Measuring Housing Vacancies in Japanese Cities: Spatial Analytics Using Utilities Data

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Abstract

In this study, we analyze the quality of water hydrant data for identifying housing vacancies based on their spatial relationships with the other spatial data that we consider are correlated with such vacancies. Through applying object-oriented spatial analysis, we compare with in-situ vacant house data in several small districts, thus verifying the applicability of water hydrant data to the spatial analysis of vacant house distributions. Using the object-oriented spatial analysis, it is possible to deal with the relations among more than two distributions of spatial objects. We discuss the results of this analysis using relations between the temporal intervals associated with turning off metering, fluctuations in local populations, the densities of water hydrants as indicators of vacancies and several other spatial objects relevant to building good estimations of vacant housing in different parts of the city.

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1. Introduction

A key housing problem in many large cities in the developed world involves high levels of vacancies that are spatially clustered. There are many causes that generate high vacancy rates, ranging from housing in large cities being regarded by mobile capital as an asset class, with luxury homes kept empty in order to maximize the performance of asset management (Gerald (2005), Norris (2009), Hoekstra (2011), Vakili-Zad (2011)). Another key factor is population aging (Deilmann (2009), Sasaki (2010), Yamamoto (2011)). Japan is a rapidly aging society with a very low birth rate now below its replacement rate with the National Institute of Population and Social Security Research (2012) suggesting population will keep declining until 2060. Throughout Japan, the government in 2008 reported that 13.1 % of houses were vacant with prospects for an increasing vacancy rate for the foreseeable future (Ministry of Internal Affairs and Communications, Statistic Bureau (2008)). Vacancy generates many problems such as crime, susceptibility to fire, as well as reinforcing a vicious circle of flight from areas of vacant housing thus reinforcing the run-down of housing areas and increasing abandonment (Schachterle, et al. (2012)). The monetary value of areas which includes much vacant houses is decreasing and this again reinforces the spiral of decline (Ministry of Land, Infrastructure, Transport and Tourism (2011)).

To grasp the distribution of vacant houses, individual housing surveys need to be carried out. But these surveys are expensive and often need to be based on household interviews and on detailed archival and historical work associated with exploring land tenure, ownership and housing finance. Field work is needed to initially distinguish vacant houses through visual inspections after which owners must be traced often through interviews with their neighbors. The difficulty with such surveys depends on the definition of a vacant house (Parsons (2014)). Owners often do not consider their houses to be vacant even though their status is empty, and increasingly vacant houses are used as depositories, or for temporary or future living.

An increasingly important way of measuring housing vacancies is through the provision of utilities where most connections from these services to housing are now available through digital data sources (Gerald (2005)). It is now possible to recognize vacant houses where data shows their connection to utility lines such as electricity, water supply, possibly telephones and increasingly broadband services. This lifeline network data is usually recorded and available over long periods at a fine spatial resolution (at street address) where it is maintained by local government and supply companies. This data is often large in volume and increasingly is regarded as big data, requiring new methods of mining to explore the patterns that lie within.

Despite the fact that this data does not always reveal whether a house is occupied or not, in the case of water supply the hydrant data that we have access to includes their status with respect to their turning on / off, the time when the hydrants are off and other features that pertain to the meter status. If we then compare other spatial data at fine scales such as block populations based on national census data, building plot map data generated by a city, and basic survey data from urban planning permissions, we are able to build up a detailed picture of vacancies when we compare and correlate these with the water hydrant data.

In this study, we analyze the quality of water hydrant data for identifying housing vacancies based on their spatial relationships with the other spatial data, such as demographic attributes of the population for the last 15 years, distribution of water hydrants, and other spatial distributions that we consider are correlated with such vacancies. Through applying object-oriented spatial analysis, we compare with in-situ vacant house data in several small districts, thus verifying the applicability of water hydrant data to the spatial analysis of vacant house distributions. Using object-oriented spatial analysis developed by Sadahiro (2012a), it is possible to deal with the relations among more than two distributions of spatial objects. We discuss the results of this analysis using relations between the temporal intervals associated with turning off metering, fluctuations in local populations, the densities of water hydrants as indicators of vacancies and several other spatial objects relevant to building good estimations of vacant housing in different parts of the city.

2. Data and methodology

2.1 Study area

The Neyagawa city was adopted as the area of interest in this study. This area is located in the Osaka prefecture in the western part of Japan. It covers about 5 km in an east-west direction and 5 km in a north-south direction.

