European Journal of Geography

The publication of the European Journal of Geography (EJG) is based on the European Association of Geographers' goal to make European Geography a worldwide reference and standard. Thus, the scope of the EJG is to publish original and innovative papers that will substantially improve, in a theoretical, conceptual, or empirical way the quality of research, learning, teaching, and applying geography, as well as in promoting the significance of geography as a discipline. Submissions are encouraged to have a European dimension. The European Journal of Geography is a peer-reviewed open access journal and is published quarterly.

Received: 05/01/2024
Revised: 19/03/2024
Accepted: 26/03/2024
Published: 27/03/2024

Academic Editor:
Dr. Panos Manetos

DOI: 10.48088/ejg.g.pan.15.1.042.053
ISSN: 1792-1341

Research Article

Accessibility, Rural Depopulation & the Modified Areal Unit Problem: An Analysis of Mainland Greece

George Panagiotopoulos[1] & Dimitris Kaliampakos[2]

[1] Metsovio Interdisciplinary Research Center, National Technical University of Athens, Greece
[2] National Technical University of Athens, Greece

Correspondence: g.panag@metal.ntua.gr

Abstract: In the realm of new economic geography studies, an ongoing debate centers around the role of transportation costs in redirecting economic activity away from peripheral areas towards urban spaces. This theory gains support from the phenomenon of rural depopulation in developed countries, as it is generally accompanied by improvements in accessibility due to new infrastructure and technology. This study introduces a methodology for analyzing the relationship between accessibility and regional inequality while accounting for rural depopulation. Moreover, it acknowledges the significance of the measurement timeframe, as the dynamics between accessibility components are not always synchronous. The developed methodology is employed for investigation within the geographical region of mainland Greece. The findings reveal that relative accessibility, in contrast to absolute accessibility, exhibits a correlation with rural depopulation in mainland Greece. Finally, the study examines the Modified Areal Unit Problem (MAUP) to address inconsistencies observed in similar spatial studies. The disparities in results among the various geographical administrative levels carry substantial implications for policymakers dealing with issues of urbanization and uneven regional development.

Keywords: Accessibility, Modified Areal Unit Problem, regional development, Greece, relative accessibility, absolute accessibility

Highlights:

- Introducing a methodology to analyze accessibility's impact on regional inequality, addressing rural depopulation.
- Emphasizing the connection between accessibility & human capital decline, pivotal for rural development.
- Spatial analysis tools & scale considerations are vital for addressing methodological issues like MAUP in accessibility research.

1. Introduction

Regional development policies often seek to mitigate spatial disparities through the enhancement of transport infrastructure. However, the enhancement of accessibility may not necessarily alleviate inequalities; in fact, it may exacerbate spatial polarization (Schwanen, 2016). Far from mitigating spatial disparities, the emphasis on improving European transport infrastructure (Gutiérrez & Urbano, 1996) has, in certain cases, exacerbated them (Iammarino et al., 2019; Petrakos et al., 2003; Puga, 2002). Several researchers recommend analyzing this issue using new economic geography (NEG) methodologies, such as the core-periphery model developed by Krugman (1991).

According to the core-periphery model, firms located in areas with a relatively large number of firms face strong competition in local markets, which tends to disperse firms spatially. However, the combination of increasing returns and transport costs encourages firms to cluster in large markets, generating externalities that promote the concentration of economic activity. While the concentration of economic activity was initially attributed to workers' mobility, recent applications have demonstrated the validity of the model even when workers' mobility is low, as firms can benefit from the labor market, the diffusion of know-how, and the exchange of products (Puga, 2008). In general, lower transport costs lead to the formation of the core-periphery model, and improved accessibility theoretically benefits urban development.

This study examines the role of accessibility in demographic changes, particularly in regional and rural areas. Relative and absolute accessibility have been analyzed to demonstrate which of the two affects population change. The time factor is crucial to our methodology because changes in the different components of accessibility are not synchronized. Therefore, longitudinal data have been used in conjunction with spatial analysis to capture the lagged coefficients across space and time. Finally, the analysis has been performed at three scales, along with spatial autocorrelation techniques, to assess the contribution of the Modified Areal Unit Problem (MAUP). The rest of this paper is structured as follows: Section 2 presents the study materials and methods along with an extended literature review. The results of the application of the proposed methodology for the study area are discussed in Section 3. Finally, Section 4 concludes with the important findings, limitations, and directions for future research.

2. Materials and methods

2.1 Literature review

Measuring accessibility quantifies the impedance associated with travel or transportation between locations. In terms of technical aspects, this typically entails employing network analysis to determine the most cost-effective route on a network (such as a road network) to reach one or multiple destinations (such as cities, hospitals, etc.) (Agourogiannis et al., 2023). Specifically, potential accessibility considers a size variable that combines the attractiveness of the destination with the difficulty of travel (Rosik & Stępniak, 2015; Yoshida & Deichmann, 2009). This size variable may encompass the population, gross domestic product, or other factors when accessibility is destination-specific (e.g., work or health) (Guzman et al., 2017; Hashtarkhani et al., 2020). Geurs and Van Wee (2004) categorized accessibility measures based on four perspectives (infrastructure-based, location-based, person-based, and utility-based). This is crucial since the research goal essentially determines how and for what purpose accessibility is measured.

Several parameters can be considered for measuring accessibility. Páez et al. (2012) distinguish between the positive and normative applications, i.e., the subjective measurement of the model and the actual observed measurement. Similarly, relative accessibility can be interpreted in various ways. For instance, relative accessibility can be evaluated for different modes of transport, between travel time and distance, and among different social groups (Costa et al., 2021; Paez et al., 2010; Qi et al., 2020). Panagiotopoulos and Kaliampakos (2021) also discuss people's perceptions regarding accessibility within specific places and times. Each era has its own standards regarding travel costs. Since accessibility interventions (e.g., through infrastructure) vary across space and time, some areas fall behind in terms of relative accessibility.

In recent decades, Southeast Europe has witnessed growing regional disparities, with urban areas flourishing at the expense of their rural counterparts (Petrakos & Economou, 2004). In Greece, development revolves around two major urban centers, which account for 40% of the population and almost half of economic activity (Goletsis & Chletsos, 2011; Petrakos & Saratsis, 2000; Petrakos & Tsoukalas, 1999). The remaining regions exhibit relatively little specialization, primarily in tourism (island regions), agriculture (30% of the workforce in Thessaly, Peloponnese, Macedonia, and Thrace), and light industry (Central Greece and Macedonia); regions outside the two major urban centers contribute to less than 5% of financial and other business services (Monastiriotis, 2011). This results in an unequal distribution of resources, abandonment of rural areas, a decrease in population in small and medium-sized cities, and further expansion of large urban centers (Petrakos & Psycharis, 2016).

Among the factors influencing location choice over time, accessibility favors agglomeration (Jafari Samimi et al., 2019). Several examples from field-relevant literature demonstrate that improving accessibility leads to increased agglomeration. Deng et al. (2020) and Wenner and Thierstein (2020) showed that high-speed railways in China and Germany promoted agglomeration, particularly in areas located in or near urban centers. Furthermore, Rokicki and Stępniak (2018) found that enhancing accessibility did not impact urban areas but had a negative correlation with the rural economy.

Poor accessibility is associated with rural depopulation, and one often reinforces the other (Sheludkov et al., 2020). Remote areas are already vulnerable to poverty and social exclusion. The lack of access to health and education infrastructure clearly explains why young people are discouraged from settling in such areas (Navarro Valverde et al., 2019). Especially in developed countries, the shift of economic activity from agriculture to other sectors, lower birth rates, increases in life expectancy, and low international migration exacerbate depopulation (Johnson & Lichter, 2019). Theoretically, transport infrastructure may prevent a much larger increase in spatial disparities; however, in practice, such infrastructure usually favors areas with better preconditions (Puga, 2008). Although improving accessibility plays a key role in concentrating activity in larger urban centers, spatial inequalities can only be addressed through appropriate locally tailored policies (Iammarino et al., 2019).

