Spatial Variation of Local Population in Inducement Areas under Urban Shrinkage

Ayano Shiraishi[1]*, Kiichiro Kumagai[2]

[1] *Graduate School of Science and Engineering, Setsunan University, 17-8 Ikeda-Nakamachi, Neyagawa, Osaka, Japan. 24m209sa@edu.setsunan.ac.jp*
[2] *Faculty of Science and Engineering, Setsunan University, 17-8 Ikeda-Nakamachi, Neyagawa, Osaka, Japan. kumagai@civ.setsunan.ac.jp*

Abstract: Japanese population is currently declining. This population decline may lead to slowed social development and difficulties in maintaining urban functions. The government is promoting policies to improve urban sustainability by guiding housing and urban functions. On the other hand, the "Urban spongification" phenomenon, in which vacant houses and lots are scattered within urbanized areas, is also a challenge as it risks hindering population concentration. We have focused on the spatial distribution of local populations in urban areas and developed methods to statistically define and understand the size of low population density areas. However, the population distribution characteristics within these guided zones have not been analyzed from the viewpoint of the Urban spongification effect. In this study, we analyzed the spatial variation characteristics of population distribution by land use type using the methods developed by the authors.

Keywords: Local population dynamics; Population decline; Densely populated area; Spatial autocorrelation

1. Introduction

Japanese population has increased with rapid postwar economic growth, surpassing 100 million in 1967. Following a peak in 2008, it is projected to fall below 100 million again by 2053. This decline is expected to reduce societal motivation for development, make it difficult to maintain urban functions, and potentially accelerate further urban decline. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is promoting the "Compact Plus Network" as a countermeasure. This initiative aims to concentrate urban functions within walking distance and encourage population clustering. Specifically, it seeks to enhance urban sustainability by advancing location optimization plans. These plans aim to guide residential and urban functions into specific areas. On the other hand, the "Urban spongification" phenomenon, where low-use or unused space such as vacant houses and lots are randomly occurring on small plots within cities, is one of the challenges. This phenomenon can promote community decline and worsen public safety and aesthetics, potentially becoming a factor hindering population concentration. Therefore, it is required to implement medium-to long-term monitoring of urban structure that responds to Urban spongification as urban structures continue to change. Thus, we have developed a methodology to statistically define and identify areas of low population density within urban districts by focusing on the spatial distribution of local populations itself (Kumagai et al., 2021, 2022). However, while this methodology quantifies the spatial characteristics of local population distributions, the relationship between the obtained characteristics and land use conversion, regulations, and the designation of guided areas has not been sufficiently examined. In this study, based on the spatial analysis methods developed thus far, we focus on changes in land use to clarify the characteristics of spatial shifts in local population distribution over a 25-year period.

2. Methodology

This study applied a spatial analysis method comprising spatial autocorrelation analysis based on the G-statistic and overlay analysis. Based on statistical tests using G statistics, the target areas were classified into three types of results: positive spatial autocorrelation, no spatial autocorrelation, and negative spatial autocorrelation. Positive spatial autocorrelation indicates that larger local groups cluster within a distance d from observation point i. The spatial analysis approach we developed is based on the generation of positive spatial autocorrelation areas following the distance parameter d. Figure 1 shows a conceptual diagram regarding the detection of spatial characteristics of local populations. Regions showing positive autocorrelation within a distance d_{max} from point i generally encompass positive regions located at distances d_{max-1} or less from i. This occurs because the G-statistic is fundamentally derived from the sum of local populations within distance d from point i (see Figures 1a and 1b). The transition from positive spatial autocorrelation to no spatial autocorrelation occurs at a specific point at distance d_n as the distance decreases from d_{max} (see Figures 1b and 1c). Therefore, the distance d_n is defined as the Ambiguity of Spatial scale in a densely Populated area (ASP). That is because, the hypothesis that the set of local clusters within distance d_n from position i constitutes a random sample cannot be rejected even when positive spatial autocorrelation is continuously observed between distances d_{max} and d_{n+1}. In other words, this d_n indicates the potential occurrence of local population voids in urban areas. Therefore, we applied ASP calculations to a moving window operation to repeatedly process the target area on a mesh unit basis.