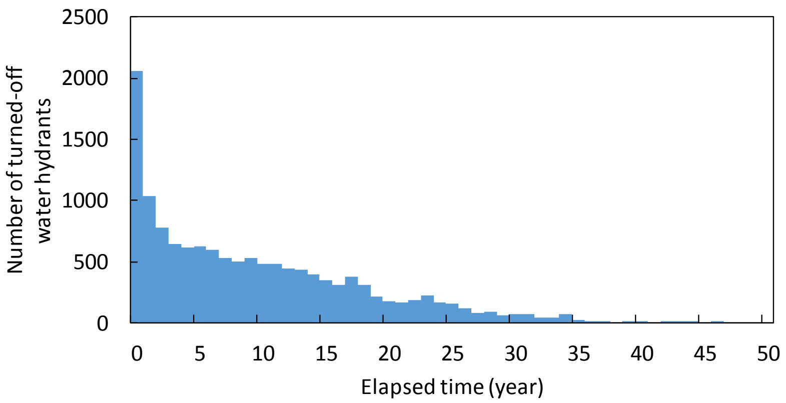

Fig. 1. Histogram of the turned-off water hydrants in each elapsed time (year) when they are off.

2.2 Geographical data

We used water hydrant data the Neyagawa city provided. There are addresses of water hydrants, status with respect to their turning on / off, and the time when the hydrants are off in the data. The data was acquired in March, 2013. Fig. 1 shows the histogram of the turned-off water hydrants in each elapsed time (year) when they are off. In the class of "zero year", which means less than one year, we can see the projecting maximum number of the hydrants. It seems to contain short term cases depended on moving in / out, demolition / rebuilding, and other factors regarding the active housing market. We can also see the considerable numbers of the turned-off water hydrants in the intervals of more than three years. The reason of these distributions is based on the management of water hydrant meters. For instance, a house owner needs to buy a water hydrant meter when he has a new house. Local government, however, does not refund the money of the meter when he has to leave the house several years later. They then leave the meters in the houses after their moving. As a result, the data of water hydrants has been recorded though they were turned off. The data of the elapsed time when water hydrants are off seems to contain information with respect to housing vacancies, while it is difficult to distinguish whether a house has existed or not, whether renovation of a house has been undergone or not, and whether other changes regarding a house status have occured or not. The analysis of relation between the water hydrant data and the other data related to the vacancies is required. Geographical relationships between them should also be clarified through the analysis because there is the possibility of the detection of geographical factors with respect to the vacancies in the results.

The basic unit blocks population data of the Population Census of Japan in 1995, 2000, 2005, and 2010 were applied as demographic dynamics. We used the basic map the Neyagawa city made in 2010. The map includes building polygon data, road line data, and railway line data. We adopted the building polygon data as building footprint data for extracting the features of water hydrant distributions.

2.3 Methodology

We applied the object-oriented spatial analysis to exploring spatial relations between the geographic data. The spatial analysis was developed by Sadahiro (2012a) as a generalised method on a basis of several methods proposed in Sadahiro (2010, 2011, and 2012b), Sadahiro and Kobayashi (2012), and Sadahiro et al. (2012). A major feature of the analysis is availability of spatial analysis for more than two objects. Many spatial analysis methods for one or two object distributions have been proposed, while there are few spatial analysis methods for more than two spatial object distributions. In addition, the object-oriented spatial analysis can be applied to various types of spatial objects: point, line, polygon, and network data.

Fig. 2 shows the concept of the spatial analysis. The figure is simplified for the explanation of an application approach in this study. We adapted algorithm CB (Center detection and Body clustering) in this study (Sadahiro (2012a)). There are five types of objects, from A to E, in this figure. In this spatial analysis, the type is called *body*. *Center* means a cluster of many bodies. The large number of centers means representative feature in the field of interest. The key of the generation of the cluster is called *tag*, which plays a role in connecting between objects.