2.2 Research aim

The primary objective of this study is to investigate the potential impact of changes in accessibility on rural depopulation. This research question carries significant implications. To address it, we construct a conceptual model consisting of various hypotheses derived from existing literature, with the aim of establishing the relationship between accessibility and regional activity. The model serves as a schematic representation of these hypotheses, highlighting the dynamic interplay between accessibility and population flow between different locations. It is important to note that while population flows are influenced to a large extent by accessibility, other factors also play a role.

Subsequently, we identify a set of variables associated with accessibility and the activity levels of different areas, based on the aforementioned conceptual model. We then examine the correlations between these variables. In this analysis, we utilize two distinct measures of accessibility and consider three population age groups that can potentially indicate the likelihood of depopulation in a particular area. These correlations offer valuable insights into the relationship between accessibility and rural depopulation.

Finally, we explore the implications of the Modifiable Areal Unit Problem (MAUP) in the context of this research. While our aim is not to provide a definitive solution to the MAUP, we aim to identify aspects that should be considered in future studies addressing similar research questions.

2.3 Model and hypotheses

Apart from the perspectives of accessibility, Geurs and Van Wee (2004) identify four major components, namely, land use, travel costs, time, and individual components. Changes in accessibility can result from any of these components or the complex dynamics between them. Time is a critical factor because changes resulting from the dynamics between components are not necessarily immediate and may occur after a significant period. For instance, while the effects of transportation infrastructure on accessibility are relatively immediate, their effects on the spatial redistribution of activities (the land-use component), which leads to further changes in accessibility, take longer to have an observable impact.

In this context, the modeled hypotheses and scenarios of temporal change are schematically presented as follows (Figure 1):

a. Transport network intervention: Improving the network positively affects transport costs and, thus, accessibility.
b. Activity distribution may change due to the reduction in transport costs.

At this critical juncture, three scenarios are possible:

- No change.
- Relocation of activity from peripheral to urban areas: This is the situation predicted by Krugman's (1991) 'core-periphery' model, wherein lower transport costs benefit large markets.
- Relocation of activity from urban to peripheral areas: Although not common, some activities in the periphery (such as those related to natural resources, tourism, or land-use costs) benefit from lower transport costs. Regional development policies also play an important role in this regard.

c. The relocation is followed by a new spatial distribution of activities.

d. The new spatial distribution of activities changes accessibility: Depending on the scenario in (b), the change may be zero, ascending, or descending for various areas. For example, if the relocation took place in urban areas, accessibility would decrease in peripheral areas and, perhaps, increase in urban areas. The increase in urban areas is not certain and depends on how accessibility is considered. If the only criterion is the transport cost incurred in a specific activity, the urban area is most likely already covered. If supply-demand or other criteria (e.g., variety or quality of services) are accounted for, accessibility may change. A change in accessibility alters the perceived transport cost, that is, what people in a specific area experience because of the relocation. The change is also proportional to the effects mentioned in (b) and (c) and may vary across areas. For example, if activities are relocated to urban areas, the cost of traveling from the periphery to urban centers to access these activities will increase (as the periphery lacks a supply of these services).
e. A change in accessibility due to activity redistribution may cause further relocation of activities and the repetition of the cycle.

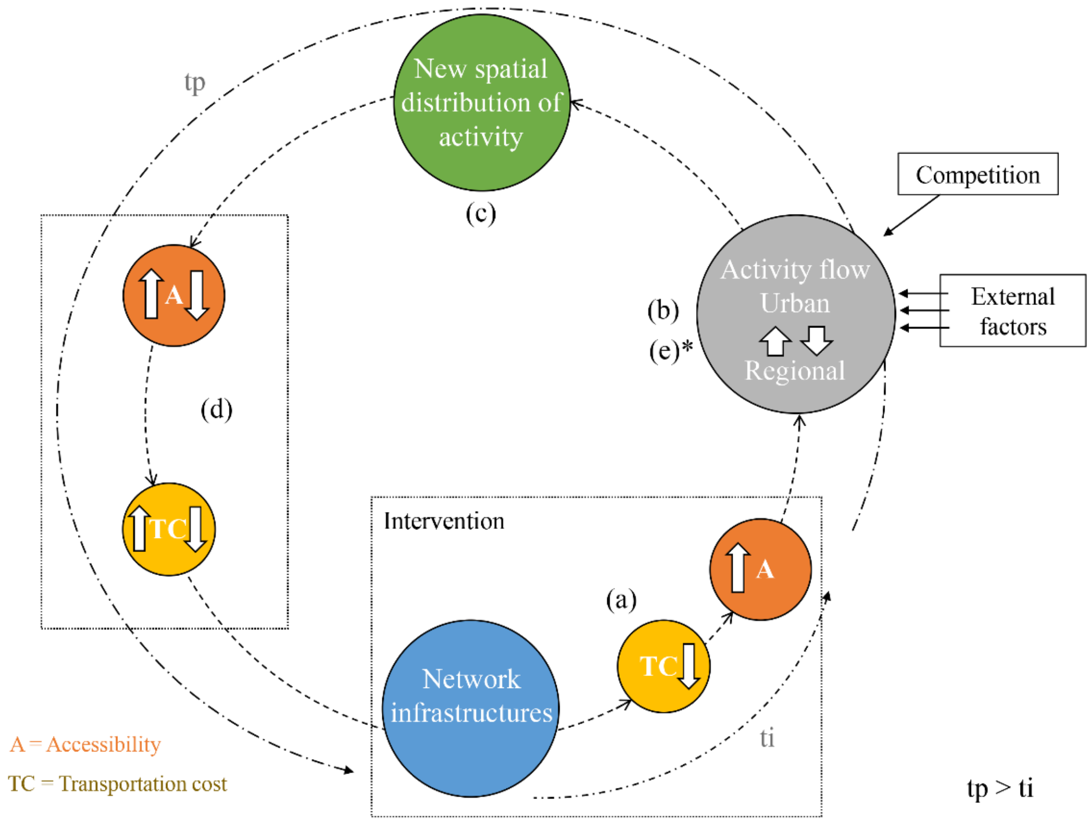

Figure 1. Schematic modelling of the relationship between accessibility and activity/population flows.

Note that the cycle of changes (Figure 1) occurs without interference in the transport network if activity relocation is caused by other factors. Furthermore, the changes can be observed and measured either locally or globally. While the accessibility of a set of areas (e.g., a country) may change positively, negatively, or not at all over a period, there may be a variety of changes at the local level. Finally, the timing of the change is quite different for the two components of accessibility, that is, the activity and the transport cost. The effects of changes in the transport network on accessibility are relatively immediate (ti), whereas the changes resulting from the spatial redistribution of activities are gradual (tp).

2.4 Relation of accessibility and depopulation

To test the aforementioned hypotheses, we examine correlations between accessibility and population age groups for three years (1991, 2001, and 2011), utilizing available demographic data for the study area, which is mainland Greece. We employ two accessibility indicators, one relative (location quotient-based) and one absolute, as provided by Panagiotopoulos and Kaliampakos (2021), to assess the impact of these two types of accessibility on rural depopulation.

The absolute accessibility indicator gauges the travel time required to reach the nearest service center from each settlement. The service centers are determined based on population size, with larger settlements indicating higher levels of activity, be it economic or otherwise. Therefore, a higher value of this indicator indicates lower accessibility for a given location.

Conversely, the relative accessibility indicator is based on a location quotient approach. It involves dividing the travel time to a destination (i.e., a service center) by the average travel time of all locations within the study area to reach their respective nearest destinations. Consequently, the accessibility indicator represents a relative value, indicating how far a location is from service centers, such as cities, compared to all other locations within the study area.

