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Impact of depopulation of municipalities in the Świętokrzyskie voivodeship on green infrastructure changes

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Abstract

Background: Depopulation leads to changes in green spaces and quality of life, but can also provide opportunities for spatial regeneration. Green infrastructure is crucial for sustainable development, public health, and adaptation to climate change.

Aim: The aim was to analyse and evaluate the relationship between depopulation in municipalities in the Świętokrzyskie voivodeship and the development of green infrastructure in a resource-constrained environment. The study focused on the impact of depopulation on the quality of green infrastructure.

Methodology: The study used literature analysis, statistical methods, and TOPSIS, collecting empirical data from municipalities in the Świętokrzyskie voivodeship in 2014 and 2022, which allowed to capture the dynamics of the phenomena and monitor conjunctural changes.

Results: The study of the impact of depopulation on green infrastructure in municipalities of the Świętokrzyskie voivodeship showed positive changes in the quality of green spaces, promotion of sustainable development, revitalisation of urban spaces, and the creation of new green spaces in response to demographic changes.

Implications and recommendations: It is recommended to continue investing in green infrastructure, especially in areas with its lower concentration and to monitor changes in green space distribution and demographics.

Originality/value: The author analysed the relationship between demographic structure and green infrastructure in municipalities, using a synthetic measure for both areas to compare 2014 and 2022,

allowing an assessment of their impact on the environment, the depopulation process, and infrastructure.

Keywords: green infrastructure, demographics, synthetic measure, CRITIC-TOPSIS method

1. Introduction

Depopulation is the process of population decline due to emigration of young people, economic stagnation and population ageing, with negative consequences such as lower standards of living, weakening of the labour market and loss of agricultural land. Depopulation has an impact on the environment, causing both the degradation and the spontaneous revitalisation of green spaces (San Martín González & Soler-Vaya, 2024). Moreover, the working-age population is declining and the proportion of elderly people is increasing, which leads to a weakening of social ties and a decline in civic participation. In the context of green infrastructure, depopulation requires management strategies that take into account environmental protection, biodiversity and adaptation to climate change.

The phenomenon of depopulation is particularly evident in areas with low levels of economic development, which suffer from loss of population and economic dynamism. In response to these challenges, the key to development is innovation, local entrepreneurship, and the development of new economic activities that can stop the trend of depopulation and improve the social and economic situation (Sánchez et al., 2024).

The economies of regions are becoming less efficient, and the number of hands to work is decreasing, which negatively affects innovation and entrepreneurship. These changes are leading to widening regional inequalities, with the dominance of larger cities attracting resources and investment. In response to these challenges, policies that support the development of depopulated areas, stop migration, and adapt public services to the changing demographic structure are becoming necessary. Green infrastructure (GI) can support stormwater management, reduce flooding, retain water in the landscape, and improve groundwater quality. In addition, properly designed green spaces can help raise the quality of life of local communities by offering places for recreation, environmental education, and social integration (Zeng et al., 2021).

Green infrastructure, including parks, forests, tree canopies, and aquatic ecosystems, plays a key role in protecting the environment and improving the quality of life. It provides ecosystem services such as bettering air quality, managing stormwater, protecting biodiversity, and mitigating the effects of climate change. Additionally, it influences public health by offering recreational spaces and improving microclimates. The proper management of green infrastructure supports sustainable development, climate change adaptation, and builds resilience to environmental challenges. In the context of the global problems of pollution and climate change, green development is becoming an important tool in the pursuit of sustainable productivity, regional competitiveness, and environmental protection (Wen et al., 2024). Municipalities and local governments are increasingly recognising the benefits of green infrastructure and incorporating it into municipal policies. Green infrastructure also supports health, recreation, and education, as well as economic development and social capital (Nygaard, 2024).

The aim was to analyse and evaluate the relationship between depopulation in municipalities in the Świętokrzyskie voivodeship and the development of green infrastructure in a resource-constrained environment. The study focused on how depopulation affects the quality of green infrastructure and the ability of municipalities to cope with climate change, and whether a smaller population promotes the development of green infrastructure or leads to a deterioration in the quality of life and social and ecological structures. In this aspect, the questions posed were: What demographic changes are related to the processes of green infrastructure development in the municipalities of the Świętokrzyskie voivodeship? Which municipalities of the Świętokrzyskie voivodeship are characterised by different levels of demography and green infrastructure?

The study considered the relationship of variables related to green infrastructure and demography, in order to understand their interdependence. A novelty was the use of a synthetic measure (for 2014 and 2022), allowing for a comprehensive comparison of these processes, and the inclusion of differences in the development of green infrastructure in different municipalities, to analyse their impact on ecosystems. The study took into consideration the differences in demographics and green infrastructure development in selected municipalities, analysing their mutual impact on each other.

