Transition Analysis of Regional Characteristics Using Building Geo Big Data and National Census Data throughout Japan ~Focusing on Compact City, Re-urbanization, and Suburban Sprawl~

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Abstract

This study attempts to develop a method to understand situations of compact city, re-urbanization, and sprawl in all major Japanese cities using building geo big data and national census data for the whole of Japan. In this study we first developed a 500m square grid (TGD) that can monitor the time-series transition of the resident population, employees, building area, and building volume to the aggregation of building geo big data, population census, and economic census by grid polygons. Second, regional characteristics of mass grids were evaluated by x-means clustering based on the attributes of each grid. Finally, the development status of urbanization promotion areas (UPA) and urbanization control areas (UCA) in Japanese 744 cities were elucidated by integration of TGD with the UPA and UCA polygon data. The situations of compact city, re-urbanization, and sprawl of all 744 cities can be monitored by combing the UPA and UCA development statuses.

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1 Introduction

1.1 History of Japanese city after World War II

Suburban expansion of Japanese cities has occurred consistently in periods of high economic growth such as the 1960's after World War II and during the economic bubble of the early 1990's. After WWII, many Japanese cities were modernized and planned according to the constitution of the Special city planning law for war-damage reconstruction (Hein et al. 2003; Koshizawa 2005).

The regulation of urban sprawl was one of the most important problems in urban planning in Japan before the war and it was included in the reconstruction planning after the war. However, in the period of high economic growth that followed the postwar reconstruction, these regulations failed to function properly in Tokyo and in many local cities because of mass population flow from agricultural areas to cities (Hebbert 1986; Yamada et al. 1995). In particular, in provincial cities where the transportation network was not well developed, roadside shop clusters appeared and resident areas sprawled around them due to motorization. On the other hand, the old city centers became hollowed out, as they did not react sufficiently to the newly motorized society. These trends reached a peak in the early 1990s coupled with a sudden rise in real estate values and the development of resort areas.

In addition, many large-scale commercial facilities were rapidly constructed in suburbs throughout Japan due to a relaxation of regulations on large-scale commercial development facilities due to a revision of the Large-scale Retail Store Law of Japan in 2000 (Matsuura and Motohashi 2006). Such facilities fulfilled all the functions previously delivered by shopping streets and districts in city centers, and huge parking lots were built in response to the motorized society (Perrigot and Cliquet 2006).

Therefore, the hollowing of city centers increasingly occurred as customers flowed to the suburbs from shopping streets in the city centers. These phenomena continue to be observed today even though Japan has a decreasing population.

1.2 Japanese Urban policies in a depopulating society

Many Japanese cities are attempting to implement urban planning aimed at realizing compact cities that suppress suburbanization and promote re-urbanization. The concept of a compact city is to regenerate communities and provide a comfortable city to live in to set the sphere of life into a walking sphere by the suppression of suburbanization and urban sprawl and keep the urban area as small as possible (Frans and Michael 2004). Disorganized suburbanization is also questionable from the viewpoint of sustainability of local communities and environmental protection. In addition, urban sprawl causes an increase in the fiscal burden due to deterioration in the efficiency of public investment, including roads and water supply, and sewerage systems.

Since 2005, when the Japanese population began to decrease, there has been a demand to shrink cities while maintaining the citizen's quality of life (Brumann and Schulz 2012). Therefore, it is important in present-day Japan to realize a method of monitoring policy effects of local Japanese governments on compact cities, both quantitatively and spatially.

1.3 Evaluations of a compact city and their problems

Many previous studies have attempted to understand and evaluate compact city policies in Japan. For example, Kotani and Abe (2013) evaluated the compact city concept in two Japanese local cities: Kobe city and Toyama city using 13 OECD indicators. In addition, Takeda et al. (2011) evaluated and compared the concept in densely inhabited districts in more Japanese cities using their own evaluation index. Similar studies have been carried out to evaluate the concept in cities and other areas of other countries (Burton 2000; Thinh 2002; Abdullahi et al. 2015). However, many of these studies only evaluated and compared cities using aggregated results by city units in cases of a national scale. Time-series transition of urban areas and their suburbs occur spatial-continuously and they are not homogeneous even for one specific city. Higher resolution evaluation is required as well as finding areas with problems in realizing the compact city. Nakamichi et al. (2004) pointed out the reasons why available data are not aggregated into municipalities or city blocks and why high-resolution analysis and generalization of the method are difficult. If analytical cities are limited, detailed analyses could be performed using more indexes than our paper

(Sanada et al. 2002; Ikeda et al. 2004). However, it was difficult to collect evaluation index data in these studies.

1.4 Our approach to this problem

This study aims to develop data to have the ability to monitor the transition of regional characteristics quantitatively, spatially, and temporally throughout Japan and examine a method to understand the generation status of a compact city, re-urbanization, and suburban sprawl. We also aim to achieve results which will contribute to the development of policies that promote the compact city concept.

