# SPATIAL VARIATION ANALYSIS OF LOCAL POPULATION DATA AND LOCAL HOUSEHOLD-SIZE DATA FOR URBAN MANAGEMENT IN A DECLINING POPULATION

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**KEY WORDS:** Local population dynamics, Population Decline, Local Household Size, Urban Spongification, Spatial Autocorrelation.

# ABSTRACT:

In Japan, population decline is one of the important issues that need to be tackled in socioeconomic fields. We apply an analysis method composed of a spatial autocorrelation analysis to the local population data and the local household-size data generated through the 1995 and 2015 national census, and detect their spatial dynamics in this study. Under the concept that the application of local population and local household can detect the details of the spatial features of population decline, we newly define an index regarding the size of an area where lower local mean sizes of households are distributed in urbanized areas, in addition to the spatial local-population index defined previously. It is shown that the local population dynamics are described by the combination of the variations of the 2 indices between 1995 and 2015.

#### 1. BACKGROUND

Population decline in an ageing society with low birthrates is one of the issues of urban management in Japan (National Institute of Population and Social Security Research, 2012, Ministry of Land, Infrastructure, Transport and Tourism, 2014, Kutsuzawa, 2016). A rapid decline in the population induces a number of problems: underpopulation in rural areas, expansion of lower population density in urban areas, as well as increased expenditure on the maintenance of public transportation and infrastructure under the pressure of lower revenue. The Japanese government has taken several measures to address this phenomenon, including "Compact Plus Network". In the concept of "Compact Plus Network", there is a land use strategy for living space and urban function. Residence Attraction Districts and Urban Function Attraction Districts are defined as core areas for maintaining sufficient population density given current and predicted population dynamics. It is, however, required to address "Urban spongification" in which vacant land and vacant houses in urbanized areas randomly occur. This phenomenon is considered as a cause for concern about an impediment to maintaining sufficient population density because it is generally difficult to integrate urban redevelopment due to the randomness of its occurrence (Ministry of Land, Infrastructure, Transport and Tourism, 2019). In addition, it has been clarified that the larger a low population-density area is, the lower its population density becomes (Kumagai et al. 2021). Hence, monitoring the spatial distribution of the population in urbanized areas is needed. Likewise, the number of households is also an important factor for urban management. In Japan, the number of households continues to increase even under the population decline so that the household size keeps on shrinking in the last decade (National Institute of Population and Social Security Research, 2018, Statistics Bureau, Ministry of Internal Affairs and Communications, 2021). The number of single-person households over the age of 65 is also showing an increasing

trend toward 2040. In particular, the urban population over the age of 65 increases rapidly in the future, and there is concern that disaster preservation capabilities will decline such as a deterioration of community functions, delayed evacuations, etc. (Ministry of Land, Infrastructure, Transport and Tourism, 2021). The spatial spread of small household size under the population decline can therefore be seen as one of the signs of "Urban spongification". In this study, we apply an analysis method composed of a spatial autocorrelation analysis to the local population data and local household data generated through the 1995 and 2015 national census, and detect their spatial features.

#### 2. DATA AND METHODOLOGY

# 2.1 Study Area

The area of Osaka prefecture was selected as the study area. Figure 1 shows the location of the study area. Osaka prefecture is located in the west part of Japan. There is a second largest city in the Osaka prefecture, while a lot of satellite cities are located around the city. Local populations are distributed in various spatial patterns in the study area since there are completely urbanized areas, moderately urbanized areas, and suburban areas.

#### 2.2 Population Data

The basic unit block population data of the Population Census of Japan in 1995 and 2015 were applied to the spatial analysis of demographic dynamics. The Population Census data is one of the results of the National Census. The basic unit block population data has the highest spatial resolution based on the management of National Census investigators. In the study area, the total population was 8,797,268 in 1995 and 8,839,469 in 2015, while the total household was 3,300,335 in 1995, and 3,923,887 in 2015. The mean size of households shows 2.67 in

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Figure 1. Study area and its location. The grey area in the enlarged view of the map shows Osaka prefecture.