2. Literature review

The depopulation of municipalities leads to a decline in local revenues, which reduces funds for maintaining green infrastructure such as parks and green spaces. In smaller municipalities with limited financial resources, ecosystems are being neglected, reducing the quality of life for residents and public involvement in caring for public spaces. However, depopulation can also create an opportunity for wasteland revitalisation and sustainable green space development. Rural depopulation in Europe exacerbates demographic and socioeconomic inequalities, leading to the marginalisation of regions where the lack of access to basic services, such as healthcare and education, accelerates the depopulation process (Alonso et al., 2024). The depopulation of regions and cities around the world is due to a number of factors, including economic underinvestment, ageing populations, declining birth rates, migration, and social and political conflicts. These developments lead to weakened social and economic structures, affecting the quality of life and limiting development opportunities. As a result of depopulation, many areas are struggling to maintain (green) infrastructure, exacerbating problems related to the lack of public services, education, and healthcare (Sampson et al., 2019).

Green infrastructure is a key element in the pursuit of sustainable development, as it combines concern for ecosystems and human well-being. It is the sum of environmental, ecological, and infrastructure values, and its multidimensional nature allows to fill gaps in economic, social, and technological areas, contributing to sustainable development goals. Green infrastructure also supports the management of natural resources, improves quality of life, enhances biodiversity, and mitigates climate change (Wang B. et al., 2023). The lack of green space and the increase in impervious surfaces exacerbate these problems, affecting the increased vulnerability of cities to disasters caused by heavy rainfall. In the face of these challenges, building climate-resilient regions (cities) with green infrastructure has become a key solution at international level (Zeng et al., 2021). Green infrastructure has become a key tool in the sustainable development of regions, especially in the face of changing climate conditions and increasing urbanisation (Zabel & Häusler, 2024).

Green spaces offer important ecosystem services, including recreation, aesthetics, microclimate regulation, and carbon sequestration, which affect the health and quality of life of residents. However, rapid population growth and overuse of resources are leading to unequal access to these areas, creating social and environmental inequalities. Unequal access to green spaces is also becoming a problem due to their location and distance, creating social and environmental inequalities. Therefore, sustainable urban development requires equal management of both urban and non-urban ecosystems (Lin et al., 2024). Urban parks are a key component of green infrastructure, offering residents easy access to recreational spaces, which affects their subjective well-being and overall quality of life. Interaction with these areas has important social significance, which forms the basis for assessing the demand for urban green space from the perspective of residents (Zhao et al., 2024).

The development of green infrastructure in depopulated municipalities can also contribute to the revitalisation of public spaces, becoming the foundation of a new economic model that combines ecology with local development. As a result, these municipalities can become attractive to new investments, residents, and tourists, strengthening the local community's sense of identity. In the face of climate change, innovative city and regional planning that promotes urban resilience and sustainability becomes crucial. Peripheral areas such as environmental reserves, agricultural areas, and natural remnants, face challenges of fragmentation of space and lack of coordination between municipalities (Marques & Alvim, 2024). Green infrastructure addresses the challenges of environmental degradation, climate change, loss of biodiversity and rising costs of resources such as water (Ruan et al., 2023).

A reduced population translates into lesser need for development of housing and infrastructure, thus improving environmental quality, biodiversity, noise reduction, and better water cycles. Transforming urban areas into green spaces can also reduce the urban heat island effect, improving quality of life and promoting social integration. Activities such as community gardens can become a foundation for sustainable spatial development, strengthening the sense of local identity and fostering urban revitalisation (Gebreyesus et al., 2024).

The research aimed to assess the relationship between demographics and green infrastructure to support the multifunctionality of municipalities, and the conducted analysis related these indicators to the location characteristics of green infrastructure units in the context of depopulation. An integrated assessment of green infrastructure in depopulated municipalities of the Świętokrzyskie voivodeship was developed as a case study to test the following hypothesis: The depopulation of municipalities in the Świętokrzyskie voivodeship leads to the neglect of green infrastructure, mainly due to limited economic resources, thus negatively affecting the quality of life of its residents. However, the depopulation also creates opportunities for the revitalisation of wastelands and the creation of sustainable green spaces that promote biodiversity and adaptation to climate change, but the implementation of these initiatives is hampered by limited financial and human resources.

3. Methodology

The study of green infrastructure and depopulation was based on a detailed analysis of the literature on the subject, taking into account a variety of theoretical and empirical approaches. Sources were selected from reliable databases (Scopus, Web of Science) and journals specialised in ecology, urban planning, demography, and sustainable development. Empirical data were collected on the spatial basis of municipalities in the Świętokrzyskie region of Poland. Their selection was largely determined by the availability of data collected at Statistics Poland. The choice of 2014 and 2022 was due to data availability and significant social and environmental changes: 2014 being the year of the post-financial crisis, wheras data for 2022 allowed for assessing the impact of the pandemic and demographic changes, especially in depopulated areas. Comparing these two years enabled the analysis of changes in demographics and green infrastructure.