First, this study developed a 500m square grid of data to be able to monitor time-series transitions of the total number of resident population, employees, building area, and building volume covering all areas of Japan. The time-series transition of this data is between 2005 and 2010 when it is expected that provincial cities changed to increasingly compact cities. Second, a method is realized to find areas with re-urbanization or sprawl using the definition of regional characteristics of each grid based on these time-series transitions. Finally, we attempt to evaluate the compact city, re-urbanization, and suburban sprawl in several Japanese cities to integrate this data with Japanese city area data spatially and classify them into some areas.

2 Development of time-series grid data

The data referred to as 'Time-series Grid Data (TGD)" in this paper developed a 500m square grid data throughout Japan to understand time-series transitions of the resident population, employees, building area, and building volume between 2005 and 2010. Resident population can be used as an index of residential area and the employees is an index of commercial and business districts. In addition, the rate of change of these two indices also can be monitored. On the other hand, time-series changes of building area and volume are indices of tangible development.

800 to 900 thousand new residential housing units are constructed every year in Japan even though the resident population is currently decreasing (Nagashima 2014). At the same time, the estimated number of empty houses in 2008 was about 7.6 million (Statistics Bureau of MIC (SBMIC) 2008). TGD can find areas with these inconsistencies.

2.1 Grid data development of the resident population and the employees

The resident population data were collected from the Japanese Population Census in 2005 and 2010 (SBMIC 2010). The Population Census was aggregated by grid square polygons. The aggregating unit of this census is approximately 1km and 500m square grids. This study used the population census aggregated by approximately 500m square grids, with a difference in latitude of 15’’ and longitude of 22.5’’.

The employees data were collected from the Japanese Economic Census in 2006 and 2009 (SBMIC 2009). This census was also aggregated by approximately 500m square grids, similar to the Population Census.

Increase/decrease rates of each type of data were calculated to divide the new values from 2009 / 2010 by the old values from 2005 / 2006. In addition, dummy variables of “new settled” and “unsettled” were calculated. If the old value is 0, the dummy variable of new settled is 1 and if the new value is 0, the dummy variable of unsettled is 1. The reason why we used these dummy variables is that new settled is the meaningful value for evaluation of sprawl and unsettled is the values for evaluation of compact city.

2.2 Grid data development of building area and volume

This study developed building polygon data covering all areas of Japan using a detailed digital map called the “Residential Map” from 2004 and 2009 published by Zenrin Co., Ltd. The residential map contains layer recorded building polygons with information such as the floor and the name on the door. This geo big data recorded approximately 60 million buildings throughout Japan. In addition, it was confirmed that the reliability of this data is sufficiently high because the map is developed by field investigations by many investigators (Akiyama et al. 2008).

First, the building area and volume of all building polygons were calculated. The building volume of each building was calculated by multiplying the area by number of floors. Second, these polygons were divided by 500m square grids. Finally, the total number of building areas and volumes for each grid in each year were calculated and their increase/decrease rates were also calculated. In addition, dummy variables were defined in a similar manner to the population data. The dummy variable for “new development” is 1 if the old value is 0, and the dummy variable of “cleared land” is 1 if new value is 0.

2.3 Time-series transitions of the resident population, employees, and buildings in Japan between 2005 and 2010

Fig. 1 shows the results of the analysis. Resident population in 120,419 grids i.e. approximately 22% of the total number of grids (528,881 grids) increased by over 10%. Many of these areas were located in suburbs of provincial cities and city centers of metropolitan cities, e.g. Tokyo and Osaka. On the other hand, resident population decreased by over 10% in 193,853 grids (approx. 35%). Many of these areas were located in the center of provincial cities and depopulated areas such as mountainous regions.

The employees increased by over 10% in 167,119 grids (approx. 32%). Many of these areas were located in suburbs in relatively large cities. On the other hand, the employees decreased by over 10% in 125,334 grids (approx. 24%). Many of these areas were located in provincial cities and depopulated areas.

The building area increased by over 10% in 159,554 grids (approx. 30%). Many of these areas were located in suburbs of not only metropolitan but also provincial cities. On the other hand, building area decreased by over 10% in 80,072 girds (approx. 15%), mainly in mountainous areas and in the center of large cities. These areas were located in the center of large cities because of road widening and the development of green spaces in accordance with verticalization (that is, the redevelopment of older dense cities consisting of low-rise buildings). Actually, areas with an increase in building volume and a decrease of building area were located in center of Tokyo.

Areas with an increase in building areas were found even though the resident population or employees decreased through a combination of these results. As shown in Fig. 2, such areas are located in the suburbs of large-scale cities in all regions. The same tendency was seen in other cities throughout Japan.