In the algorithm CB, the cluster of bodies where its number shows a maximum value is firstly chosen as a candidate for a center. When the number of the clusters does not satisfy a numeric condition of a center (described later as “the condition of the minimum number of clusters, β”), maximum cluster which consists of the subclass of its bodies is newly chosen and added to the candidate. In Fig. 2, the cluster of bodies (A, B, C, and E) is selected as the candidate in the first step, but the number of the clusters does not satisfy the numeric condition. In the next step, the cluster containing the subclass of its bodies is extracted. Finally, the cluster of common bodies (B, C, and E) is determined as a center, “C_1”. The algorithm CB performs the same process over and over for the clusters except the clusters already assigned as centers. There are three conditions in this algorithm. First one is the condition of the tag: the determination of a clus-

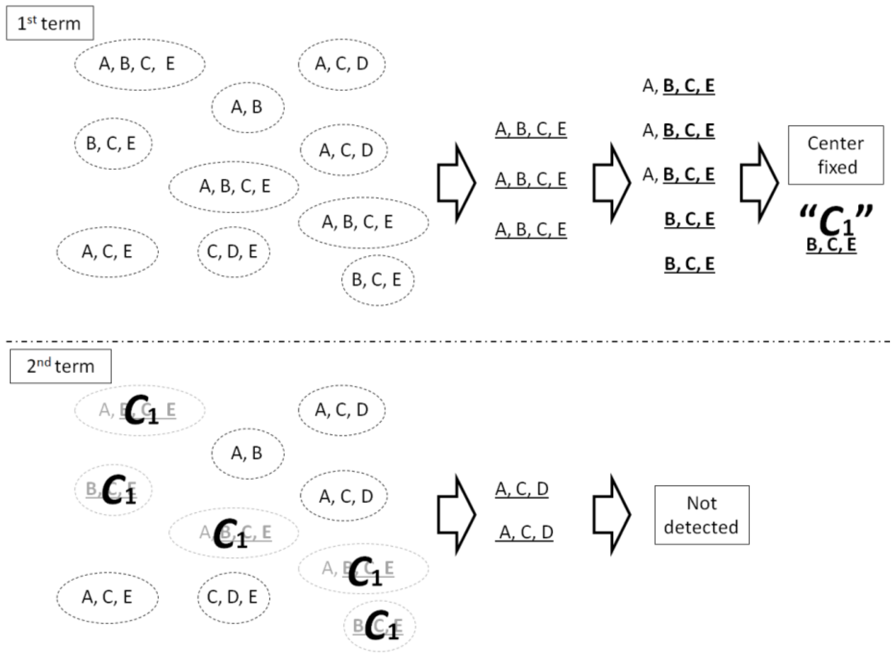

Fig. 2. Concept of the object-oriented spatial analysis. The process in this figure is shown on the conditions: the minimum number of bodies, α= 3, and the minimum number of clusters for a center, β = 4.

ter. The description of the condition is dependent on the type of objects. An overlaid area between buffers from point objects can be included as a typical example of the tag condition. Second condition is the minimum number of bodies in a center, α. Last condition is the minimum number of clusters for a center, β. In Fig. 2, the process is stopped at the first step of the second term because it is impossible to add clusters containing the subclass of the bodies to the candidate on the condition of α = 3 though the number of the clusters does not meet the condition of β = 4.

We adopt the data of the elapsed time when water hydrants are off, the demographic dynamics, and the distributions of the water hydrants as the bodies. Centers detected represent spatial relationship between the elapsed time and the other geographical data, and the distributions of the centers indicate the spatial features of vacant houses on the basis of the comparison with in-situ vacant house data.

2.4 Data preparation

For the application of the spatial analysis, we preprocessed the geographic data. The geographical data includes a variety of units, time intervals, and data types. The spatial analysis method can accept several types of geographical data simultaneously, while it is available to apply the quantitative data type to the method, as in whether a body A exists or not in a cluster in Fig. 2. We focused attention on this feature of the spatial analysis. For the analysis of housing vacancies, demographic dynamics is required generally. It is practical to apply types of increase, constant, and decrease to the method. We divided the population data arranged according to the basic unit blocks into the three statuses of demographic dynamics through applying statistical test. On the assumption that the blocks population distribution depended on the Gaussian distribution, statistics of test in regard to a real difference between the means of the blocks population were calculated with a significance level of 5 %. We transformed the statistics to values of population, and we calculated the differences between the values and the mean. Finally, the ratios of the differences to the mean were adapted as references of the divisions into the three statuses.

For extracting the feature of vacant houses, we preprocessed the number of water hydrants per building as the density of water hydrants using the building footprint data. The density data and the areas of footprint of buildings are expected to play a role in the classification of the types of houses: a detached house, a row house, and an apartment flat.