The methodology for selecting literature for the publication included a review of sources in the fields of demography, environmental protection, and spatial planning. Papers on depopulation in Poland were selected, with a particular focus on migration and its impact on rural and suburban communities. Studies on green infrastructure were also sought, covering definitions, functions, and changes associated with depopulation. The analysis included both theoretical papers and practical reports. Databases such as Scopus and Web of Science were used, and the results were analysed employing the CRITICAL-TOPSIS method. The analysis was carried out based on the following keywords: green infrastructure, demography, synthetic measure, CRITICAL-TOPSIS method.

The research process began with the selection of diagnostic variables, involving the analysis of descriptive statistics, coefficient of variation (with a limit of 0.10), inverse correlation matrix (diagonal value = 10), and identifying the stimulant and destimulant variables affecting the analysed process. The variables studied included demographic, social, economic and environmental aspects, creating a comprehensive picture of the region's quality of life and sustainability. Demographics and green infrastructure are linked, as demographic changes require adjustments in infrastructure, and adequate green space improves the quality of life and mitigates the negative effects of population density (Table 1).

Table 1. Diagnostic variables describing demographics and the green economy by municipalities in the Świętokrzyskie voivodeship

Variable	Units	S/D
Aspect of demography		
Migration balance	person per 1,000 population	S
Population density	person per km^2	S
Old-age dependency ratio	person	D
Share of population of pre-working age in total population	%	S
Share of working-age population in total population	%	S
Birth rate	person per 1000 population	S
Foundations, associations and social organizations	person per 10 thousand residents	S
Beneficiaries of community social assistance	person per 10,000 population	D
Green infrastructure aspect		
Housing	pieces per 1000 inhabitants	S
Water supply network	km per 100 km^2	S
Gas network	km per 100 km^2	S
Public libraries	objects per 10,000 population	S
Outpatient entities (clinics, as of December 31)	objects per 10,000 population	S
Population per public pharmacy	person	S
Elementary school total total	objects per 1000 population	S
Preschool education total total	objects per 1000 population	S
Urban and rural cleansing	pln per capita	S
Maintenance of greenery in cities and municipalities	pln per capita	S
Protection of atmospheric air and climate	pln per capita	S
Sewage management and water protection	pln per capita	S
Municipal waste management	pln per capita	S
Water consumption	m^3 per capita	D
Share of industry in total water consumption	%	D
Wastewater treated per year discharged	dam^3 per capita	S
Population using treatment plants	%	S
Industrial and municipal wastewater requiring treatment	dam^3 per km^2	D
Mixed waste collected during the year	kg per capita	D
Share of green areas in total area	%	S
Share of legally protected areas in total area	%	S
Number of natural monuments	pieces per km^2	S
Forest cover	%	S

Source: own study based on Statistics Poland data (S – stimulant, D – destimulant).

Next, the variables were normalised. For this purpose, the zeroed unitisation procedure was applied ($X_j \in [0, 1]$), according to the formulas:

$$X_j \in S;\ Z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \tag{1}$$

$$X_j \in D;\ Z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \tag{2}$$

where $\max_{xij}$ – the maximum value of jth variable, $\min_{xij}$ – the minimum value of jth variable, x_{ij} – the value of jth variable for ith object, Z_{ij} – the normalised value of jth variable for ith object (Sompolska-Rzechuła, 2021).

Then the weights of the indicators were determined using the CRITIC method, which allowed to give them different relevance, where the sum of the coefficients w_j is 1, and a higher value of C_j means a greater ability of the variable to provide information (Acevedo & José, 2019). The weighting process was carried out according to the formula:

$$w_j = \frac{C_j}{\sum_{k=1}^{K} C_k}, j = 1,2,\ldots,K, \quad (3)$$

$$C_j = S_{j(Z)} \sum_{k=1} (1 - r_{jk}), j = 1,2, \ldots K, \quad (4)$$

where: C_j – the measure of information capacity of *j*-th variable, C_k – the sum of the information measure of all criteria, $S_{j(Z)}$ is the standard deviation obligated from the normalised values of *j*-th variable, r_{jk} – the correlation coefficient between features *j*-th and kth.

The synthetic measure was calculated according to the TOPSIS method, which allowed to select the best solution in a multi-criteria decision analysis, according to the formula:

$$q_i = \frac{d_i^-}{d_i^- + d_i^+}, \quad (5)$$

where $q_i \in$ [0; 1]; d_i^- – the distance of the object from the anti-pattern (from 0), d_i^+ denotes the distance of the object from the pattern (from 1) (Du et al., 2024; Kuo, 2017; Vega et al., 2014).