1995 and 2.25 in 2015. We generated 60m-by-60m mesh data as local population data and local household data by counting the basic unit block population data on a mesh-by-mesh basis. We also obtained local household-size data by applying them to the calculation of the number of persons per household.

#### 2.3 Methodology

We applied a spatial analysis method composed of spatial autocorrelation analysis based on G statistics and overlay analysis (Getis 1992, Ord and Getis, 1995, Kumagai 2011, Kumagai et al. 2017).

**2.3.1** Application of G Statistics: Through the application of G statistics, a cluster of larger local objects, i.e., larger local populations, can be detected with the size of the cluster. If the local object is the local population, the G statistic can be expressed as

$$G_i(d) = \frac{\sum_i w_{ij}(d)h_j}{\sum_i h_j} \tag{1}$$

where is  $G_i$  is G statistics,  $h_j$  is the local population located in the area,  $w_{ij}$  is a symmetric binary spatial weight matrix with ones for all links defined as being within distance d of a given i; all other links are coded zero, including the link of a point i to itself (Getis 1992). If the null hypothesis is that the set of  $h_j$ values within d of location i is a random sample, we derive the Z value described in Eq. (2).

$$Z_i(d) = \frac{G_i(d) - E[G_i(d)]}{\sqrt{VarG_i(d)}}$$
(2)

Positive or negative spatial autocorrelation is obtained depending on whether the Z value is positively or negatively greater than specific level of significance (Ord and Getis, 1995). As the result of the statistical tests with a significance level of 10%, the area of interest was divided into the three kinds of results of the statistical test: a positive spatial autocorrelation, no spatial autocorrelation, and a negative spatial autocorrelation. Positive spatial autocorrelation means that a clustering of larger local populations occurs within distance d of a given i. Then,

the cluster size is usually described as a distance parameter, d. The maximum of distance d ( $d_{max}$ ) is obtained from the convergence of the differences of spatial correlation/no spatial correlation areas between contiguous distances (Kumagai et al. 2021).

Definition of Spatial Index: On the other hand, for the 2.3.2 analysis of the phenomenon of "Urban spongification", it is required to detect partially lower population density in a densely populated area. Then, the spatial analysis used in this study is based on the occurrence of positive spatial autocorrelation areas along the distance parameter d. Figure 2 shows a conceptual diagram with respect to the detection of the spatial features of local populations. Based on Figure 2, the area being within distance  $d_{max}$  of point *i*, showing positive autocorrelation, generally covers the positive areas being within distance  $d_{max-1}$  or less of *i* because G statistics are basically derived from the summation of local populations within d of i(see Figures 2a and 2b). As the distance decreases from  $d_{max}$ , a change of statistics (from positive spatial autocorrelation to no spatial autocorrelation) happens in distance  $d_n$  at some points (see Figures 2b and 2c). The distance  $d_n$  therefore is defined as the Ambiguity of Spatial scale in a densely Populated area (ASP) since the null hypothesis that the set of local populations





within  $d_n$  of location *i* is a random sample is not rejected even though positive spatial autocorrelations are consecutively shown in distance between  $d_{max}$  and  $d_{n+1}$  (Kumagai et al. 2021). In other words, there could be lower population density within distance  $d_n$  in spite of the fact that there are significantly larger local populations within  $d_{max}$  of point *i*. Figure 3 displays the relative frequency distributions of local population density within ASP. The histograms gradually become skewed right in accordance with the increase of ASP. The ASP then makes possible to the detection of the sizes of the population decline spots, as well as their locations.



Figure 3. Relative frequency distributions of local population density within ASP (Kumagai et al. 2021).