3 Regional classification of time-series grid data (TGD)

This chapter defines the regional characteristics of all grids in TGD by cluster classification based on the attributes of each grid. The following attribute values were used for the cluster classification.

1. Resident population in 2005 and 2010, dummy variables of new settled and unsettled, and increase/decrease rate
2. Employees in 2006 and 2009, dummy variables of new settled and unsettled, and increase/decrease rate

3. Building area and volume in 2004 and 2009, dummy variables of new development and cleared land, and increase/decrease rate

The attributes were normalized by Equation 1.

$$nv_i = \frac{v_i - v_{\min}}{v_{\max} - v_{\min}} \tag{1}$$

where v_i is value of grid i before normalization, v_{min} is the minimum value of v, v_{max} is the maximum value of v, and nv_i is the normalized value of grid i.

Almost all increase/decrease rates are in the range from 0 to 2 and the dummy variables are either 0 or 1. On the other hand, the range of resident population is, for example, from 0 to 13,390. This range deviates substantially from increase/decrease rates and dummy valuables. Therefore, the ranges of all attributes were normalized to between 0 and 1 by Equation 1.

Furthermore, multiple dimensions can be reduced into one new dimension by multidimensional scaling or principal component analysis (Kamishima 2003; Berkhin 2006). However, this study did not reduce dimensions to understand meaning of each cluster.

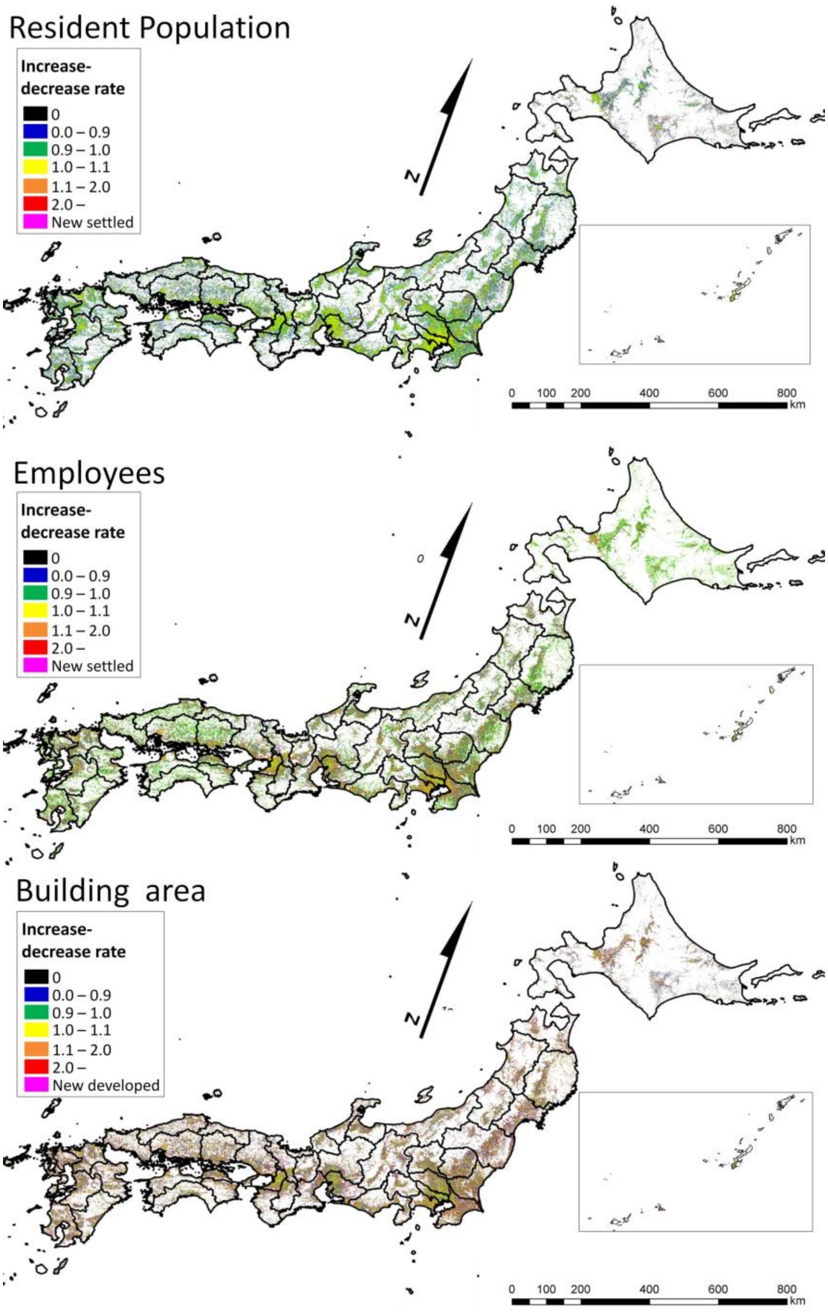


Fig. 1 Time-series transitions of resident population, employees, and building area in Japan between 2005 and 2010 aggregated by 500m square grids