Finally, the municipalities were evaluated and ranked according to the value of green infrastructure. The ordering was based on a statistical criterion using the mean and standard deviation from the value of the synthetic measure, according to the formula:

$$\begin{array}{ll} \text{Group 1} & \overline{x} + S_d \le q_i \\ \text{Group 2} & \overline{x} \le q_i < \overline{x} + S_d \\ \text{Group 3} & \overline{x} - S_d \le q_i < \overline{x} \\ \text{Group 4} & q_i < \overline{x} - S_d. \end{array}, \quad (6)$$

To assess the differentiation (inequality of distribution) of the studied population, the Gini coefficient (concentration coefficient) was calculated, according to the formula

$$G(y) = \frac{\sum_{i=1}^{n}(2i-n-1)y_i}{n^2\overline{y}} \quad (7)$$

where y_i is the value of *i*-th observation, $\overline{y}$ – the average value of all the observations y_i, G(*y*) ∈ [0,1].

Moran's global I statistic was used to test whether neighbouring plots formed clusters with similar values of the synthetic measure. The local form of Moran's I coefficient determines the similarity of a spatial unit to its neighbours and tests the statistical significance of this relationship (Anselin, 1995; Longley et al., 2006; Upton & Fingleton, 1985). Calculations were made in the PQstat program, according to the formulas:

$$I_{(globalny)} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} wij(x_i-\overline{x})(x_j-\overline{x})}{S_o\, \sigma^2}, \quad (8)$$

$$I_{i(lokalny)} = \frac{(x_i-\overline{x})\sum_{j=1}^{n} wij\,(x_j-\overline{x})}{\sigma^2}, \quad (9)$$

where: *n* – the number of spatial objects, x_i, x_j – the values of the variable for the compared objects, $\overline{x}$ – the average value of the variable for all the objects, w_{ij} – elements of the spatial weight matrix (weight matrix standardised by rows to the singularity) $S_o = \sum_{i=1}^{n}\sum_{j=1}^{n} wij$, $\sigma^2 = \frac{\sum_{j=1}^{n}(x_i-\overline{x})^2}{n}$ – variance.

4. Research results

Green infrastructure was expected to improve between 2014 and 2022, with values of the synthetic measure ranging from 0.33 to 0.54 in 2022, compared to 0.32-0.50 in 2014. This indicated a growing trend towards investment in sustainable development, including green spaces, revitalisation of urban areas, and climate change mitigation measures. In turn, demographic changes, such as an ageing population, may require the adaptation of urban spaces, with implications for the development of green infrastructure. The differences between 2014 and 2022 were due to a combination of factors such as investments in sustainable development, demographic changes, migration policies, and the impact of the COVID-19 pandemic. The increase in the values of the indicators in 2022 pointed to positive trends towards improving the quality of life of residents, protecting the environment, and adapting spaces to changing human needs, especially in densely populated cities (Table 2).

Table 2. Selected characteristics of groups of municipalities in the Świętokrzyskie voivodeship due to synthetic green economy indicator in 2014 and 2022

Year	2022				2014			
Group	A	B	C	D	A	B	C	D
Number of units	14	41	27	20	21	32	31	18
q green infrastructure	0.50	0.46	0.41	0.35	0.47	0.42	0.39	0.34
Apartments	366.16	365.33	361.16	350.93	317.74	324.61	338.61	317.30
Water supply	129.68	156.79	111.07	151.35	110.82	135.73	123.23	132.73
Gas	69.21	65.19	35.94	56.22	46.57	33.71	38.13	47.15
Library	3.35	2.98	2.83	2.64	4.23	2.60	2.70	2.54
Clinics	4.79	4.10	3.96	4.15	4.05	3.59	3.68	3.11
Cleaning of cities and villages	16.10	12.71	6.49	8.02	10.42	42.00	6.39	10.14
Maintenance of greenery in cities and municipalities	20.29	7.44	6.39	5.15	4.42	3.14	2.78	2.70
Protection of atmospheric air and climate	121.47	45.50	23.50	51.76	19.30	6.31	2.63	0.00
Sewage management and water protection	168.59	104.52	46.58	73.30	119.50	73.19	33.13	20.72
Municipal waste management	197.67	183.70	155.75	80.77	54.30	54.99	46.51	38.87
Water consumption	35.70	126.63	275.47	5458.49	36.86	133.27	187.89	5884.03
Share of industry in water consumption	1.26	5.18	5.59	15.24	1.05	3.94	8.48	10.93
Wastewater treated per year	0.03	0.02	0.01	0.01	0.02	0.01	0.01	0.01
Population using treatment plants	0.71	0.55	0.39	0.35	0.45	0.39	0.34	0.26
Industrial and municipal wastewater requiring treatment	9.85	8.10	8.84	10.71	7.66	12.62	10.11	4.13
Total mixed waste collected during the year	141.48	149.51	142.94	149.21	61.54	63.75	82.85	91.08
Share of green areas in total area	0.53	0.49	0.22	0.17	0.40	0.34	0.34	0.13
Share of legally protected areas in total area	91.71	81.69	53.44	7.34	94.45	82.51	50.02	3.57
Number of natural monuments	10.29	7.83	6.30	6.87	7.92	6.11	7.24	6.59
Forest cover	42.04	29.07	23.23	11.41	35.49	29.46	23.50	11.61
q demographics	0.44	0.44	0.42	0.41	0.41	0.44	0.42	0.41
Migration balance	0.09	−0.92	−1.85	−2.02	−1.15	−0.80	−1.12	−2.03
Population density	189.94	168.88	62.61	79.24	154.95	150.18	140.63	82.84
Old-age dependency ratio	32.64	32.06	33.11	32.77	24.27	23.21	24.37	24.89
Share of population in pre-working age	17.23	17.46	17.37	16.74	17.50	18.11	17.65	16.94
Share of population of working age	58.17	58.31	58.00	58.37	62.48	62.60	62.04	62.42
Birth rate	−6.94	−6.75	−6.82	−7.53	−3.34	−2.10	−3.34	−3.71
Foundations, associations and social organizations	37.43	39.68	42.07	43.45	29.05	28.50	30.00	33.39
Beneficiaries of community social assistance	580.36	493.49	566.37	643.35	1275.95	1136.25	1151.00	1353.50