The two accessibility indicators have been calculated for the three years based on the respective transport infrastructure and population. Population data play a crucial role in numerous studies, and typically, as demonstrated in this research, they are sourced from census surveys

https://doi.org/10.48088/ejg.g.pan.15.1.042.053

(Batsaris et al., 2023). Importantly, population has not been used directly as a factor in the accessibility indices but as a proxy for the attractiveness of destinations in both indicators. Population was assessed in terms of the percentages of three age groups: over 65 years, 20–35 years, and 0–9 years. These age groups have been selected to examine depopulation over a relatively short 20-year period. Depopulation and population aging are closely interconnected, and one may lead to the other (Reynaud & Miccoli, 2018). In theory, if the population of the elderly increases while that of younger people decreases in an area, depopulation can occur. Time is a crucial factor considered in this study because transport infrastructure directly affects the accessibility of an area; however, the consequences of such changes in activity may only become evident after several years. Hence, we have employed longitudinal data for the analysis.

The demographic data were sourced from the Hellenic Statistical Authority (ELSTAT, 2020) and were edited to eliminate a few extreme values. For example, certain very small settlements with fewer than a few dozen people exhibited a significant increase or decrease in population as a percentage between census years (e.g., 10 residents to 20 or more residents, or vice versa). Additionally, some administrative changes yielded similar results. All such cases were excluded from the analysis, comprising less than 0.1% of the total dataset. We conduct a total of 54 ordinary least squares (OLS) and spatial regressions—three for each year, two for each type of accessibility, for three population groups, and at three scales/divisions. All calculations and analyses have been conducted using GeoDa software (Anselin et al., 2010), and data processing has been carried out using the QGIS platform.

Applying regression and spatial regression to the dataset involves a series of steps due to the significant spatial dependency, particularly in relation to accessibility derived from a well-structured spatially distributed network. Initially, we employ an Ordinary Least Squares (OLS) regression to analyze the relevant variables. The results from the OLS regression in the GeoDa software provide various values and indices that aid in assessing the presence of spatial dependence. Among these, the first indicator is the Moran's I score, which reveals a robust spatial autocorrelation of the residuals (Figure 2).

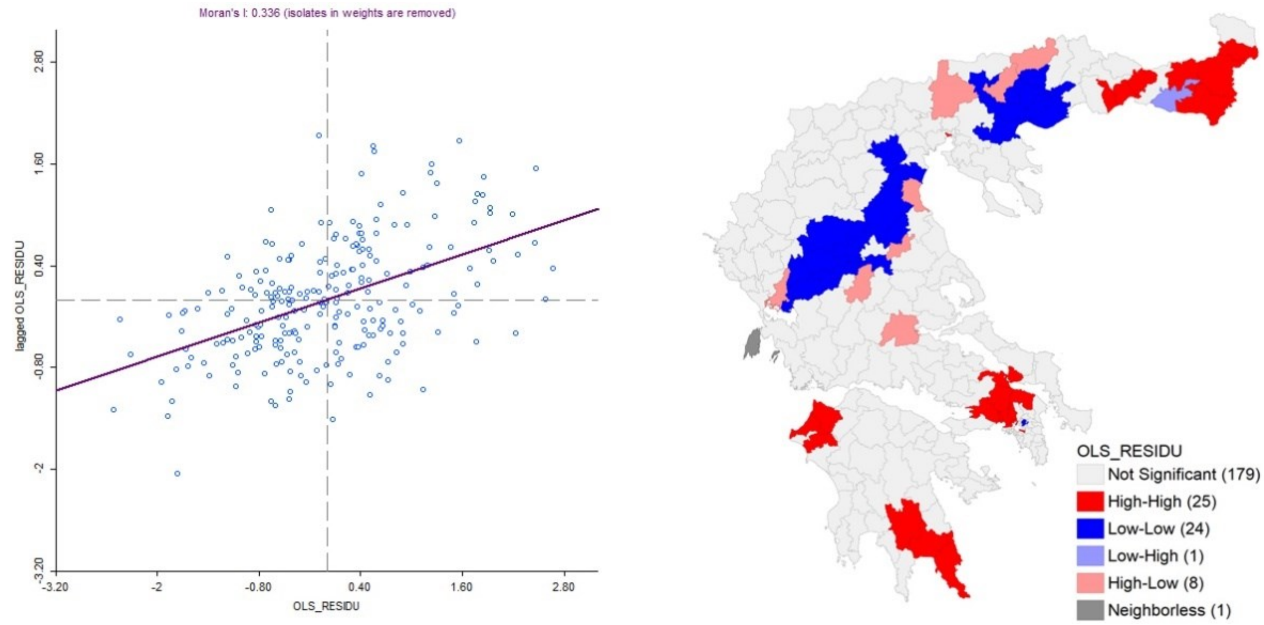

Figure 2. Example illustrating spatial autocorrelation of residuals in an ordinary least squares (OLS) regression. The left panel depicts the Moran's I indicator, indicating a strong correlation among the residuals. The right panel shows the cluster map of local indicators of spatial association (LISA), highlighting the locations where these correlations are present. Four possible outcomes can be observed: (1) high-value locations in proximity to other high-value locations (depending on the neighboring method), (2) low-value locations in proximity to other low-value locations, (3) high-value locations in proximity to low-value locations, and (4) low-value locations in proximity to high-value locations.

Additionally, several other spatial statistics are presented. These encompass the simple Lagrange Multiplier (LM) test for a spatially lagged dependent variable, the simple LM test for error dependence, robust variants that account for the presence of the other, and a portmanteau test (SARMA). These robust tests aid in comprehending the type of spatial dependence at play, leading to the subsequent step of conducting a spatial regression based on the results of the OLS regression. If both types of spatial regression show significant indication values, the spatial lag method is preferred. The distinction between the two spatial dependencies lies in the fact that spatial error indicates a violation of the assumption of uncorrelated error terms, whereas spatial lag indicates a violation of both uncorrelated error terms and independent observations.

In all conducted regressions, only one explanatory variable is used: accessibility (relative or absolute). The objective of this study is not to develop a predictive model for various socioeconomic variables based on accessibility, but rather to examine the role of accessibility in the spatial and temporal changes of those variables. Therefore, the conducted regressions serve two purposes within the scope of this paper. The first purpose is to assess whether relative or absolute accessibility influences the spatiotemporal distribution of the population. The second purpose is to provide insights regarding the MAUP in this specific context.

2.5 Modifiable Areal Unit Problem (MAUP)

The Modifiable Areal Unit Problem (MAUP), as proposed by Openshaw (1979), is widely recognized in the field of spatial analysis. It encompasses the changes in data resulting from the aggregation of information at different scales or zones, which can potentially lead to ecological

fallacies (Xu et al., 2014). Despite the advancements in spatial analysis and mapping techniques, the MAUP continues to present a significant challenge, especially in studies focusing on population flows where a single level of spatial analysis is employed (Stillwell, 2018). While scaling may not always be a major concern, as the loss of information due to aggregation at a new scale primarily affects the variance (Dark & Bram, 2007), zoning can introduce significant distortions to the spatial distribution of data, resulting in further analytical issues. To mitigate the impact of the MAUP, it is possible to address the problem to some extent by conducting tests and comparing results across different scales and zones (Hennerdal & Nielsen, 2017). Alternatively, utilizing spatial autocorrelation techniques can assist in visualizing these relationships on maps, facilitating interpretation (Nelson & Brewer, 2017).
To assess the influence of the MAUP, we conduct an analysis at three different spatial scales, using three distinct administrative divisions: "Settlements" (consisting of 8,135 point entities) and two larger geographical administrative divisions in Greece, "Municipalities" and "Regional Units" (comprising 326 and 75 polygon entities, respectively). We compare the differences between the three scales using spatial autocorrelation, local indicators of spatial association (LISA) cluster maps, and visualization techniques, following a methodology similar to that employed by Nelson and Brewer in 2017. Furthermore, we apply various spatial regression models at each scale.