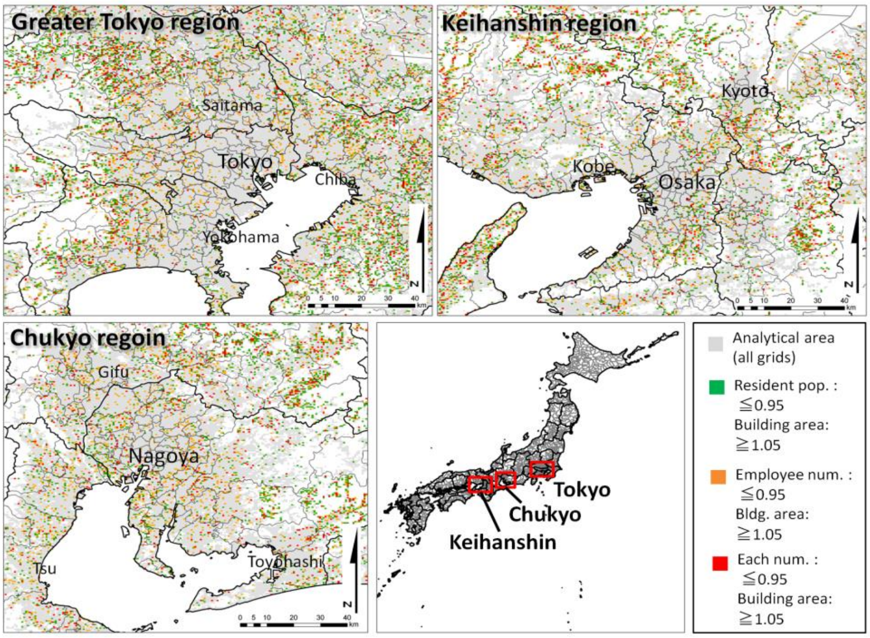
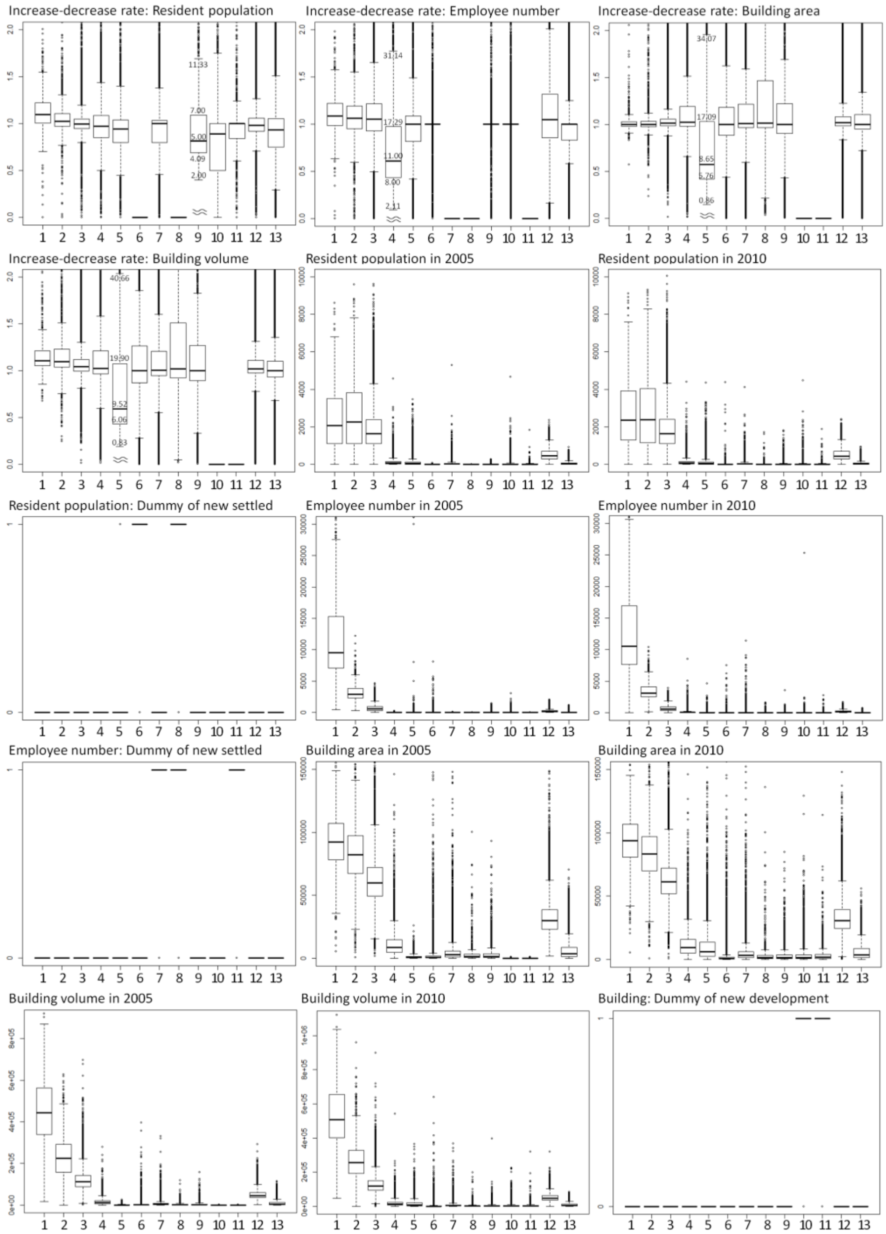