Source: own study based on Statistics Poland data.

A slight increase in the average value of green infrastructure was observed between 2014 and 2022 (0.43 vs. 0.41), suggesting an improvement in the availability of green space. The increase in volatility and Gini coefficient indicated increased inequality in access to these resources, especially in high-density cities. The demographic situation remained stable over the period, with minimal changes in the population structure, and disparity in population growth decreased (Fig. 1).

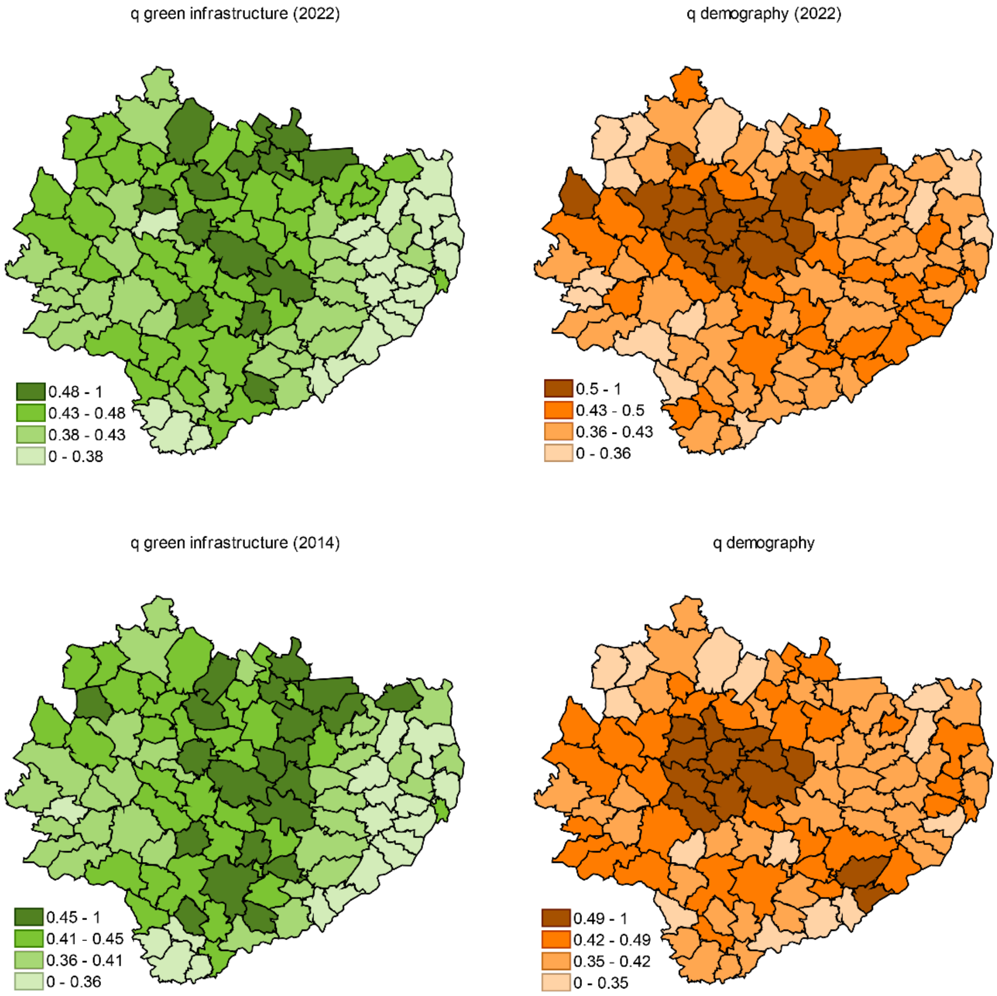

Fig. 1. Spatial distribution of synthetic measures demography and green infrastructure in municipalities of the Świętokrzyskie voivodeship in 2014 and 2022

Source: own study based on Statistics Poland data.