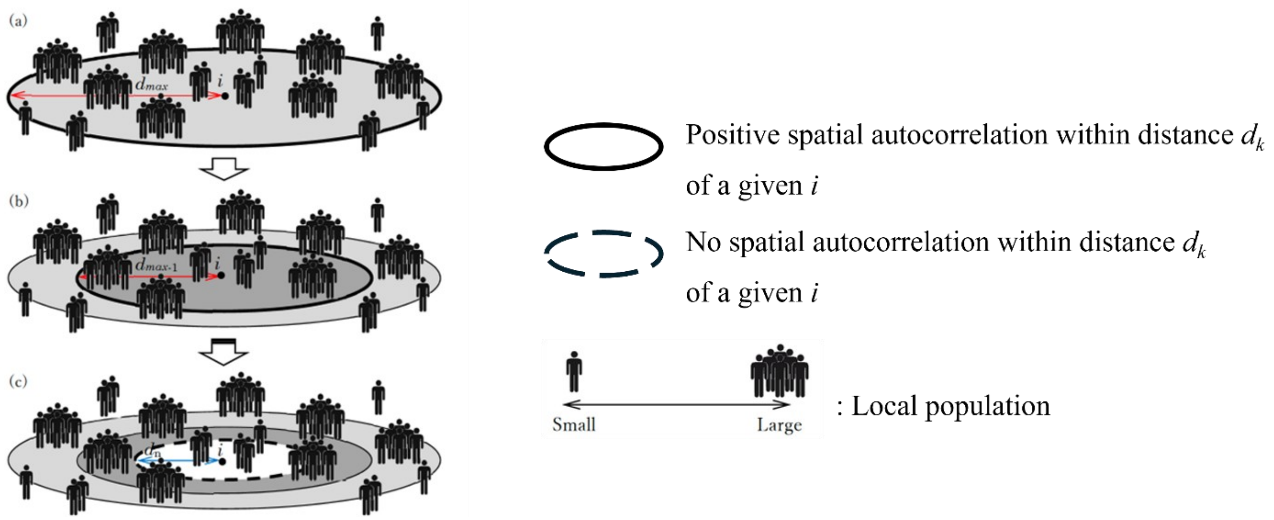

Figure: 1: Conceptual diagram with respect to the detection of the spatial features.

As a result, the ASP distribution was mapped alongside the spatial size of low-density population distributions. This study examines the spatial variation of ASP over 25 years. Spatial variation is primarily classified into two patterns: ASP contraction (-ΔASP) and ASP expansion (+ΔASP). -ΔASP indicates a regional increase in population within an ASP, while +ΔASP suggests an expansion of areas with low population density.

3. Results/Findings

Figure 2a. illustrates the ASP mapping results for Osaka Prefecture in Japan, the study area for 2020. The color gradient from green to red represents ASP variation. ASP_0 shows that districts exhibiting larger local populations exist across a range from narrow to broad areas (d_{max}). It can be confirmed that there are differences in the distribution of the size of low-density population areas (ASP) in different municipality areas. ASP is smaller in urban areas and larger in suburban areas. Figure 2b. reveals the result of mapping of -ΔASP and +ΔASP: characteristic changes over a 25-year period.