3. Results and discussion

3.1 Regression analysis

The regression results for the three levels of analysis are presented in Tables 1, 2, and 3, corresponding to the "Settlement" level, the "Municipality" level, and the "Regional Unit" level, respectively. Each table includes the dependent variable, representing the three age groups for the three years of analysis, as well as the covariate denoting relative and absolute accessibility. The remaining sections of the tables provide the regression results. The initial part presents the outcomes of the ordinary least squares (OLS) regression, along with the multicollinearity test (Jarque-Bera p), the heteroskedasticity test (Breusch-Pagan test p), and the spatial dependence diagnostics. In the tables, only the final result of the spatial dependence test is displayed, indicating the presence of spatial dependence and which model, either the spatial lag or the spatial error model, provides a better fit. Lastly, the last columns of the tables present the key findings of the spatial regression.

Starting with the broader levels, namely the "Municipality" and "Regional Unit," a significant correlation between relative accessibility and the distribution of the population within the age groups analyzed in this study is evident. Particularly for the 65+ year-old group, the correlation with relative accessibility is notably strong, even in the OLS regression. The results satisfy the diagnostic tests for the normality of errors; however, the variables exhibit substantial spatial dependence, especially at the "Municipality" level, where all the regressions show spatial dependence. The use of spatial regression enhances the accuracy of the regression models for all three years. Regarding the relationship between accessibility and the magnitude of the percentage of the elderly, the rate consistently increases over time from 1991 to 2011 at both levels of analysis (Tables 1 and 2), indicating that accessibility has an increasing impact on the percentage of the elderly. The regressions based on absolute accessibility yield satisfactory results, although they are less conclusive, particularly at the "Municipality" level. At the "Regional Unit" level, there is little to no spatial dependence for most variables, providing an initial indication regarding the MAUP.

Table 1. Regression results for the relationship between the population age group percentages and accessibility (RA = relative accessibility and AA = absolute accessibility) at the "Regional Unit" level.

			OLS regression				Spatial regression		
Dependent	**Covariate**	**Relation**	R square	Jarque-Bera p	Breusch-Pagan test p	Spatial dependence test	Pseudo-R square	Breusch-Pagan test p	Likelihood Ratio test p
65+ (2011)	RA (2011)	positive	0.501	0.99	0.784	-	-	-	-
65+ (2011)	AA (2011)	positive	0.203	0.822	0.179	error	0.311	0.302	0.03
65+ (2011)	RA (2001)	positive	0.494	0.8	0.133	error	0.567	0.396	0.025
65+ (2011)	AA (2001)	positive	0.134	0.355	0.581	error	0.379	0.694	0
65+ (2011)	RA (1991)	positive	0.459	0.545	0.13	error	0.622	0.242	0
65+ (2011)	AA (1991)	positive	0.048	0.145	0.853	error	0.445	0.988	0
20-35 (2011)	RA (2011)	negative	0.288	0.261	0.863	error	0.369	0.732	0.05
20-35 (2011)	AA (2011)	negative	0.126	0.151	0.003	error	0.254	0.117	0.021
20-35 (2001)	RA (2001)	negative	0.529	0.989	0.248	-	-	-	-
20-35 (2001)	AA (2001)	negative	0.266	0.866	0.118	error	0.401	0.399	0.009
20-35 (1991)	RA (1991)	negative	0.429	0.734	0.611	-	-	-	-
20-35 (1991)	AA (1991)	negative	0.163	0.882	0.464	-	-	-	-

0-9 (2011)	RA (2011)	nega-tive	0.202	0.044	0.3	-	-	-	-
0-9 (2011)	AA (2011)	nega-tive	0.016	0.08	0.805	-	-	-	-
0-9 (2001)	RA (2001)	nega-tive	0.076	0.019	0.252	-	-	-	-
0-9 (2001)	AA (2001)	-	0	-	-	-	-	-	-
0-9 (1991)	RA (1991)	nega-tive	0.038	0.443	0.948	-	-	-	-
0-9 (1991)	AA (1991)	nega-tive	0.018	0.312	0.018	-	-	-	-

Table 2. Regression results for the relationship between the population age group percentages and accessibility (RA = relative accessibility and AA = absolute accessibility) at the "Municipality" level.

			OLS regression				Spatial regression		
Depend-ent	**Co-vari-ate**	**Rela-tion**	R square	Jarque-Bera p	Breusch-Pagan test p	Spatial depend-ence test	Pseudo-R square	Breusch-Pagan test p	Likelihood Ratio test p
65+ (2011)	RA (2011)	positive	0.502	0.105	0	error	0.564	0	0
65+ (2011)	AA (2011)	positive	0.111	0.047	0	error	0.452	0.008	0
65+ (2001)	RA (2001)	positive	0.519	0.044	0	error	0.604	0	0
65+ (2001)	AA (2001)	positive	0.082	0	0	error	0.499	0.004	0
65+ (1991)	RA (1991)	positive	0.452	0	0	error	0.611	0	0
65+ (1991)	AA (1991)	positive	0.033	0	0	error	0.513	0.041	0
20-35 (2011)	RA (2011)	negative	0.362	0.324	0.282	error	0.501	0.919	0
20-35 (2011)	AA (2011)	negative	0.086	0.197	0	error	0.446	0.578	0
20-35 (2001)	RA (2001)	negative	0.513	0.694	0.006	error	0.622	0.018	0
20-35 (2001)	AA (2001)	negative	0.126	0.366	0	error	0.583	0.262	0
20-35 (1991)	RA (1991)	negative	0.42	0.717	0.124	error	0.557	0.008	0
20-35 (1991)	AA (1991)	negative	0.059	0.264	0	error	0.519	0.128	0
0-9 (2011)	RA (2011)	negative	0.308	0.201	0.688	error	0.418	0.462	0
0-9 (2011)	AA (2011)	negative	0.033	0.345	0.002	error	0.336	0.004	0
0-9 (2001)	RA (2001)	negative	0.165	0	0.012	error	0.315	0.005	0
0-9 (2001)	AA (2001)	negative	0.005	0	0	error	0.268	0	0
0-9 (1991)	RA (1991)	negative	0.127	0	0.046	error	0.226	0.019	0
0-9 (1991)	AA (1991)	negative	0.014	0	0	error	0.117	0	0

https://doi.org/10.48088/ejg.g.pan.15.1.042.053

Table 3. Regression results for the relationship between the population age group percentages and accessibility (RA = relative accessibility and AA = absolute accessibility) at the “Settlement” level.

