0.100	<0.001
Built-up unit size	1,715.93	0.099	<0.001
Landscape type	912.42	0.073	<0.001
Protection status	783.54	0.134	<0.001
Slope category	113.48	0.026	<0.001

3.6Multivariable Socio-Environmental Drivers and Model Performance

Categorising the landscapes by population, elevation, temperature, wind and landscape showed additional variation in the odds of recent development, with the adjusted logistic regression model showing a mean balanced accuracy of 0.299 (SD = 0.026) based on five-fold cross validation, and protected-area status not significant (aOR = 1.01, 95% CI: 0.33–4.65), and nearly flat terrain showing a small positive association (aOR = 1.16, $p = 0.017$).

4.Discussion

The present study showed that the extent of built-up areas in the Czech Republic increased considerably over the last 177 years (from 1842 to 2019). The mapped built-up area increased from 93.63 ha in 1842 to 406.02 ha in 1950 and 609.60 ha in 2019, representing a net increase of 515.97 ha across the full study period. Recent development had the largest proportion of area mapped (84.71%), followed by continuous, extinct, temporal and redeveloped areas. They suggest that the built landscape of the present-day is determined more by expansion of the built landscape than by unbroken continuity of historically established settlements. This is in line with empirical evidence that urban expansion is driven by a set of temporally varying demographic, economic, environmental, and institutional variables, not by a single stable process (Wu et al., 2021).

There were significant differences between different settlement settings. Recent development was 94.35% of the urban mapped area, 87.53% of the peri-urban area, and 59.62% of the rural area. The adjusted odds indicated that recent built-up development was over three times more likely to occur in urban locations than in peri-urban locations, and 13 times more likely than in rural locations. There were higher percentages of both continuous and extinct settled and constructed areas in rural places, reflecting the historical continuity and the settlement loss or abandonment. Peri-urban landscapes had both high recent expansion and a higher historical component than urban landscapes. Similar studies have demonstrated that peri-urban expansion often involves the reclamation of previously farmed or semi-natural land, and can take place in areas with environmental constraints and risk (Fekete, 2023).

A clear unadjusted pattern of protected areas was identified. Proportionally more of the landscapes that were in the continuous category or extinct were protected compared to those in the recent development category (85.85% vs. 64.58%). A significant association between protection status and built-up dynamics was seen in the bivariate analysis, which was lost after adjusting for settlement, population, terrain, climate, and landscape characteristics. Protected status thus seemed to be more a reflection of the broader geographical context than a stand-alone determinant of recent development. The global evidence also shows that development growth is lower in protected areas, but that in the surrounding areas there may be development pressures depending on accessibility and governance, and such pressures might differ in and near protected areas (De La Fuente et al., 2020). Lastly, recent evidence from the Czech Republic also shows a growing anthropogenic pressure in protected areas – meaning that legal designation does not mean long-term elimination of anthropogenic pressure (Janík et al., 2024).

Recent development was also significantly related to population category, elevation, temperature, wind conditions, slope, and landscape type in the adjusted analysis. The population estimates were non-linear, some having significantly raised odds, and others lowered odds. This pattern indicates that the intensity of development might be related to population concentration, settlement hierarchy, infrastructure, and the regional economic function, rather than simply the size of the population. Land expansion studies have also revealed that the impact of demographic and environmental factors can differ between sites and that development scenarios and local spatial structures can influence their effects (Chen & Yao, 2023).

The odds of recent development were found to be significantly higher at several of the higher elevation categories, and modestly higher at nearly flat terrain. This finding contradicts the notion that urban growth occurs only at low elevations. The pattern can be related to the geographical concentration of tourism, mountain settlements, regional centres, or other processes that are not measured. Any associations found for the other variables, temperature and wind categories, were also relatively large but should be considered as proxies for other regional associations, not as direct causal pathways. Changing landscapes can be shaped by multiple environmental factors, land needs, policy preferences, and regional development priorities (Qu et al., 2020).

The environmental value of ongoing built-up expansion goes beyond the mapped built-up area. Developers should be concerned with the conversion of undeveloped land that can cause habitat fragmentation, ecological isolation, a decrease in landscape permeability, and pressure on natural systems. The data presented here did not directly measure biodiversity or habitat loss, but the predominance of recent development suggests that there is considerable potential for ecological impacts as development invades or overlaps natural and semi-natural habitats. However, worldwide there are examples of the high habitat losses that can occur with urban expansion, especially in ecologically sensitive areas with little planning control (Ren et al., 2022).

The Czech results are also representative of the general trend of land-use modification in the post-socialist countries of Central Europe. The growth in the area has been associated with industrial restructuring, the demand for suburban housing, transport development, commercial investment, and a lack of co-ordinated planning. Based on the evidence from Hungary, with small population growth, there may also be too much land take, as local economic strategies and development incentives support the conversion of undeveloped land (Csomós et al., 2024). This may partly be the reason why, despite the high regional variation found in the Czech dataset, most of the built-up development was recent.

The long time span, large analytical sample, area-weighted summaries, and the incorporation of social, climatic, topographic, and landscape variables strengthened this study. The drawbacks were that it had unequal historical intervals, environmental classifications that were static, no polygon geometry, the potential for spatial dependence between adjacent units, a lack of temporal and redevelopment categories, and poor predictive power. It was found that there were statistical drivers and no causal determinants. For future analysis, transport accessibility, economic activity, historical population movements, planning rules, and spatial regression should be added to the analysis of Czech built-up-area dynamics to account for the remaining variation.

5.Conclusion

The growth of built-up areas in the Czech Republic has been unevenly distributed both in space and in time, particularly between 1842 and 2019 when this share was largest. The highest rate of change was observed in urban and peri-urban areas, while larger shares of built-up land that has been continuous and extinct were found in rural areas, indicating high local continuity and declines over the longer term. Recently developed proportions were lower for protected landscapes, with no protection status associated with recently expanded areas of the landscape after socioeconomic, climatic, topographic, and landscape variables were accounted for. Built-up change was related to a variety of factors that are not necessarily independent, including population category, settlement context, elevation, temperature, wind conditions, slope, and landscape type. The results reflect the importance of combining the three sources of spatial data (historical cartography, GIS-based spatial data, and multivariable analysis) to be able to reconstruct the processes of long-term land transformations. They also highlight the importance of planning approaches which reduce excessive land appropriation, are sensitive to ecologically sensitive areas, and respond to differential pressures on urban, peri-urban, and rural development. To improve causal interpretation and predictive power across the Czech regions, future research should include accessibility, economic activity, policy change, and spatial dependence.

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