The elapsed time when water hydrants were off was defined as a temporal interval associated with turning off metering. The number of the bodies is 33 in total, while the maximum number of the bodies in a center reaches actually 7 because of exclusive relationships between the bodies in the temporal intervals, the bodies in the area of footprint, and the bodies in the number of water hydrants.

There are several units of the data we applied. We transferred the spatial resolutions of all the geographic data to highest resolutions of the water hydrant before applying the spatial analysis. Consequently, all the clusters of the bodies were satisfied the condition of the tag: the determination of a cluster. We set up the conditions of α and β. $\alpha = 4$, 5, and 6 were set because of the analysis of relationship between the temporal intervals and the other geographical data, while $\beta = 34$, 68, and 135 meant 0.25%, 0.5%, and 1% of the number of turned-off water hydrants, respectively.

3. Result and Discussion

3.1 Result of the object-oriented spatial analysis

Fig. 3 shows the numbers of the centers detected. The number of centers tends to increase with decreasing α and β. We can see the large number of

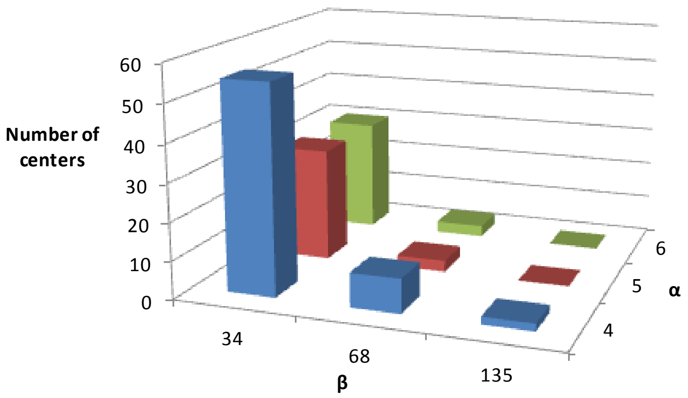

Fig. 3. Numbers of the centers detected. The α and β are the numerical conditions in the object-oriented spatial analysis. The number of centers tends to increase with decreasing α and β.

the centers are extracted in α = 4 and β = 34. The number of centers shows more than 50. This condition of α and β does not seem to be appropriate in this field because the detection of many centers means weak representativeness of centers in terms of spatial features.

On the other hand, in case of α = 4 and β = 68, 9 types of centers are detected. It has been shown that there are, however, 3 types of the centers including the bodies with respect to building factors (the area of footprint and the number of water hydrant). There do not seem to be enough centers for the analysis of the relationship between the temporal intervals associated with turning off metering and the other data related to housing vacancies. Table 1 reveals the result of center detection on the condition of α = 5 and β = 34. "O" in the table means the body which is contained in each center. We can see all the centers contain the bodies of multiple types of the geographical data. On the condition of α = 4 and β= 34, it has been shown that about 40 % of the centers consist of the temporal intervals and the demographic attributes without the building factors though 55 centers are extracted. We choose therefore the detection result on the condition of α = 5 and β = 34, for the comparison with the results of field survey.

3.2 Comparison with the results of field survey

The field survey with respect to the vacancies was carried out from June to July, 2013. 5 districts in the test site were selected as fields of typical features of this area. We conducted the survey through checking facility me-

Table 1. Result of the center detection on the condition of α = 5 and β = 34. “O” in the table means the body which is contained in each center. At the bottom line in this table, the results of agreement between the centers and the house types identified by the field survey. “d” means a detached house, “r” is a row house, “f” is an old apartment flat, “*” means the centers do not agree with the vacant houses in the field survey, and “-” means the centers are not detected in the districts for the field survey.