Fig. 2 Distribution of areas with an increase in building areas even though resident population or employees decreased in Japan between 2005 and 2010 aggregated by 500m square grids

3.1 Method of classification

Many types of cluster classification exist. Initially, we planned to adopt one of the nonhierarchical cluster analytical methods by the k-means method that performs excellent processing on multi-dimensional large-scale data. The k-means method is an algorithm to find centroids of similar observation points. This is a relatively common method of multidimensional clustering proposed by MacQueen (1967).

However, the disadvantage of this method is the requirement of specifying the number of clusters at the input stage of performing the analysis. In our study, it is impossible to specify the optimum number of clusters at the input stage, thus adopting this method is difficult. Therefore, this study adopted the x-means method proposed by Pelleg and Moore (2000) that expanded the k-means method and classified all grids throughout Japan into 13 kinds of clusters. In addition, we performed 1000 times x-means processing and adopt the mode number of cluster i.e. 13 because numbers of cluster were not constant in each x-means processing. Finally, clusters were given new numbers of clusters close to numbers of similar clusters by renumbering. Fig. 3 shows the distributions of all dimensional values constituting each cluster. In addition, Table 1 shows the regional characteristics of each cluster defined based on the results of Fig. 3.



Note: All dummy variables of unsettled of resident population and employee number and that of new development of building are 0.

Fig. 3 Distributions of all dimensional values constituting each cluster in the boxplot

Table 1 Medians of all dimensions and regional characteristics of each cluster

Original Cluster No.	Cluster No. (renumbered)	Number of grid	Increase-decrease rate: Resident population	Increase-decrease rate: Employees	Increase-decrease rate: Building area	Increase-decrease rate: Building volume	Resident population: 2005	Resident population: 2010	Resident population: New settled	Employees: 2005	Employees: 2010	Employees: New settled	Building infotmation: Area 2005	Building infotmation: Area 2010	Building infotmation: Volume 2005	Building infotmation: Volume 2010	Building infotmation: New developed
9	1	614	**1.0958**	**1.0879**	1.0012	**1.1049**	2055	2362.5	0	9542.5	10554	0	92387.39	93753.48	444316.85	507869.52	0
1	2	2426	1.0258	**1.0602**	1.0009	**1.0970**	2258.5	2373	0	2886.5	3080.5	0	82294.97	83393.79	223763.82	257598.07	0
10	3	35480	0.9927	1.0531	1.0135	1.0410	1622	1625	0	546	570	0	59881.72	61272.84	111333.64	117598.31	0
8	4	7297	0.9699	**11.0000**	1.0239	1.0222	74	71	0	3	38	0	8540.94	9172.31	12210.90	13093.65	0
11	5	13661	**0.9426**	1.0000	**8.6491**	**9.5196**	38	35	0	7	5	0	527.56	5928.24	700.55	8270.95	0
2	6	12053	-	1.0000	1.0000	1.0000	0	3	1	0	0	0	753.87	720.64	968.01	934.20	0
3	7	44553	1.0000	0.0000	1.0111	1.0043	18	16	0	0	5	0	2868.72	3174.65	3911.97	4266.26	0
5	8	1326	-	-	1.0145	1.0186	0	4	1	0	6	1	1251.41	1459.36	1463.88	1702.73	0
13	9	3499	**5.0000**	1.0000	1.0001	1.0008	2	10	0	0	0	0	1431.86	1329.38	1904.99	1764.32	0
4	10	17237	**0.8889**	1.0000	-	-	7	7	0	0	0	0	0.00	1447.53	0.00	1928.31	1
12	11	3260	1.0000	-	-	-	1	2	0	0	5	1	0.00	1786.22	0.00	2212.28	1
6	12	63001	0.9810	1.0469	1.0182	1.0210	446	442	0	135	140	0	29763.91	30789.87	45951.50	48196.34	0
7	13	324474	**0.9298**	1.0000	1.0012	1.0000	26	24	0	3	1	0	3650.98	3632.37	5146.65	5078.39	0
	All grids	528881	0.9539	1.0000	1.0055	1.0034	37	34		4	6		4646.69	5133.71	6554.10	7202.63	

Note1: Coloers in increase-decrease rate: Red bold:Over 10% increase Orange bold: 5-10% increase black: Maintain(-5%~+5%) Blue bold: over 5% decrease -: new setteled / devel

Note2: Coloers in resident population, employee number and building information in 2010 : Red: increase Blue: decrease

Note3: All dummy variables of unsettled of resident population and employee number and that of new development of building are 0.