An increasing correlation (0.20 in 2022) between green infrastructure development and demography was observed between 2014 and 2022, suggesting that green spaces were becoming an important factor in attracting residents and improving their quality of life. Green infrastructure is more strongly associated with quality of life indicators such as forest cover and spending on healthcare and education, suggesting benefits for communities that invest in nature. At the same time, in densely developed communities, green space development is associated with negative impacts on residential infrastructure. The findings point to the need for further investment in green infrastructure, an integrated approach to development, and the involvement of local communities in environmental protection that support positive demographic change. The results show the need for investment in green infrastructure and sustainable development, especially in regions with depopulation problems (Table 3).

Table 3. Spearman's correlation between green infrastructure measure and demographics measure and selected variables for municipalities in the Świętokrzyskie voivodeship in 2014 and 2022

Detailes	2022		2014	
	q green infrastructure	q demography	q green infrastructure	q demography
q green infrastructure	1.00	0.20	1.00	0.08
Housing	0.00	−0.65	−0.03	−0.41
Water supply	−0.12	0.23	−0.14	0.11
Gas	0.01	0.13	−0.03	−0.06
Library	0.03	−0.14	0.21	−0.17
Clinics	−0.03	−0.11	0.09	0.07
Population per pharmacy	0.30	0.43	0.14	0.31
Primary	0.07	−0.03	0.21	−0.12
Kindergartens	0.14	0.05	0.26	−0.06
Cleaning of cities and villages	0.15	0.03	0.12	0.05
Maintenance of greenery in cities and municipalities	0.01	−0.01	0.14	0.06
Protection of atmospheric air and climate	0.02	0.14	0.31	−0.12
Sewage management and water protection	0.12	0.01	0.26	0.03
Municipal waste management	0.37	0.07	0.11	0.09
Water consumption	−0.11	0.00	−0.04	0.12
Share of industry in water consumption	−0.07	0.12	−0.11	0.27
Wastewater treated per year discharged	0.50	0.31	0.26	0.42
Population using treatment plants	0.47	0.30	0.30	0.39
Industrial and municipal wastewater requiring treatment	0.32	0.40	0.13	0.46
Mixed waste collected	−0.12	−0.12	−0.33	0.02
Share of green areas in total area	0.05	0.00	0.06	0.18
Share of legally protected areas in total area	0.70	0.15	0.72	0.01
Number of natural monuments	0.10	0.08	0.00	0.10
Forest cover	0.49	0.12	0.43	0.11
q demographics	0.20	1.00	0.08	1.00
Migration balance	0.16	0.34	0.13	0.18
Population density	0.14	0.43	−0.01	0.46
Old-age dependency ratio	−0.14	−0.77	−0.07	−0.72
Share of population in pre-working age	0.14	0.70	0.10	0.47
Share of population of working age	0.10	0.67	0.08	0.61
Birth rate	0.12	0.77	0.10	0.64
Foundations, associations and social organizations	−0.23	−0.11	−0.16	0.01
Beneficiaries of community social assistance	−0.17	−0.27	0.01	−0.40

Source: own study based on Statistics Poland data (Correlation coefficients are significant with $p < .05000$).

The results of the Moran's I index analysis showed clear spatial relationships in the distribution of green infrastructure and demographics between 2014 and 2022, with index values ranging from 0.34-0.38. The higher index for green infrastructure in 2022 suggests a greater concentration of investment, which may be due to increasing environmental awareness. Index values for demographic variables were stable (0.32-0.34), indicating a continued concentration of population in certain areas, especially where access to green spaces is better. It is recommended to invest in green infrastructure in less green areas and to monitor changes in green space distribution and demographics (Fig. 2).