Dependent	Co-variate	Relation	OLS regression				Spatial regression		
			R square	Jarque-Bera p	Breusch-Pagan test p	Spatial dependence test	Pseudo-R square	Breusch-Pagan test p	Likelihood Ratio test p
65+ (2011)	RA (2011)	positive	0.139	0	0	error	0.293	0	0
65+ (2011)	AA (2011)	positive	0.009	0	0	lag	0.273	0.239	0
65+ (2001)	RA (2001)	positive	0.158	0	0	error	0.339	0	0
65+ (2001)	AA (2001)	positive	0.002	0	0	lag	0.322	0.726	0
65+ (1991)	RA (1991)	positive	0.113	0	0	lag	0.339	0	0
65+ (1991)	AA (1991)	positive	0	0	0.212	error	0.331	0	0
20-35 (2011)	RA (2011)	negative	0.063	0	0	error	0.131	0	0
20-35 (2011)	AA (2011)	negative	0.007	0	0.321	lag	0.113	0.248	0
20-35 (2001)	RA (2001)	negative	0.086	0	0	lag	0.156	0	0
20-35 (2001)	AA (2001)	negative	0.006	0	0.085	lag	0.135	0	0
20-35 (1991)	RA (1991)	negative	0.073	0	0	lag	0.141	0	0
20-35 (1991)	AA (1991)	negative	0	0	0.809	lag	0.121	0.011	0
0-9 (2011)	RA (2011)	negative	0.112	0	0	error	0.159	0	0
0-9 (2011)	AA (2011)	negative	0.001	0	0	lag	0.124	0.061	0
0-9 (2001)	RA (2001)	negative	0.067	0	0	error	0.112	0	0
0-9 (2001)	AA (2001)	-	0	0	0.128	lag	0.085	0	0
0-9 (1991)	RA (1991)	negative	0.051	0	0	error	0.129	0	0
0-9 (1991)	AA (1991)	negative	0	0	0.037	lag	0.113	0	0

The correlation with relative accessibility is quite strong for the 20–35 age group across the three years, with increasing strength observed through higher R2 and pseudo-R2 values. However, for absolute accessibility, the correlations in this age group do not yield satisfactory results.

At the "Municipality" level, the correlations for the last age group (0–9 years) with relative accessibility are weaker compared to the previous values but still acceptable. Over time, these correlations become stronger, exhibiting increased weights, similar to the 65+ age group. There is no clear correlation observed with absolute accessibility at this level. The "Regional Unit" level does not provide satisfactory indications for relationships in this age group.

The corresponding correlations at the “Settlement” level are generally weak and inconclusive (Table 3), highlighting the impact of the MAUP. Absolute accessibility shows almost no correlation with any age group. Although relative accessibility seems to have the strongest correlation with the 65+ age group, the diagnostic tests indicate poor results. However, even in this case, the relationship with relative accessibility appears to strengthen over time. The 20–35 and 0–9 age groups show correlations of similar intensity, and the importance of accessibility becomes more pronounced. Nevertheless, these results are insufficient for developing clear models, unlike those obtained at the "Municipality" level.

Overall, the results demonstrate a relationship between relative accessibility and the age distribution of the population, which may be associated with rural depopulation. Although the correlations at the “Settlement” scale are not as robust as at the "Municipality" scale, a clear and increasing trend can be observed. As relative accessibility decreases, the percentage of elderly individuals (65+) increases, while the percentages of young adults (20–35) and children (0–9) decrease. This finding indicates that unequal improvement in accessibility (expressed as relative accessibility) has had a negative impact on demographics in the study area, potentially leading to further depopulation. Previous research by Panagiotopoulos and Kaliampakos (2021) has already shown that low relative accessibility in the study area is primarily concentrated in rural regions. Further reduction in accessibility leads to a decline in the active population and potentially exacerbates the decrease in relative accessibility, creating an amplified vicious cycle (Figure 1). Based on recent research and the findings of this study, it should be noted that although relative accessibility is a key factor influencing the age distribution of the population, it is not the sole determinant. Modeling the flows between rural and urban areas requires the consideration of additional catalysts.

3.2 Investigation of the MAUP

The regression analyses provided initial indications of the MAUP and highlighted its significant impact on the results across all variables and study years within the research area. However, further investigation is warranted to gain a deeper understanding of this issue and to visualize it on maps, thereby offering more insights into its interpretation through spatial autocorrelation. Spatial autocorrelation can provide valuable information about the spatial distribution of a variable. If a variable exhibits signs of clustering, it can assist in identifying broader areas with similar characteristics, thereby providing decision-makers with better tools.

Most variables at all levels of analysis exhibit spatial autocorrelation, as evident from the Moran's I index and the corresponding LISA cluster maps (Figures 3 and 4). The variables of relative accessibility and absolute accessibility demonstrate higher spatial autocorrelation values (Figure 3), followed by the percentages of individuals aged over 65 years and young people (Figure 4). Notably, the spatial autocorrelation of both accessibility and age groups exhibits substantial variation across the three geographical levels, serving as an indicator of the MAUP. Accessibility displays a more evenly distributed pattern with minimal variations at the “Settlement” and "Municipality" levels, while its spatial autocorrelation significantly decreases at the "Regional Unit" level.

The "Regional Unit" level exhibits the lowest spatial autocorrelation. In this larger geographical unit, data aggregation leads to significant spatial homogenization of the variables, potentially resulting in the loss of information. Numerically, the results are more pronounced at larger geographical levels. For example, at the "Regional Unit" level, 57% of the entities display spatial autocorrelation, whereas this percentage is 46% at the “Settlement” level. However, map visualization offers better insights into the distribution of spatial autocorrelation, enabling the identification of broader areas with high or low values. This is particularly crucial in accessibility studies where precise planning of network infrastructure is essential.