3.2 Urban transition of Japan between 2005 and 2010 by the result of regional classification

Fig. 4 shows the results of regional classification in the city centers of Tokyo, Toyama, Aomori, Nikko, and Osaka. The results show that Toyama city where the compact city concept was addressed and in 2007 the “Downtown Basic Revitalization Plan” that was designed by the Japanese Cabinet Office to revitalize the city center accomplished the goal of maintaining the city center and associated high density. In addition, there were few developments in suburbs of Toyama city without southwest areas. There were also the same tendencies in Aomori city that addressed the same plan in the same year. However there was no densification in the city center and little expansion of the suburbs.

On the other hand, Nikko city is an example of another provincial city that designed their plan after 2010. In Nikko city where the plan was designed after 2011, there were small areas with cluster numbers of 1, 2, and 3, i.e. high density urban areas. This indicates that there are very few areas constructed in the city core that are judged to be the city center. In addition, Nikko city was found to be suburbanizing because areas existed where cluster numbers were 5 and 10 even though the population of Nikko city decreased from about 94 to 90 thousand between 2005 and 2010. The development of new residential areas, roads, and large-scale commercial facilities was confirmed by overlaying past digital maps and satellite images using Google Earth®.

In the city center of Tokyo, some areas with a cluster number of 5 were found, i.e. low density areas under development. These are areas where old high-density urban areas with low story buildings that were being redeveloped. An example of such an area is around Tokyo terminal. Actually, there were large-scale redevelopments and verticalization between 2005 and 2010. Osaka also showed the same tendency.

Consequently, an understanding of time-series regional transition throughout Japan with 500m square grid units was accomplished by collection and aggregation of existing census data, building data and cluster analysis.

4 Monitoring of compact city, re-urbanization, and sprawl by integration of time-series grid data (TGD) and city area data

Under the City Planning Act of Japan, major cities must set “Urbanization promotion areas (UPA)” and “Urbanization control areas (UCA)” as city planning area. This Act states that “UPA shall be those areas where urban areas have already formed and those areas where urbanization should be implemented preferentially and in a well-planned manner within approximately the next 10 years”, and “UCA