Body No.	Geographical data		Center																														Unit
			C1	C3	C23	C25	C13	C18	C19	C21	C24	C4	C5	C6	C7	C8	C9	C10	C12	C16	C17	C20	C22	C27	C29	C14	C15	C2	C11	C26	C28	C30	
1		0-1	O	O	O					O					O											O	O	O	O	O	O	O	
2		2-3															O			O													
3		4-5										O																					
4		6-10				O	O		O		O		O	O		O		O			O	O			O								
5	Temporal intervals (year)	11-15						O											O				O										Water hydrant
6		16-20																						O									
7		20-25																															
8		26-30																															
9		more than 30																															
10		1995 -> 2000 : +																								O							
11	Demographic attribute	1995 -> 2000 : −	O	O		O	O	O	O		O	O	O	O	O	O	O	O	O			O		O			O	O	O		O		
12		2000 -> 2005 : +																														O	
13		2000 -> 2005 : −	O	O	O	O	O	O	O	O		O	O	O	O	O	O	O	O	O	O	O	O		O	O	O	O	O	O			Block
14		2005 -> 2010 : +																									O					O	
15		2005 -> 2010 : −	O	O	O		O			O	O	O	O	O	O	O	O	O	O	O	O		O	O	O	O		O	O	O	O		
16		less than 10																															
17		10-27																															
18		27-44	O		O	O																						O					
19		44-61		O				O	O																				O				
20	Area of footprint of building (m^2)	61-78																			O												
21		78-95																															
22		95-112					O																										
23		112-129																				O											
24		129-146									O																						
25		146-163														O																	Building
26		more than 163								O		O	O	O	O		O	O	O	O			O	O	O	O	O			O	O	O	
27		1	O	O	O	O																											
28		2						O	O												O							O	O				
29	Number of water hydrant per building	3																															
30		4-7					O			O	O			O								O											
31		8-12										O	O		O	O	O		O					O	O	O					O		
32		more than 12																O		O			O				O			O		O	
33	Building existing	y	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	
	Number of clusters (tags)		48	44	37	35	36	35	36	37	34	43	84	34	76	35	37	36	66	40	36	35	34	37	36	34	34	35	43	36	35	34	
	Type of houses in field survey		"d"				"r" or "r & f"					"f"														"*"		"−"					

Table 2. Error matrix of turned-off water hydrants between the vacant houses and the centers.

		Field Survey	
		Vacant Houses	Others
Spatial Analysis	Centers	82[75.2%]	27[24.8%]
	Others	338[41.8%]	470[58.2%]

ters, the occupation of a house, and the status of a building and a garden. The vacant houses were identified on a basis of the filed survey. Table 2 displays the error matrix of turned-off water hydrants between the field survey results and the spatial analysis results. In the table, the turned-off water hydrants in the vacant houses identified by the field survey are not good agreement with the centers. It is suggested that strong spatial correlation in the geographic data, described as the centers, does not mostly exist in the vacant house distributions. Table 2 indicates, however, the ratios between the vacant houses and others identified by the field survey in the centers and others detected by the spatial analysis, respectively. The proportion of the vacant houses in the centers shows more than 75 %, while the proportion in the others reveals 41.8 % in Table 2. Thus, the distributions of the centers seem to be related significantly to the vacancy distributions.

In the field survey, we divided the vacant houses into three types of houses: a detached house, a row house, and an old apartment flat which is the type of Japanese house incorporating Western elements that was made popular in the 1950s and 1960s. At the bottom line in Table 1, the types of houses, which are in close agreement with each center, are shown. "d" means a detached house, "r" is a row house, "f" is an old apartment flat, "*" means the centers do not agree with any vacant houses in the field survey, and "-" means the centers are not detected in the districts for the field survey. Comparing the types of the houses in the field survey with the bodies regarding the house factors, the features of the types of houses seem to be detected in the centers, i.e. the centers of the detached house contain the bodies of small footprint and 1 water hydrant per building, the centers of the row house include middle footprint and 2 to 7 water hydrants, and the centers of the old apartment flat consist of large footprint and almost more than 7 water hydrants. We can see all the centers assigned "*" and "-" also include the temporal intervals of 0-1 year irrespective of the bodies regarding the house factors. It is suggested that such short intervals do not seem to be related to vacancies.

Fig. 4 shows the frequency of the agreement between the centers and the field survey data. The centers detected in this study generally agree with both the vacancies and the others in the field survey results. For comparison both sides of the agreements, we use the scatter diagram shown in Fig. 4: the frequency of the agreement between the centers and the vacancies is indicated in the horizontal axis, while the frequency of the agreement be-