To monitor Urban spongification, it is necessary to understand the spatial characteristics of local populations, as well as the land use conditions that give rise to these changes. Furthermore, it has been demonstrated that fluctuations in local population and changes in land use mutually influence each other. It is therefore desirable to analyze the characteristics of spatial fluctuations in local population based on the history of land use transitions. In this study, using land use data generated by MLIT, we define "urbanization" as the transformation into medium-to-high-rise buildings or low-rise buildings (in non-dense and dense areas), which are considered closely related to local population fluctuation patterns. By consolidating land use data across multiple periods, we categorize

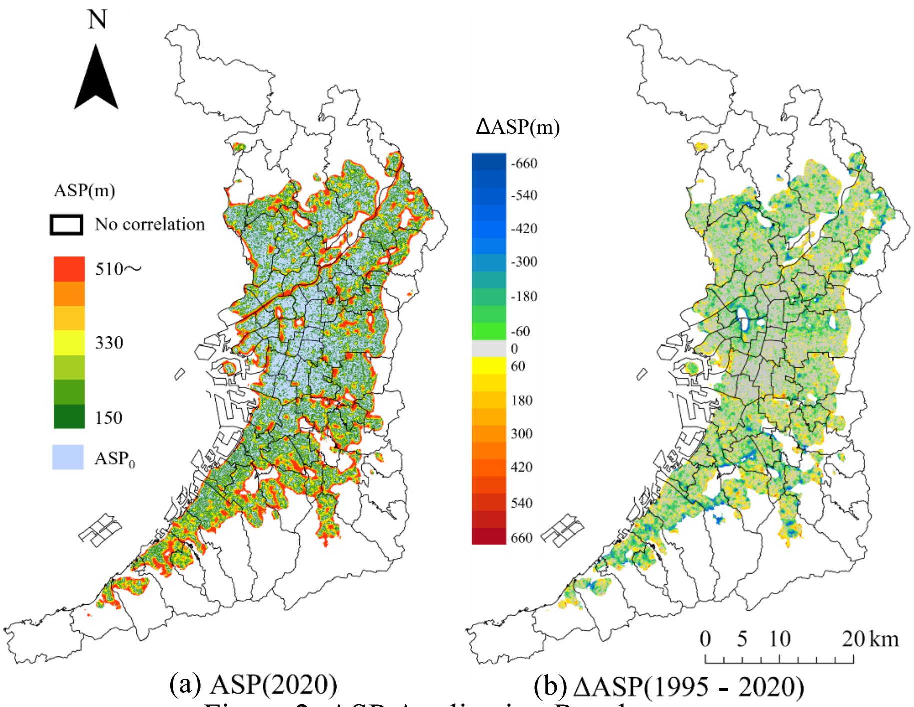

Figure 2: ASP Application Results.

Table 1: Results of the residual analysis between ΔASPs and urbanized periods.

(a)Exclusively low-rise residential zone	ΔASP(m) -660	-600	-540	-480	-420	-360	-300	-240	-180	-120	-60	0	60	120	180	240	300	360	420	480	540	600	660
Period of Urbanization: No urbanization		(-)**	(-)**	(-)**			*	***	***	***	**	(-)***	***		*			**					
~1974	(-)**	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***		***		(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)**	(-)**		
1974~1996		(-)*	(-)*		(-)***	(-)**	(-)**	(-)*	(-)**	(-)***	(-)***		***	***	***	***							
1996~2021	***	***	***	***	***	***	***	***	***			(-)***	(-)***			*	*			*		**	

***0.001, **0.001-0.01, *0.01-0.05

(b)Exclusively low-rise residential zone & residential promotion areas	ΔASP(m) -660	-600	-540	-480	-420	-360	-300	-240	-180	-120	-60	0	60	120	180	240	300	360	420	480	540	600	660
Period of Urbanization: No urbanization			(-)**	(-)**			**	***	***	***		(-)***			**			***	**				
~1974	(-)*	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***	(-)***		***		(-)***	(-)***	(-)***	(-)*	(-)***	(-)**	(-)*			
1974~1996			(-)**		(-)***	(-)*	(-)**	(-)*		(-)***	(-)***		***	***	***	***		**	*	**			
1996~2021	***	***	***	***	***	***	***	***	***	**	***	(-)***	(-)***	(-)*									