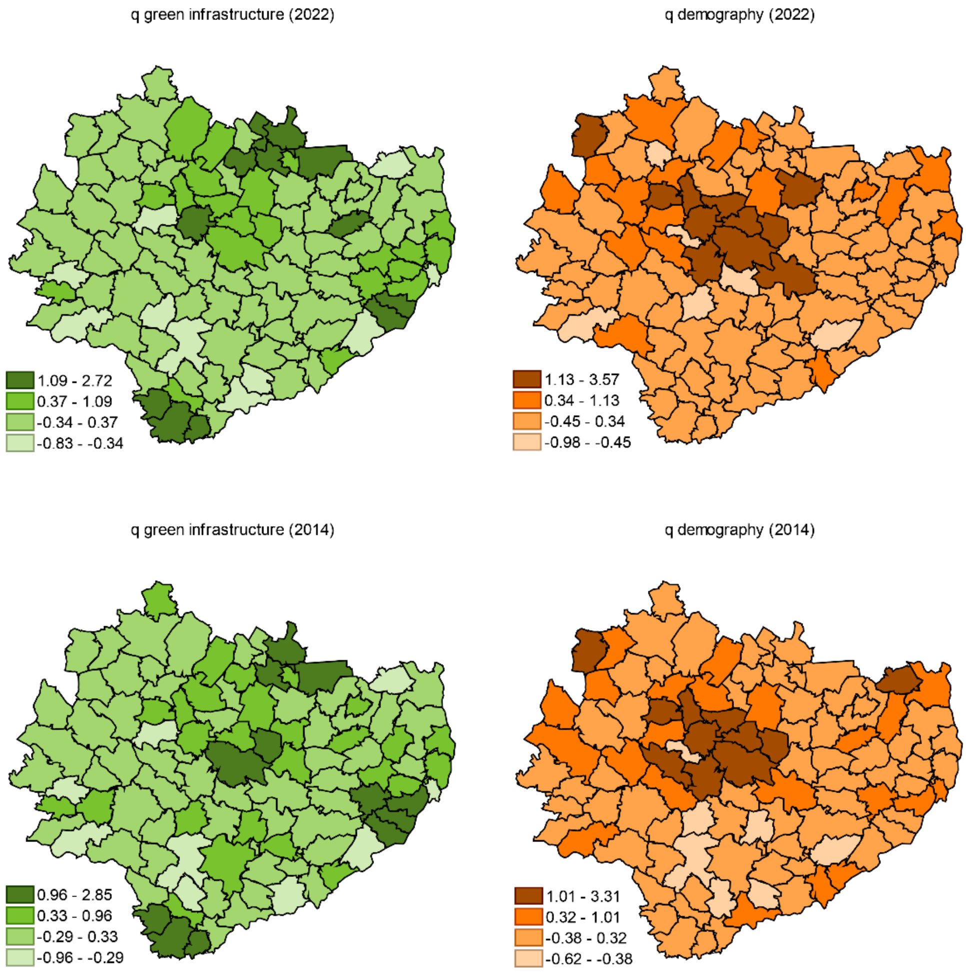

Fig. 2. Spatial distribution of synthetic measures of demography and green infrastructure in municipalities of the Świętokrzyskie voivodeship in 2014 and 2022 based on I Moran's local statistics

Source: own study based on Statistics Poland data.

The analysis of local autocorrelation indicators (Moran's I) showed clear differences in the distribution of green infrastructure and demographics in the municipalities studied. The analysis also revealed a noticeable increase in the concentration of green areas in 2022, which could be an indication of increasing environmental awareness and the implementation of sustainable development strategies. In terms of demographics, however, the trend towards population concentration in larger municipalities continues, while smaller municipalities face depopulation problems, indicating the need for investment to improve the quality of life in these regions. Recommendations suggest a continued infrastructure development in municipalities with a high concentration of green infrastructure and sustainable development in less developed areas. In municipalities with large populations, the key is to develop infrastructure and attract residents, and in smaller ones to invest in public services to prevent depopulation.

5. Discussion

Depopulation can have both positive and negative effects on the development of green infrastructure, depending on the local territorial capital. On the one hand, a smaller population can reduce pressure on resources and space, encouraging the creation of new green spaces and the development of sustainable infrastructure whilst on the other, depopulation can limit human and financial resources, making it more difficult to invest in green infrastructure and engage communities in environmental action. A key element is how local authorities and communities are able to use available resources and invest in green infrastructure development, which determines the ultimate impact of depopulation on the process.

The depopulation of municipalities in the Świętokrzyskie voivodeship affects the management of green infrastructure, leading to a decrease in municipal revenues, making it difficult to maintain parks and green spaces. Depopulation reduces the demand for urban space, which can lead to neglect, but also provides an opportunity to transform urban areas into green spaces. Green spaces promote rainwater infiltration, reducing the risk of flooding, while vegetation improves air quality, absorbs pollution, and reduces noise. Green infrastructure also regulates temperature, improving thermal comfort and landscape aesthetics (de Manuel et al., 2021; Kaveh et al., 2024; Popławski et al., 2024). Maintaining the sustainability of these ecosystems to continue providing services to residents requires ensuring their resilience. Ecological resilience, or the ability of an ecosystem to cope with disturbance while maintaining stability, is a key element of ecosystem management, although it is rarely addressed in the ecological literature (Wu et al., 2020).