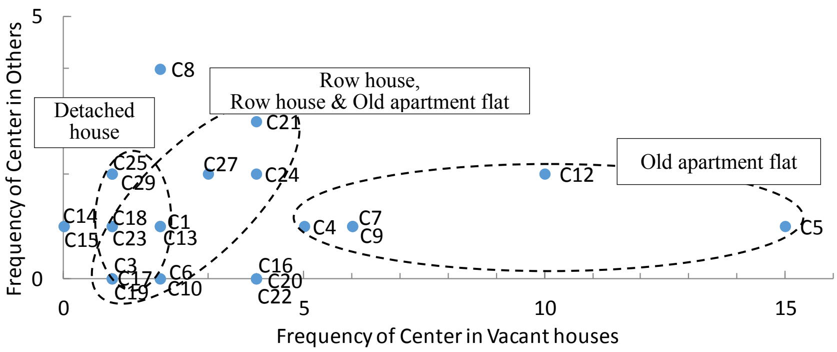

Fig. 4. Frequency of the agreement between the centers and the field survey data. The frequency of the agreement between the centers and the vacancies is indicated in the horizontal axis, while the frequency of the agreement between the centers and the others is shown in the vertical axis.

tween the centers and the others is shown in the vertical axis. The distributions in the right side of the graph mean high agreement with the vacancies and low agreement with the others in the districts for the field survey. For supporting understandings, the ellipses which cover centers every type of house assigned as the bottom line of Table 1 are described with the dotted lines in this figure. In the case of the centers of the old apartment flat, the ellipse includes the centers containing same bodies with respect to the demographic attributes and the house factors: C4, C5, C7, C9, and C12 because of the extraction for the features of the apartment flat.

It appears that the detached house centers are slightly distributed along the vertical axis and they are located near the origin in this graph. Most of the centers of the detached house include the temporal intervals of 0-1 year in Table 1. Hence, it seems apparent that the centers of the detached houses may have weak relation to the vacancies. The distribution of the old-apartment flat centers is located along the horizontal axis. It means that these centers have potentially high degree of agreement with the vacancies in the study area. In the bodies of C5 and C12 which are allocated in the right side of this graph, the temporal intervals show from 6 years to 15 years, while the demographic attributes show consecutive decline for 15 years in Table 1. We can see the row house centers and the row house and old apartment house centers are distributed towards almost diagonal direction from the origin. The bodies in these centers mainly include the temporal intervals of 6 to 15 years, being similar to the case of the old-apartment flat centers, while the demographic attributes have hardly shown the consecutive decline yet.

Fig. 5 shows the spatial distributions of the centers assigned as the de-

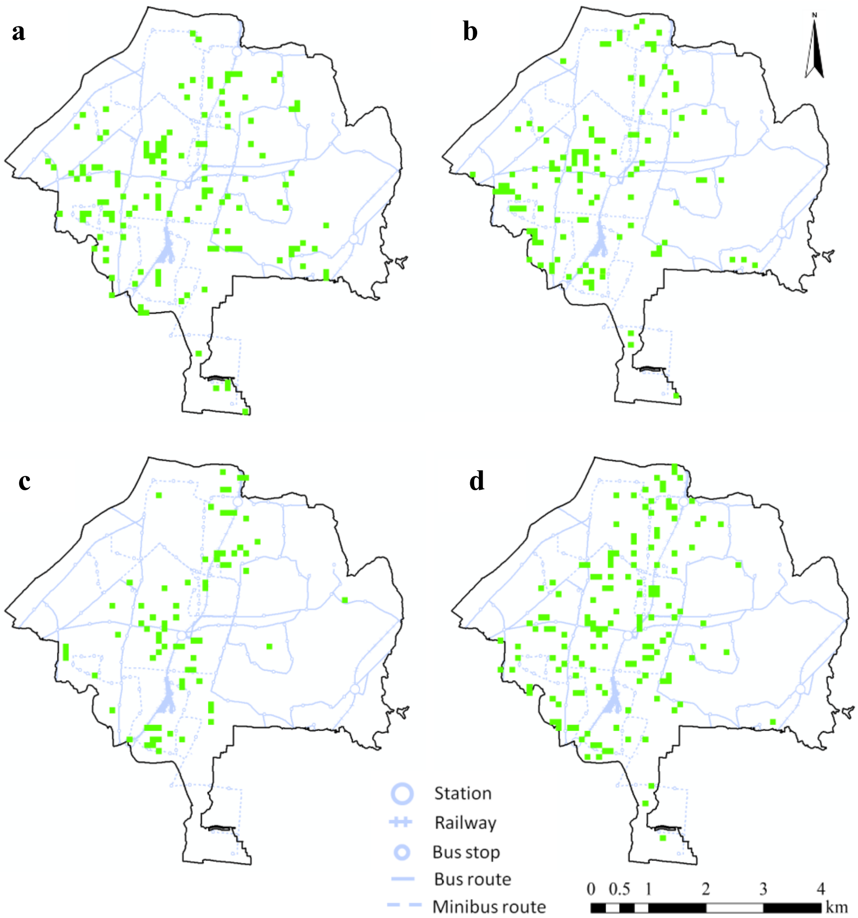

Fig. 5. Spatial distributions of the centers assigned as **a** "d", **b** "r" and "r & f", **c** "f", and **d** "*" and "-" in Table 1. This figure describes the water hydrant distributions detected as the centers using discretization of 100 m by 100 m mesh. A green mesh in these figures means that one or more centers exist in the square.