#### 2.4 Application of Local Household-size Data

**2.4.1** Relationship between Population and the Number of Households: The number of households is one of the important factors for urban management. Figures 4 and 5 reveal the trends of the population, the number of households and the number of persons per household in this study area over the last 20 years (Osaka Prefecture, 2019). In Figure 4, the number of households continues to increase, while the population decline began after a period of population growth up to 2010. In Figure 5, the mean size of households, however, keeps on shrinking for the last 20 years. The relationship between population and the number of households seems to have changed for 20 years. It is necessary to apply population and the household size simultaneously for the analysis of "Urban spongification".

2.4.2 Concept of Application of Local Household-size Data: Figure 6 shows a conceptual diagram with respect to the detection of the spatial features of the local mean size of households. The local mean size of households is generated from the calculation of local population and the local number of households on a mesh-by-mesh basis. The size of a household generally is defined as the number of persons who live in the same dwelling and share meals. It is important to note that the local mean size of households is calculated at the district level, based on the results of the block-level census. The application of the spatial analysis to the local mean size of households could therefore detect the spatial features of the local composition of the headcount per household, independently of the spatial analysis of the local population distributions. In Figure 6, the arrow in (a) shows the spread of districts where the mean sizes of households have increased, while the arrow in (b)



Figure 4. Trends of the population and the number of households in the study area (Osaka Prefecture, 2019).



Figure 5. Trend of the number of persons per household in the study area (Osaka Prefecture, 2019).



Figure 6. Conceptual diagram with respect to the detection of the spatial features of local mean size of households.



(b) ASP (Kumagai, 2021) Figure 7. Results of the spatial analysis: distributions of ASH and ASP.

reveals the spread of districts where the averages of persons per household has decreased. We therefore define the distance  $d_n$  as the Ambiguity of Spatial scale in a higher local size of Households (ASH) based on the statistical test of the spatial autocorrelation.

# 3. RESULTS

## 3.1 Results of Spatial Analysis

Figure 7 shows the results of the spatial analysis of local mean size of households. There are also those of the analysis of local population for comparison in Figure 7. Gradations in colour from yellow to red denote the fluctuation of ASH and ASP. ASH<sub>0</sub> means that districts showing larger local mean sizes of households exist from the narrowest range to the widest range  $(d_{max})$ , while the red hue of areas indicates large ASH districts. The ASP legend is presented in the same way as in the ASH legend. It is shown that the districts with higher ASHs are distributed mostly around the edges of the coloured areas. This trend is almost similar to the distribution of larger ASPs. In Figures 7a and 7b, the ranges of ASH are larger than those of ASP. Moreover, the largest ASH increases from 1995 to 2015, while the largest ASP slightly decreases from 1995 to 2015. There seem to be differences between ASH and ASP in their spatial distribution features.

## 3.2 Relationship between ASH, ASP and Land Use

Figure 8 reveals the zoomed-in images of ASH and ASP in the site A of Figure 7 and an aerial photograph for the comparison of the results of the spatial analysis and current land use. ASP and ASH depend on the distance parameter d described in Figures 2 and 6. The interval of ASP and ASH shows 60 m as the calculation was carried out by mesh-by-mesh basis. Dashed circle denotes ASH (= 390 m) in 2015, while a circle of ASP does not appear (ASP<sub>0</sub>). We can recognize a lot of standardised housing complexes in the photograph. In this site, these standardised housing complexes were developed in the late 60s and 70s in order to provide housing for the growing population. It has been pointed out that although many people still live in the standard housing complexes, the next generation tends to leave them because of their inadequate layout. The difference between ASH and ASP seems to contain the details of the spatial features of population decline.