***0.001, **0.001-0.01, *0.01-0.05

(c)Outside low-rise residential districts & residential promotion districts	ΔASP(m) -660	-600	-540	-480	-420	-360	-300	-240	-180	-120	-60	0	60	120	180	240	300	360	420	480	540	600	660
Period of Urbanization: No urbanization								***	***	***	***	(-)***					(-)*						
~1974												**											
1974~1996									(-)**		(-)*			**									**
1996~2021								(-)*		(-)**	(-)***	***				*	*						

***0.001, **0.001-0.01, *0.01-0.05

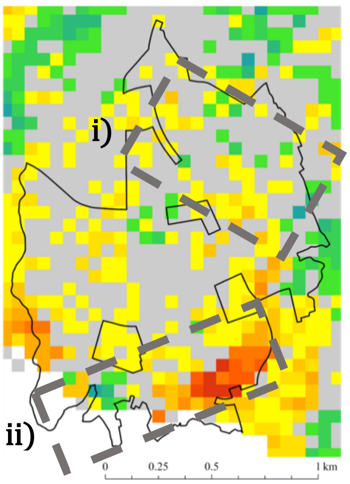

Figure 3: Distinctive Areas.

urbanization into three phases: before 1974, from 1974 to 1996, and from 1996 to 2021. In this study, to understand the impact of zoning categories, we apply residual analysis to the timing of urbanization and ΔASP specifically within Osaka Prefecture's Type 1 Low-Rise Residential Districts and Type 2 Low-Rise Residential Districts. The results are shown in Table 1.

In areas urbanized before 1974, both +ΔASP and -ΔASP are significantly smaller than expected values for many items, while ΔASP indicates significantly larger than expected values in low-density population distribution areas showing no change (ΔASP=0). For areas urbanized between 1974 and 1996, significant increases in +ΔASP are observed for many items. For areas urbanized between 1996 and 2021, the distribution of -ΔASP changes is significantly above the expected value, indicating many locations related to the reduction of low-density population spots. Land use zones, once established, are often maintained for extended periods. Low-rise residential zones impose stricter usage restrictions compared to other zones. As a result, after 30 to 50 years of urban development, these restrictions appear to have contributed to the expansion of localized areas characterized by low-density population distribution in many regions.

Similarly, for low-rise residential areas, we perform the residual analysis through comparing regions inside and outside the induction zones in the location optimisation plan. Within the induction zones, the areas urbanized before 1974 and between 1996 and 2021 show results equivalent to those for Osaka Prefecture as a whole. In the areas urbanized between 1996 and 2021, focusing on the induction zones, a greater number of items showing a positive and significant -ΔASP is identified. Outside theinduction zones, no significant changes were observed across the three periods likely due to complex conditions.

An enlarged map of the characteristic area, Osaka Sayama City, is shown in Figure 3. The black lines indicate boundaries within the residential promotion areas and low-rise residential districts. The legend for Figure 3. is the same as that for Figure 2b. In this region, areas urbanized before 1974, enclosed by the dotted line labeled i), are located in the northern part of the area, while areas urbanized between 1974 and 1996, enclosed by the dotted line labeled ii), are located in the southern part. On the basis of the residual analysis results, areas urbanized before 1974 show relatively small changes in low-density population areas, suggesting that population turnover has largely been completed. In contrast, area ii) shows a concentration of +ΔASP, indicating an expansion of low-density areas. This suggests that the previous generation has settled there, population turnover is not progressing, and there is a high likelihood of declining household size and vacant houses. Given the ongoing population decline, it seems difficult to expect increased inflows through population turnover. Therefore, there is concern that the phenomenon of Urban spongification will further expand. Monitoring areas with low population density will remain important going forward.

4. Conclusions

This study compared temporal changes in land use patterns with the accompanying spatial changes in population distribution. After categorizing urbanization into three phases, we analyzed changes in the spatial spread of low population density within residential promotion zones and low-rise residential zones. In regions where urbanization occurred approximately 30 to 50 years ago, a tendency toward greater expansion of low local population distribution was confirmed.

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