tached houses, the row houses (including the row houses and old apartment flats), the old apartment flats (C4, C5, C7, C9, and C12), and the others, respectively. These figures describe the water hydrant distributions using discretization of 100 m by 100 m mesh. A green mesh in the figures means that one or more centers exist in the square. In Fig. 5d, the distributions of the centers assigned as the others cover from north parts to south and south-west parts in this area. The centers of the detached houses in Fig. 5a distribute wider in an east-west direction and fewer in north edge than those of the others. The distribution of the row house centers spread mainly in south-west parts and north parts in Fig. 5b. On the other hand, the old-apartment flat centers distribute along the railway mostly in Fig. 5c. Relationship between the elapse of 6 - 15 years of turned-off water hydrants, the consecutive population declines for 15 years, and the type of the old apartment flat seems to have some spatial feature with respect to vacancy distributions.

3.3 Relation to local population decline

In Table 1, the bodies of the demographic attributes show mainly consecutive decline from 1995 to 2010. The centers containing the consecutive decline represent 43.3 % of the 30 centers in this study. We compare the demographic attributes of the centers detected with those of all the clusters of bodies for verifying their relation to the turned-off water hydrants. Fig. 6 shows the proportion of demographic attributes in all the clusters. The bodies where their proportions are more than 5.0 % are shown separately in this figure. The consecutive decline shows highest proportion (20.1 %), while the bodies partly contain increase terms occupy about 40 % in total. We can see that in terms of the consecutive decline, the proportion of the centers in Table 1 is higher than that of all the clusters. Spatial relationship between the turned-off water hydrants and the local consecutive population decline seems to appear significantly in the centers.

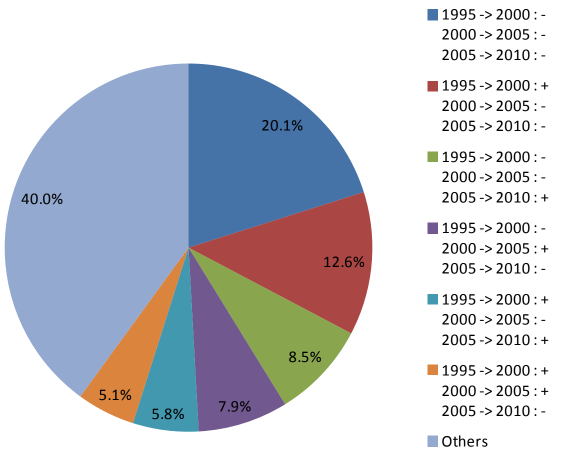

Fig. 6. Proportion of demographic attributes in all the clusters of the bodies. The bodies where their proportions are more than 5.0 % are shown separately in this figure.

4. Conclusions

In this paper, we pointed out the possibility of utility data for applying the analysis of vacancy distributions. We adapted water hydrant data as the utility data, and we applied the data to the object-oriented spatial analysis with the other geographic data. The turned-off water hydrants were detected as one of the bodies of the centers on the several conditions. The appropriate condition of the spatial analysis was clarified on the basis of the comparison between the numbers of the centers and bodies. Through referring to the results of the field survey, the centers detected on the condition seemed to be related to the vacancy distributions. Strong spatial relationship between the local population decline and the turned-off water hydrants was apparent. Especially, the distributions of the centers consisting of 6 - 15 year intervals associated with turning off metering, the consecutive population decline for 15 years, and the type of the old apartment flat showed relative high degree of agreement with the vacant house distributions in the districts of the field survey. It was suggested that the difference of spatial distribution between the centers appeared in accordance with the types of vacant houses assigned to them by the field survey results.

As problems remaining for future research, the application of multi-temporal water hydrant data will be required. This approach may contribute to higher accuracy of the analysis because short term cases of turning-off meter could be excluded. The application of other utility data also will be able to develop better analytical models.

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