Inequalities in access to green infrastructure are due to economic, social, and psychological factors. Wealthier neighbourhoods have better access to green spaces, while barriers such as entry costs and transport limit access for the poor. In addition, safety concerns and cultural exclusion can hinder the use of these spaces. It is necessary to design inclusive spaces and create policies that ensure equal access to green infrastructure for all residents (Wu et al., 2023). Green spaces play a key role in improving the health and well-being of urban residents. A well-designed constructed environment that combines housing, public transport, and green spaces reduces stress, supports social resources, and improves the quality of life, promoting healthy communities and a healthy environment (Karanikola et al., 2023).

6. Conclusions

Between 2014 and 2022 an increase in the value of the synthetic green infrastructure indicator was observed, indicating a growing trend of investment in sustainable development, including green spaces, revitalisation of urban spaces, and climate change mitigation measures. At the same time, demographic changes, such as an ageing population, may require the adaptation of urban spaces, with important implications for the development of green infrastructure. The values of the indicators in 2022, compared to 2014, indicate a progressive development of green spaces in municipalities, as well as greater inequalities in access to these resources, especially in cities with high population density. The increasing correlation between green infrastructure and demographics suggests that green spaces are becoming an important factor in attracting residents and improving the quality of life. Therefore, key recommendations include further investment in green infrastructure, especially in municipalities with lower levels of green infrastructure development. In addition, in municipalities with a high concentration of population, further development of public infrastructure is essential to attract new residents and improve the quality of life. Conversely, in smaller municipalities with depopulation problems, investment in public services and green spaces is needed to counteract depopulation and increase the attractiveness of these areas.

This study on the impact of depopulation on the green infrastructure of municipalities in the Świętokrzyskie voivodeship analysed changes in the quality of green infrastructure in the context of declining population and growing awareness of climate change. Green infrastructure indicators showed small but positive changes in the spatial development of green spaces, indicating a growing trend of investment in sustainable urban development, including revitalisation of urban spaces, improved air quality, and rainwater management. In turn, demographic changes such as population growth and aging influenced the need for new green spaces.

The study also focused on analysing changes in the natural landscape and the functionality of green spaces, taking into account differences between depopulated municipalities and more developed areas. Research challenges included data collection, classification of information sources, and the difficulty of attributing changes solely to depopulation, taking into account other factors such as climate change. In addition, the diversity of definitions of green infrastructure and the limited availability of long-term data made accurate comparisons difficult.

The latest research directions include new methods of analysis (non-linear models), as well as the analysis of the impact of depopulation on the management of green spaces, the involvement of local communities in the conservation of green spaces, and the study of the relationship between demographic structure and the quality of green spaces, which can contribute to the development of effective management strategies in the context of changing conditions.

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Wpływ depopulacji gmin województwa świętokrzyskiego na zmiany zielonej infrastruktury

Streszczenie

Tło: Depopulacja prowadzi do zmian w obszarze terenów zielonych i jakości życia, ale może również stwarzać szanse na rewitalizację przestrzeni. Zielona infrastruktura jest kluczowa dla zrównoważonego rozwoju, zdrowia publicznego i adaptacji do zmian klimatycznych.

Cel: Celem jest ocena i identyfikacja wyzwań związanych z wyludnianiem gmin województwa świętokrzyskiego oraz ocena możliwości rewitalizacji terenów zielonych przy ograniczonych zasobach. Badanie koncentruje się na tym, jak depopulacja wpływa na jakość zielonej infrastruktury.

Metodyka: W badaniach zastosowano analizę literatury, metody statystyczne oraz TOPSIS, zbierając dane empiryczne z gmin województwa świętokrzyskiego w latach 2014 i 2022, co pozwoliło uchwycić dynamikę zjawisk i monitorować zmiany koniunkturalne.

Wyniki: Badanie wpływu depopulacji na zieloną infrastrukturę w gminach województwa świętokrzyskiego wskazało na pozytywne zmiany w jakości terenów zielonych, sprzyjające zrównoważonemu rozwojowi, rewitalizacji przestrzeni miejskich oraz tworzeniu nowych przestrzeni zielonych w odpowiedzi na zmiany demograficzne.

Implikacje i rekomendacje: Zaleca się kontynuowanie inwestycji w zieloną infrastrukturę, szczególnie w obszarach o jej mniejszej koncentracji, oraz monitorowanie zmian w rozmieszczeniu terenów zielonych i demografii.

Oryginalność/wartość: Badanie analizuje zależności między strukturą demograficzną a zieloną infrastrukturą w gminach, wykorzystując miarę syntetyczną dla obu obszarów w celu porównania lat 2014 i 2022, co pozwala ocenić ich wpływ na środowisko naturalne, proces depopulacji, infrastrukturę.

Słowa kluczowe: zielona infrastruktura, demografia, miara syntetyczna, metoda CRITIC-TOPSIS