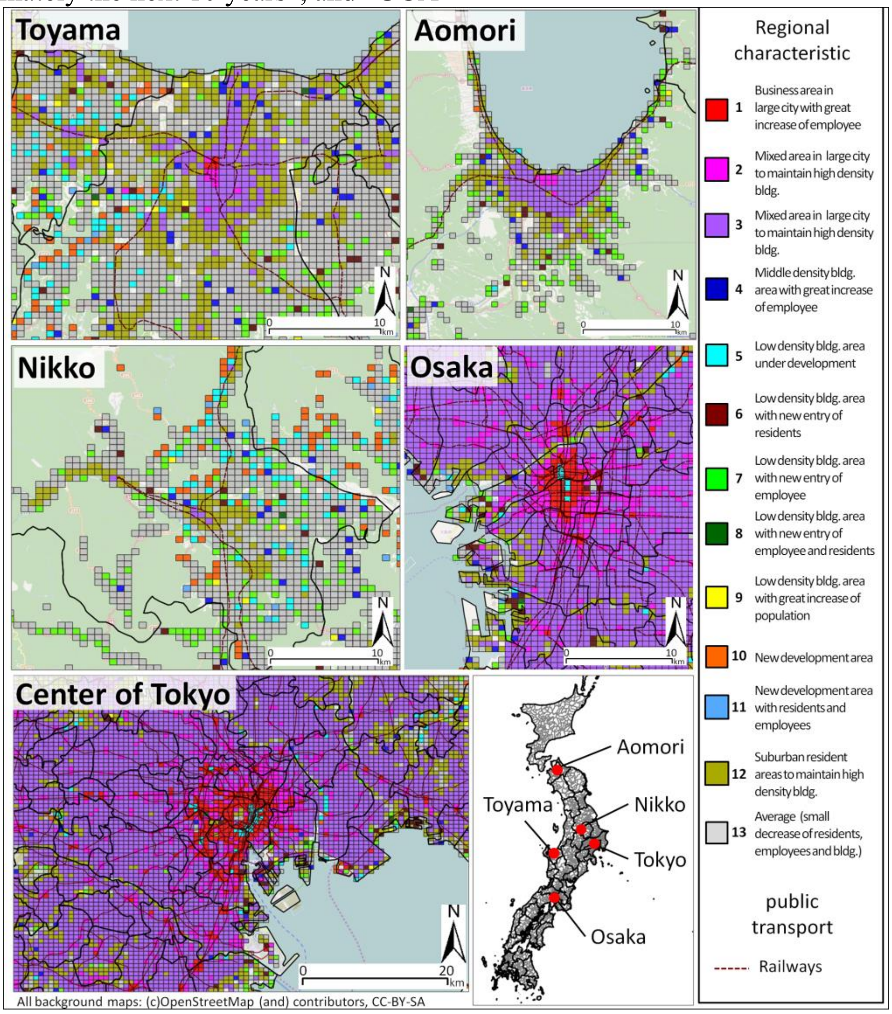


Fig. 4 Urban transition between 2005 and 2010 using regional classification in Tokyo, Toyama, Nikko, Aomori, and Osaka.

shall be those areas where urbanization should be controlled". Urban facilities at least loads, parks and sewage systems are developed intensively in UPA. In addition, developments focusing on the land surface were also implemented by Land readjustment projects and urban redevelopment projects. On the other hand, development and building construction were controlled in UCA as areas where superior natural environments should be protected. By division of city planning area into UPA and UCA, it is expected to restrict the chaotic expansion of urban areas, to develop public facilities e.g. roads and sewage systems effectively, and to realize deliberate city planning. However, UCA could be developed because new buildings can be constructed in UCA to satisfy some licensing standards e.g. building location, situation of adjacent roads, building use and so on. In addition, whole area is designed as UPA in wards of large cities e.g. Tokyo, Osaka and Nagoya and so on. On the other hand, only city planning area is designed without any division into UPA and UCA in local small cities.

In other words, cities where UPA were maintained or densified and the development of UCA was controlled were developing toward a compact city.

Therefore, this chapter proposes a method to reveal whether each city was developed into a compact city and to monitor re-urbanization and sprawl of each city by paying attention to the composition ratio of regional characteristics of TGD in UPA and UCA.

4.1 Classification of UPA and UCA

First, we collected polygon data of UPA and UCA throughout Japan using the City Area Data provided by the digital national land information (National Spatial Planning and Regional Policy Bureau, MLIT 2011). Furthermore, these polygons were divided into each municipality unit using Japanese municipality polygons.

Second, grids of TGD on UPA and PCA polygons were extracted using spatial search. As a result, 56,128 grids from UPA and 99,771 grids from UCA were extracted.

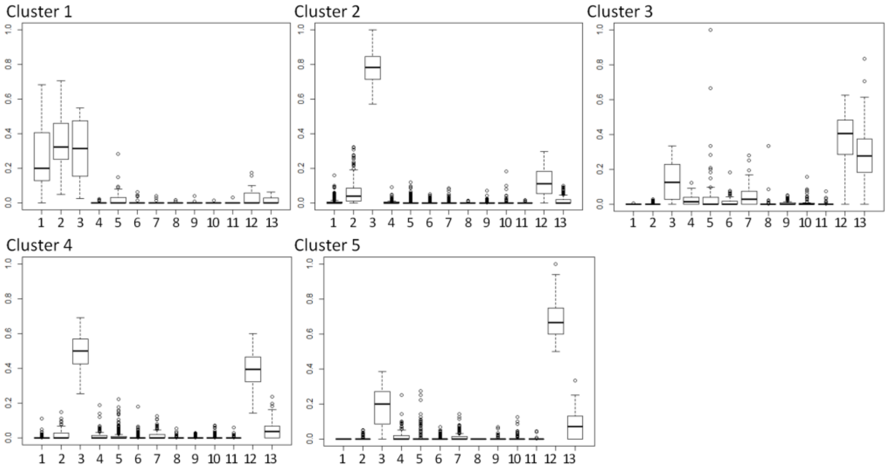
Third, 13 composition ratios of regional characteristics by TGD were calculated to tally the numbers of each kind of grid in each UPA and UCA.

Finally, all UPA and UCA were classified by x-means clustering based on the composition ratios of 13 kinds of classification. As a result, UPA and UCA were classified into 5 types and 4 types of area, respectively. Fig. 5 shows details of these classifications.