#### 4. **DISCUSSION**

## 4.1 Spatial Variation between 2 Periods

ASH and ASP may each have spatial characteristics related to population decline. It would be therefore appropriate to apply ASH and ASP simultaneously to the spatial analysis of population dynamics. In addition, it is desirable to discuss the detection of the fluctuations of the spatial features for the application to the monitoring of population dynamics. Figure 9 shows a conceptual diagram with respect to the variation of ASP. We also described the conceptual diagram regarding the variation of ASH in Figure 6. In order to simultaneously adopt ASH and ASP fluctuations, 4 variations described as the arrows in Figures 6a, 6b, 9c, and 9d are combined on a graph with 2 axes. Figure 10 displays the 4 variation combinations of ASH and ASP on the basis of 95% of their distributions. Based on the



(e)Aerial photograph

Figure 8. Comparison between ASH, ASP and an aerial photograph in the site A of Figure 7. Dotted lines show the circles with radius ASH (= 390 m) which is indicated with colour of centre pixels in ASH images. The circle of ASP does not appear (ASP<sub>0</sub>).

division of colours in Figure 10, we mapped the spatial variations between 1995 and 2015. Figure 11 indicates the spatial variation map of local population dynamics in the study area. The status of local spatial variations is described in colours gradated by the transformation of the 2 variations into hue and saturation, as in Figure 10. The grey areas, meaning slight changes such as within 60 m for both indicators, cover widely in the study area. The distribution of the different coloured areas can be seen in the southern parts. The light purple areas, meaning the slight increase of ASH, are also scattered widely as small patches. Figure 12 shows the enlarged view of the site B of Figure 11 with the local mean size of households and the local population of 1995 and 2015. A purple pixel at the centre point of Figure 12 denotes the spatial variation described in the lower left quadrant of Figure 10: both ASH and ASP are increasing from 1995 to 2015. In comparison with the variation of ASP, the fluctuations of ASH are quite larger. This area is located in a part of a residential area developed as a newtown in the late 60s. In this area, a large reconstruction on the basis of a housing revitalization project has been implemented since 2016 (Sakai city, 2018). The spatial variations described in the lower left quadrant of Figure







Figure 9. Conceptual diagram with respect to the detection of the fluctuations of ASP.



Figure 10. 4 variation combinations of ASH and ASP. The direction of the arrows in (a), (b), (c), and (d) mean the variation described in Figures 6a, 6b, 9c, and 9d, respectively.

10 seem to be detected in areas where some issues of population decline occur.

## 4.2 Comparison of Spatial Features and Elderly Population

One of the characteristics of population decline in Japan is that it is accompanied by a rapid ageing of the population, i.e. rapid increase in elderly population rate. It is therefore required to examine the relationship between the spatial features we obtained and the distributions of elderly data the government supplies.

**4.2.1 Elderly Data**: For the discussion, we apply 2 kinds of elderly data: the percentage of elderly population aged over 65 and over and the percentage of households with relatives aged

65 and over (Statistics Bureau of Japan, 2021). These data were generated as polygon data of each Cho/Aza which means a small town corresponding to the address. Figure 13 reveals the distributions of the percentage of households with relatives aged 65 and over in 2015, as an instance. The number of the polygons with an area larger than the area of a single pixel we obtained from the spatial analysis shows more than 99% of the total. In addition, these elderly data were prepared every five years since 2000 until 2015 although the basic unit block population data we applied to the spatial analysis are produced five-yearly from 1990 to 2015. For the examination of relationship between the spatial features and the elderly data, it is necessary to sort out the issues of the differences with respect to the spatial resolutions and the durations.





**4.2.2 Issues of the Spatial Resolutions and the Durations:** Firstly, for the spatial resolution issue, we detect the number of pixels of each of the four quadrants shown in Figure 10 in the Cho/Azas where the various changes of the 2 indices occurred, in order to analyse the distributions of the spatial variations we obtained. The distributions of the 4 types of spatial variations are finally shown as the share of the elderly-indices changes. The share through the calculation of the relative frequency distribution trends of the spatial variations. Secondly, for the duration issue, we apply larger spatial variations to the examination. In Figure 14, the representative rates of the 2 elderly indices in Osaka Prefecture, our study area, show a