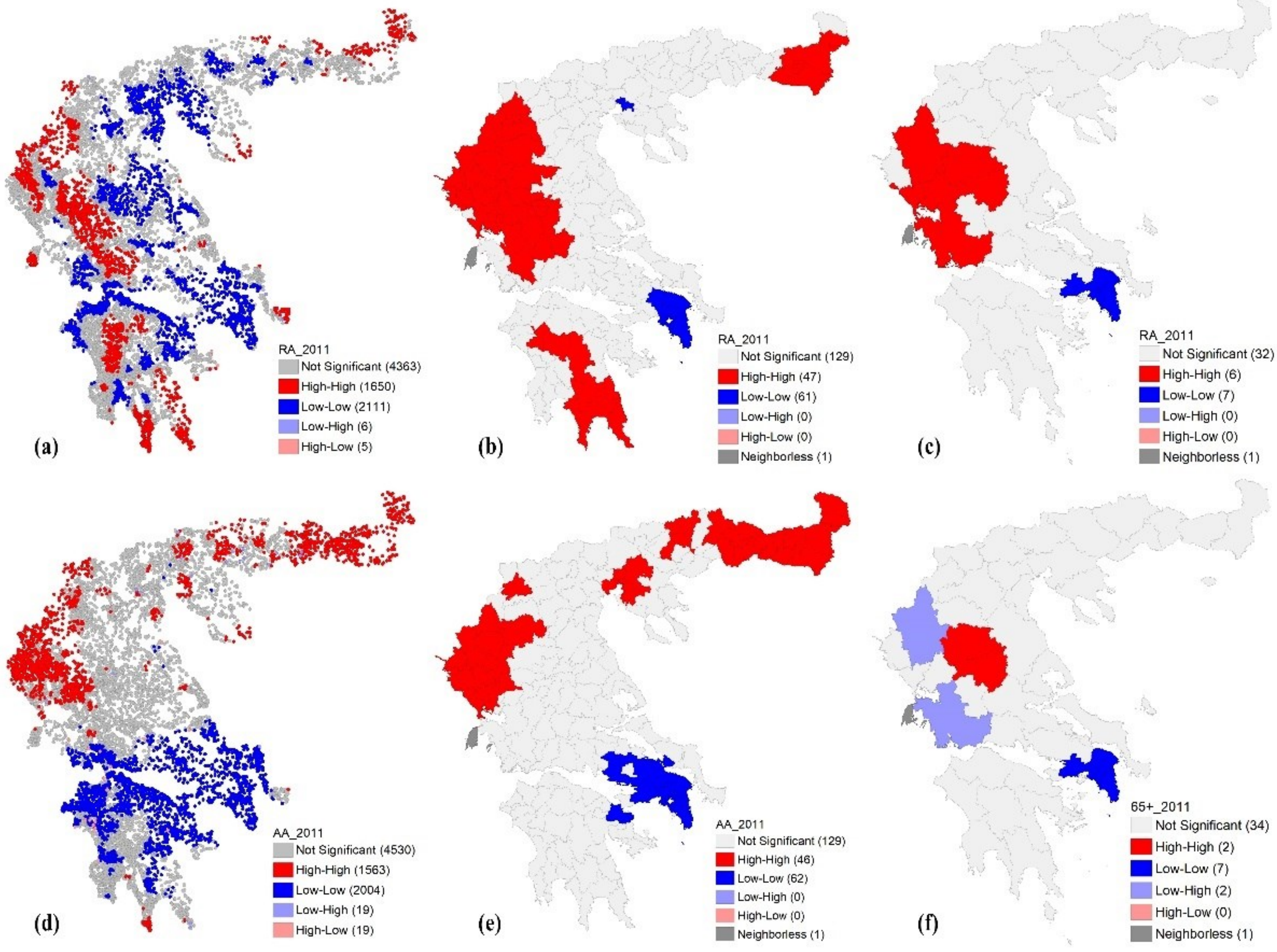

Figure 3. LISA cluster maps for (a) relative accessibility at the “Settlement” level (Moran’s I = 0.899), (b) relative accessibility at the “Municipality” level (Moran’s I = 0.804), (c) relative accessibility at the “Regional Unit” level (Moran’s I = 0.707), (d) absolute accessibility at the “Settlement” level (Moran’s I = 0.862), (e) absolute accessibility at the “Municipality” level (Moran’s I = 0.909), and (f) absolute accessibility at the “Regional Unit” level (Moran’s I = 0.868)

https://doi.org/10.48088/ejg.g.pan.15.1.042.053

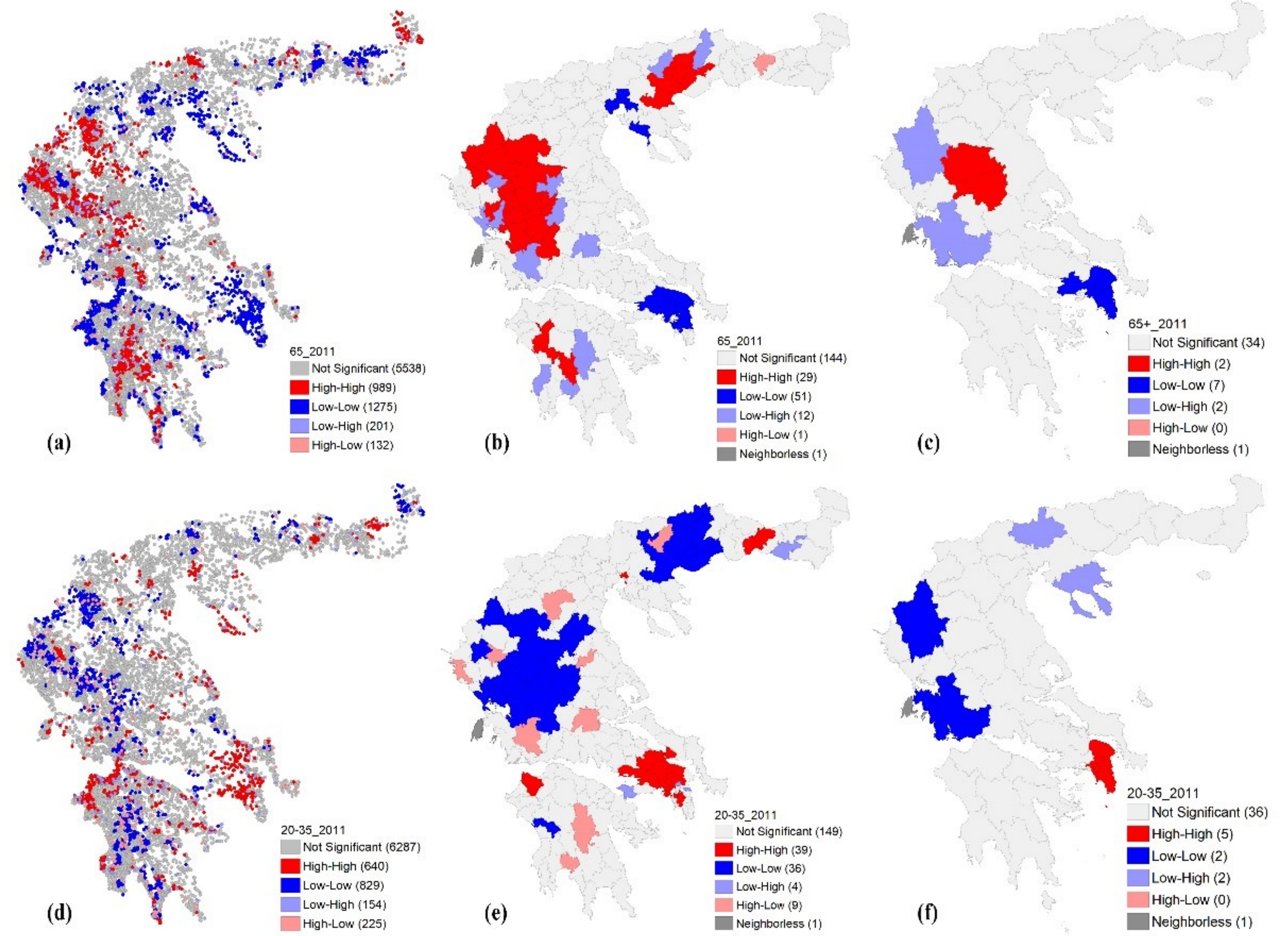

Figure 4. LISA cluster maps for the (a) percentage of 65+-year-olds relative to the total population at the "Settlement" level (Moran's I = 0.360), (b) percentage of 65+-year-olds relative to the total population at the "Municipality" level (Moran's I = 0.539), (c) percentage of 65+-year-olds relative to the total population at the "Regional Unit" level (Moran's I = 0.373), (d) percentage of 20–35-year-olds relative to the total population at the "Settlement" level (Moran's I = 0.202), (e) percentage of 20–35-year-olds relative to the total population at the "Municipality" level (Moran's I = 0.525), and (f) percentage of 20–35-year-olds relative to the total population at the "Regional Unit" level (Moran's I = 0.262).

Similarly to the spatial autocorrelation of individual variables, bivariate spatial autocorrelation can be utilized to gain insights into the clustering patterns of multiple related variables. Figure 5 displays the Local Indicators of Spatial Association (LISA) bivariate analysis for the percentage of individuals aged 65 and above in relation to the relative accessibility during the reference year of 2011. The findings remain consistent for the other two years. The bivariate LISA cluster map represents the spatial autocorrelation quotient between the two variables. In Figure 5, the category of "High" values indicates a high percentage of individuals aged 65 and above, coupled with low accessibility for each geographical entity. Conversely, the "Low" values indicate the opposite pattern for both variables.

In this particular example, the Modifiable Areal Unit Problem (MAUP) poses a more substantial challenge, particularly at the "Regional Unit" level, where the aggregation of data has significantly altered the landscape compared to the "Settlement" level and, to some extent, the "Municipality" level. Despite the loss of information at the "Municipality" level, it can be argued that it is relatively easier to identify broader problematic areas. This, in turn, facilitates the interpretation of the results for decision-makers.

Map visualizations offer additional insights that are challenging to glean from statistics alone. Substantial disparities between high–high and high–low values, or low–low and low–high values at the "Settlement" level may seem inconsequential at the "Municipality" level. Depending on the research question, this can provide valuable information. For example, in the context of accessibility, a pronounced variance in the bivariate LISA clusters map potentially elucidates why population distributions are not impacted by accessibility. In contrast, in regions exhibiting uniformity, it is more probable that population distributions are linked to accessibility.