Figure 12. Spatial variation composed of ASH and ASP between 1995 and 2015 and an aerial photograph in the site B of Figure 11. (c) Dotted lines show the circles with radius ASH (= 630 m in 2015), while the circle of ASH does not appear (ASP<sub>0</sub>) in 1995. (d) Dotted lines show the circles with radius ASP (= 150 m in 1995, 270 m in 2015).

steady increase from 1999 to 2015 (Statistics Bureau of Japan, 2021). The differences in the values of the 2 elderly indices between 2000 and 2015 would be smaller than the differences in the values between 1999 and 2015. We therefore use the 4 types of the spatial variations, i.e., Upper Right, Upper Left, Lower Right, and Lower Left of Figure 10, based on the ranges shown in Table 1 in order to enhance the characteristics of the relationship between the spatial variations and the elderly data.

**4.2.3 Distribution Trends**: Figure 15 shows the cumulative relative frequency of the changes in the elderly population rate between 2000 and 2015, in accordance with the amount of the 4 types of the spatial variations. The spatial variations of the Lower Left and the Upper Left seem to be distributed more widely in the small towns where the larger increase of the elderly population rate occurs. It appears that in areas with the rapid increase of ageing population rate, the spatial distributions of low local populations are likely to be larger. There are few differences



Figure 13. Percentage of households with relatives aged 65 and over in 2015, as an instance.





Quadrant in Figure 10	Range (m)	
	Variation of ASH	Variation of ASP
Upper Right	-480>=, >=-580 -300>=, >=-420 -120>=, >=-240	-120>=, >=-480 -300>=, >=-900 -540>=, >=-900
Upper Left	-480>=, >=-580 -300>=, >=-420 -120>=, >=-240	120<=, <=240 300<=, <=900 540<=, <=900
Lower Left	120<=, <=240 300<=, <=420 480<=,<=580	and 540<=, <=900 300<=, <=900 120<=, <=240
Lower Right	120<=, <=240 300<=, <=420 480<=,<=580	-540>=, >=-900 -300>=, >=-900 -120>=, >=-480

**Table 1.** Range of variations in Figure 10 in order to define the 4 types of the spatial variations for the examination of relationship between the spatial features and the elderly data.

 between the Upper Right and the Lower Right in Figure 15 even though these spatial variations tend to occur in areas with the relatively lower increase of ageing population rate. Figure 16 indicates the cumulative relative frequency of the changes in the percentage of households with relatives aged 65 and over between 2000 and 2015. The small differences between the Lower Left and the Upper Left appear. The Lower Left means that the spatial distributions of low local populations become larger and those of low local household sizes become also larger, as in Figures 6b and 9d. In comparison with the Upper Left, the share of the spatial variations of the Lower Left shows relatively higher between 33% and 41% of change in Figure 16 (the dotted lines in the figure). This denotes the Lower Left seems to be distributed slightly more widely in the small towns where the significant increase of elderly households happens. It seems to be possible to detect the differences of distributions of elderly households through the application of the local mean size of households to the spatial analysis.



Figure 15. Cumulative relative frequency of the changes in the elderly population rate between 2000 and 2015. The legend except "All data" is based on Table 1.



Figure 16. Cumulative relative frequency of the changes in the percentage of households with relatives aged 65 and over between 2000 and 2015. The legend except "All data" is based on Table 1.

# 5. CONCLUSIONS

Under the concept that the application of local population and local household could detect the details of spatial features of population decline, we newly defined an index regarding the size of an area where lower local mean sizes of households are distributed in urbanized areas, in addition to the spatial localpopulation index (ASP) defined previously. The index, named the Ambiguity of Spatial scale in a higher local size of Households (ASH), indicated additional spatial features to the results of the spatial analysis of local populations. We also discussed the spatial features of local population dynamics and elderly data. It was shown that the 4 types of the spatial variation composed of ASH and ASP seemed to have the possibility to contribute to the classification of the population decline. In this paper, we used only two census timesteps. For the contribution to the authorities, more research is needed with respect to the time interval of the census data.

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