The Modifiable Areal Unit Problem (MAUP) is a pivotal parameter in this study, and the distinctions between the three levels of analysis become evident. At the "Settlement" level, greater differentiation of the variables reduces their correlation and significantly affects the normality of the data. Nevertheless, spatial regression indicates a correlation between the variables, both in terms of spatial lag and spatial error, underscoring the critical role of spatial dependence in similar analyses.

The aggregation of results at different scales and zoning has both positive and negative consequences. The loss of detail in the spatial distribution of variables can lead to the exclusion of problematic areas, as observed in the planning of a new network infrastructure. However, if the aggregation is moderate, decision-makers may be more receptive to the results. Spatial autocorrelation enables the identification of cluster zones with similar characteristics, which holds great significance in accessibility research, planning, and development.

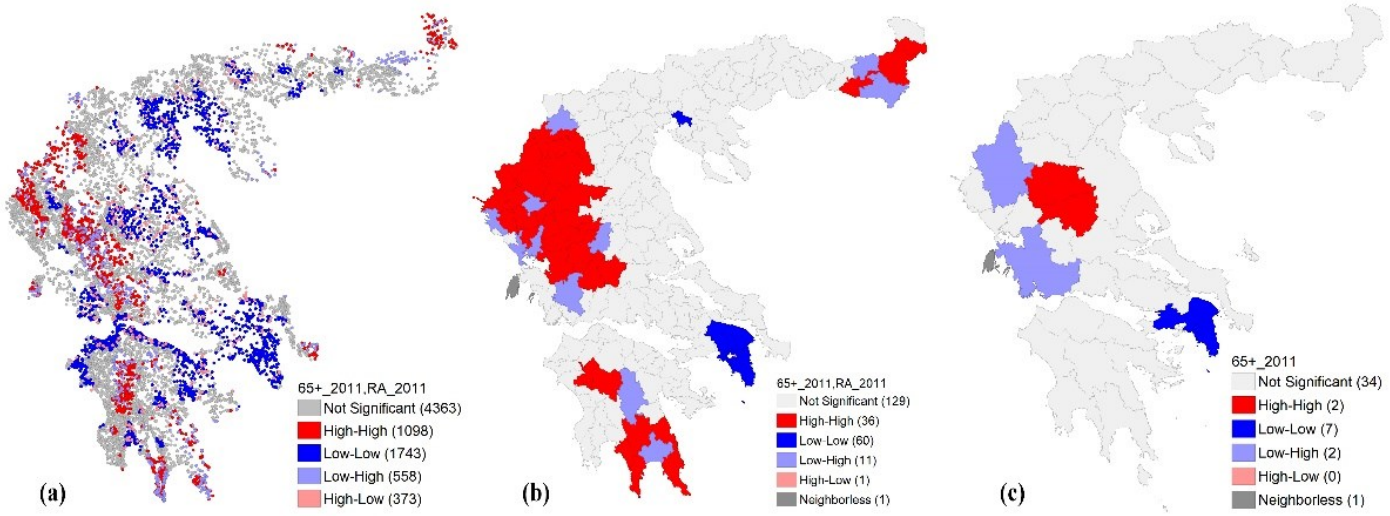

Figure 5. Bivariate LISA cluster maps for (a) percentage of 65+-year-olds relative to the total population and relative accessibility at the "Settlement" level (Moran's I = 0.340), (b) percentage of 65+-year-olds relative to the total population and relative accessibility at the "Municipality" level (Moran's I = 0.581), and (c) percentage of 65+-year-olds relative to the total population and relative accessibility at the "Regional Unit" level (Moran's I = 0.466).

4. Conclusions

This study contributes to the literature on the growing problem of rural depopulation, demonstrating its relationship with accessibility. We argue that relative accessibility, as measured by the location quotient-based method, is a suitable metric for analyzing rural depopulation. This is partly because this type of accessibility measure aligns more closely with human perception of a location's accessibility. Uneven improvements in accessibility can negatively impact how people in a given area perceive such improvements across a wider region. Human capital plays a vital role in strengthening rural economies, and the study results for the examined area indicate an association between relative accessibility and a reduction in human capital.

This observation has significant implications for other factors influencing urbanization and uneven regional development. NEG studies highlight the issues of increasing agglomeration and, consequently, regional deprivation due to reductions in transport costs. In this study, relative potential accessibility is proposed as a better measure for modeling the flow of activities from peripheral to urban areas and vice versa. Time is also established as a crucial determinant in the model, as changes in transport costs and activity redistribution are not synchronous.

Taking into account the effect of the MAUP on related analyses, the comparative results for the three levels indicate significant variation, although the general trend is evident in most cases. The "Settlement" level exhibited significant spatial noise, which strongly influenced the regression results and hindered diagnostic tests. The optimal level of geometric scale or administrative division should be selected based on the case and the study's objectives. For instance, when formulating development policies, analyzing a larger geographical area is more desirable. In contrast, for designing transport infrastructure, analysis at the "Settlement" or even more disaggregated levels may yield better results. Finally, this study confirms that spatial autocorrelation methods and map visualization are valuable tools for addressing the MAUP, considering both scale and zoning.

This study has certain limitations. First, regarding longitudinal data, only three years of census data were available in conjunction with changes in the transport network. Future research should focus on a longer and more detailed time span for population data (or other types of data related to peripheral deprivation), while accounting for changes in the transport infrastructure. Additionally, potential correlations between accessibility and population or activity changes should be examined across different time frames. For example, if a change in accessibility impacts future population or activity distribution.

Further research is needed to examine the contribution of accessibility to urbanization and the associated abandonment of peripheral areas. The role of transport infrastructure and the subsequent improvement in accessibility has been shown to enhance this phenomenon. Improving accessibility offers numerous benefits that cannot be ignored. Over the past three decades, Greece has witnessed substantial advancements in its network infrastructure. However, rural depopulation remains a noticeable and persistent issue with no signs of abating. Furthermore, this study suggests that the enhancement of accessibility may have inadvertently exacerbated the problem. Therefore, appropriate measures should be taken to retain socio-economic activity in regional areas where new transport infrastructure significantly improves accessibility.

Conflicts of Interest: The author declares no conflict of interest.

References

Agourogiannis, P., Kavroudakis, D., Batsaris, M. and Zafeirelli, S., (2023). Towards a Similarity Index of network paths in Spatial Networks. *European Journal of Geography*, 14(1), pp.1-9. https://doi.org/10.48088/ejg.p.ago.14.1.1.9

Anselin, L., Syabri, I., & Kho, Y. (2010). GeoDa: an introduction to spatial data analysis. In *Handbook of Applied Spatial Analysis* (pp. 73-89). Springer, Berlin, Heidelberg.

Batsaris, M., Zafeirelli, S., Vaitis, M., & Kavroudakis, D. (2023). PoD: A Web Tool for Population Downscaling Using Areal Interpolation and Volunteered Geographic Information. *European Journal of Geography*, 14(4), 22-36. https://doi.org/10.48088/ejg.m.bat.14.4.022.036

Costa, C., Ha, J., & Lee, S. (2021). Spatial disparity of income-weighted accessibility in Brazilian Cities: Application of a Google Maps API. *Journal of Transport Geography*, *90*, 102905. https://doi.org/10.1016/j.jtrangeo.2020.102905

Dark, S. J. & Bram, D. (2007). The modifiable areal unit problem (MAUP) in physical geography. *Progress in Physical Geography*, *31*(5), 471–479. https://doi.org/10.1177/0309133307083294

Deng, T., Wang, D., Hu, Y., & Liu, S. (2020). Did high-speed railway cause urban space expansion?——Empirical evidence from China's prefecture-level cities. *Research in Transportation Economics*, *80*, 100840. https://doi.org/10.1016/j.retrec.2020.100840

Geurs, K. T. & Van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography*, *12*(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Goletsis, Y. & Chletsos, M. (2011). Measurement of development and regional disparities in Greek periphery: A multivariate approach. *Socio-Economic Planning Sciences*, *45*(4), 174–183. https://doi.org/10.1016/j.seps.2011.06.002

Gutiérrez, J. & Urbano, P. (1996). Accessibility in the European Union: The impact of the trans-European road network. *Journal of Transport Geography*, *4*(1), 15–25. https://doi.org/10.1016/0966-6923(95)00042-9

Guzman, L. A., Oviedo, D., & Rivera, C. (2017). Assessing equity in transport accessibility to work and study: The Bogotá region. *Journal of Transport Geography*, *58*, 236–246. https://doi.org/10.1016/j.jtrangeo.2016.12.016

Hashtarkhani, S., Kiani, B., Bergquist, R., Bagheri, N., VafaeiNejad, R., & Tara, M. (2020). An age-integrated approach to improve measurement of potential spatial accessibility to emergency medical services for urban areas. *The International Journal of Health Planning and Management*, *35*(3), 788–798. https://doi.org/10.1002/hpm.2960

Hellenic Statistical Authority (ELSTAT). (2020). *Population Censuses 1991, 2001, 2011.* Retrieved from https://www.statistics.gr/en/home/. Accessed November, 2020.

Hennerdal, P. & Nielsen, M. M. (2017). A multiscalar approach for identifying clusters and segregation patterns that avoids the modifiable areal unit problem. *Annals of the American Association of Geographers*, *107*(3), 555–574. https://doi.org/10.1080/24694452.2016.1261685

Iammarino, S., Rodríguez-Pose, A., & Storper, M. (2019). Regional inequality in Europe: Evidence, theory and policy implications. *Journal of Economic Geography*, *19*(2), 273–298. https://doi.org/10.1093/jeg/lby021

Jafari Samimi, A., Rasekhi, S., & Asadi, S. P. (2019). The monetary policy, credit constraint and spatial distribution of economic activity: A contribution of new economic geography. *Iranian Economic Review*, *23*(1), 1–27. https://doi.org/10.22059/ier.2018.69096

Johnson, K. M. & Lichter, D. T. (2019). Rural depopulation: Growth and decline processes over the past century. *Rural Sociology*, *84*(1), 3–27. https://doi.org/10.1111/ruso.12266

Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, *99*(3), 483–499. https://doi.org/10.3386/w3275

Monastiriotis, V. (2011). Making geographical sense of the Greek austerity measures: Compositional effects and long-run implications. *Cambridge Journal of Regions, Economy and Society*, *4*(3), 323–337. https://doi.org/10.1093/cjres/rsr026

Navarro Valverde, F. (2019). Depopulation and aging in rural areas in the European Union: Practices starting from the LEADER approach. *Perspectives on Rural Development*, *2019*(3), 223–252.

Nelson, J. K. & Brewer, C. A. (2017). Evaluating data stability in aggregation structures across spatial scales: Revisiting the modifiable areal unit problem. *Cartography and Geographic Information Science*, *44*(1), 35–50. https://doi.org/10.1080/15230406.2015.1093431

Openshow, S. (1979). A million or so correlation coefficients, three experiments on the modifiable areal unit problem. *Statistical Applications in the Spatial Science*, 127–144.

Paez, A., Mercado, R. G., Farber, S., Morency, C., & Roorda, M. (2010). Accessibility to health care facilities in Montreal Island: An application of relative accessibility indicators from the perspective of senior and non-senior residents. *International Journal of Health Geographics*, *9*(1), 1–15. https://doi.org/10.1186/1476-072x-9-52

Páez, A., Scott, D. M., & Morency, C. (2012). Measuring accessibility: Positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, *25*, 141–153. https://doi.org/10.1016/j.jtrangeo.2012.03.016

Panagiotopoulos, G. & Kaliampakos, D. (2021). Location quotient-based travel costs for determining accessibility changes. *Journal of Transport Geography*, *91*, 102951. https://doi.org/10.1016/j.jtrangeo.2021.102951

Petrakos, G. & Economou, D. (2004). Spatial Asymmetry in Southeastern Europe. *The Journal of Economic Asymmetries*, *1*(1), 127–149. https://doi.org/10.1016/j.jeca.2004.01.009

Petrakos, G. & Psycharis, Y. (2016). The spatial aspects of economic crisis in Greece. *Cambridge Journal of Regions, Economy and Society*, *9*(1), 137–152. https://doi.org/10.1093/cjres/rsv028

Petrakos, G., Rodríguez-Pose, A., & Rovolis, A. (2003, August). *Growth, integration and regional inequality in Europe.* 43rd Congress of the European Regional Science Association: "Peripheries, Centres, and Spatial Development in the New Europe", European Regional Science Association (ERSA), Jyväskylä, Finland.

Petrakos, G. & Saratsis, Y. (2000). Regional inequalities in Greece. *Papers in Regional Science*, *79*(1), 57–74. https://doi.org/10.1111/j.1435-5597.2000.tb00759.x

Petrakos, G. & Tsoukalas, D. (1999). Metropolitan concentration in Greece: an empirical investigation. *The Development of the Greek Cities*, *247*, 265.

Puga, D. (2002). European regional policies in light of recent location theories. *Journal of economic geography*, *2*(4), 373–406. https://doi.org/10.1093/jeg/2.4.373

Puga, D. (2008). Agglomeration and cross-border infrastructure. *EIB Papers*, *13*(2), 102–124.

Qi, Z., Lim, S., & Hossein Rashidi, T. (2020). Assessment of transport equity to Central Business District (CBD) in Sydney, Australia. *Transportation Letters*, *12*(4), 246–256. https://doi.org/10.1080/19427867.2019.1584694
Reynaud, C. & Miccoli, S. (2018). Depopulation and the aging population: The relationship in Italian municipalities. *Sustainability*, *10*(4), 1004. https://doi.org/10.3390/su10041004
Rokicki, B., & Stępniak, M. (2018). Major transport infrastructure investment and regional economic development–An accessibility-based approach. *Journal of Transport Geography*, *72*, 36–49. https://doi.org/10.1016/j.jtrangeo.2018.08.010
Rosik, P., & Stępniak, M. (2015). Monitoring of changes in road potential accessibility at municipality level in Poland, 1995-2015. *Geographia Polonica*, *88*(4), 607–620. https://doi.org/10.7163/gpol.0036
Schwanen, T. (2016). Geographies of transport I: Reinventing a field?. *Progress in Human Geography*, *40*(1), 126–137. https://doi.org/10.1177/0309132514565725
Sheludkov, A., Kamp, J., & Müller, D. (2020). Decreasing labor intensity in agriculture and the accessibility of major cities shape the rural population decline in postsocialist Russia. *Eurasian Geography and Economics*, 1–26. https://doi.org/10.1080/15387216.2020.1822751
Stillwell, J., Daras, K. and Bell, M., 2018. Spatial aggregation methods for investigating the MAUP effects in migration analysis. *Applied Spatial Analysis and Policy*, 11, pp.693-711. https://doi.org/10.1007/s12061-018-9274-6
Wenner, F., & Thierstein, A. (2020). Which Regions Benefit from New Rail Accessibility? Germany in 2030. *disP-The Planning Review*, *56*(3), 59–76. https://doi.org/10.1080/02513625.2020.1851910
Xu, P., Huang, H., Dong, N., & Abdel-Aty, M. (2014). Sensitivity analysis in the context of regional safety modeling: Identifying and assessing the modifiable areal unit problem. *Accident Analysis & Prevention*, *70*, 110–120. https://doi.org/10.1016/j.aap.2014.02.012
Yoshida, N., & Deichmann, U. (2009). Measurement of accessibility and its applications. *Journal of Infrastructure Development*, *1*(1), 1–16. https://doi.org/10.1177/097493060900100102

European Journal of Geography