4.2 Results of UPA and UCA classifications

UPA were classified into 5 types of area. Cluster 1 is when all factors (resident population, employees, and buildings) were highly-dense and tended to be increasing. This is the ideal type of UPA as a compact city. However, UPA of this type were located only in metropolitan cities, e.g. Tokyo, Osaka and Sapporo . They were not located in provincial cities. Cluster 2 consists of relatively highly-dense residential areas, although all factors were less than those in Cluster 1 and tended to be maintained or decrease. Cluster 3 consists of medium-dense cities under development and it is expected that they will transmute into Cluster 2. Cluster 4 is

Urbanization promotion areas (UPA)

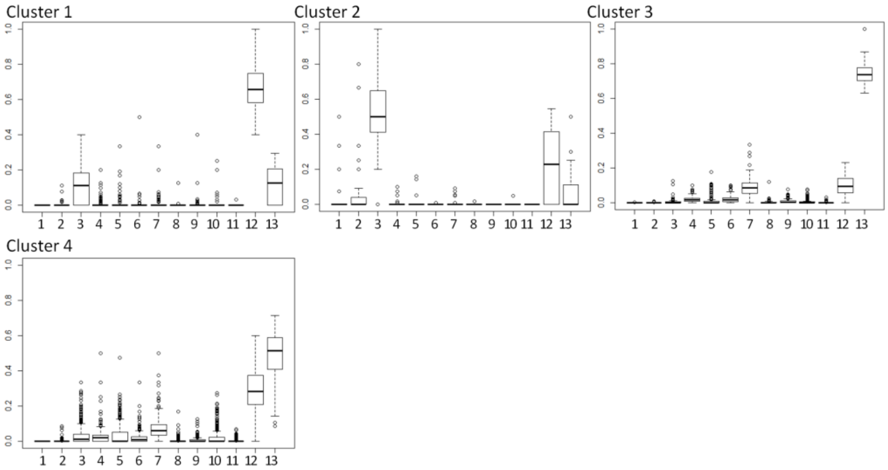


Characteristics and the Compact City Point (CCP) of each cluster in UPA

Cluster No.	Number of area	Resident population	Empolyee number	Building area /	Tendency Resident	Tendency Employee	Tendency Building	Dominated area type	Examples
1	31	■■■	■■■	■■■	■■■	■■■	■■■	Densifing city center	Minato-ku Tokyo, Naka-ku Hiroshima, Hiroshima
2	290	■■■	■■	■■■	■	■	■■	Highly-dense residential area	Mishima-city Shizuoka, Kanazawa-city Ishikawa
3	61	■■	■■	■■	■■■	■■■	■■■	Middle-dense developing area	Tsukuba-city Ibaraki, Otsu-city, Shiga
4	256	■■■	■■	■■	■	■	■■	Middle-dense urban residential area	Maebashi-city Gunma, Kurashiki-city Okayama
5	186	■■	■■	■■	■	■	■■	Middle-dense suburbicarian area	Ebetsu-city Hokkaido, Iwaki-city, Fukushima

Note:■■■: Large/Increase ■■: Middle/Maintain or little increase ■: Small/Maintain or decrease

Urbanization control areas (UCA)



Characteristics and the Compact City Point (CCP) of each cluster in UCA

Cluster No.	Number of area	Resident population	Empolyee number	Building area /	Tendency Resident	Tendency Employee	Tendency Building	Dominated area type	Examples
1	87	■■	■■	■■	■	■	■	Middle-dense suburban residential area	Kawaguchi-city Saitama, Imabari-city Ehime
2	31	■■■	■■	■■■	■	■	■	Highly-dense suburban residential area	Tsukuba-city Ibaraki, Naka-ku Hiroshima
3	238	■	■	■	■	■■	■■	Low-dense suburbs with development	Kitami-city Hokkaido, Tottori-city, Tottori
4	401	■■	■	■■	■■	■■	■■	Middle-dense suburbs with development	Kofu-city, Yamanachi, Toyohashi-city, Aichi

Note:■■■: Large/Increase ■■: Middle/Maintain or little increase ■: Small/Maintain or decrease

Fig. 5 Details of cluster constitution and results of classification of UPA and UCA lower density than Cluster 2 although it is similar to Cluster 2. Cluster 5 is much lower density than Cluster 4. Therefore, the smaller the cluster number is, the higher the density, and UPA for becoming compact cities.

On the other hand, UCA were classified into 4 types of area. Cluster 1 represents that all factors were small and tended to decrease. Cluster 2 had more population and buildings than Cluster 1 although it is similar to Cluster 1. All factors in Cluster 3 were small, however all factors tended to increase, i.e. UCA were developing. Cluster 4 consists of more developed areas than Cluster 3 and was not developing or reducing. Therefore, the smaller cluster number is, the less developed the UCA was and the better the control of the UCA.

5 Discussion

Table 2 shows the results of mapping 744 cities to design UPA and UCA based on each cluster number. In addition, Fig. 6 shows the clustering results of UPA and UCA in major metropolitan areas. The problems relating to the development of the compact city nature of each city are given in Table 2.

Upper right cities in Table 2 controlled UPA and UCA well. It is believed that these cities should maintain current policies. Wards constituting metropolitan cities with relatively large neighboring cities are principally located here. Toyama city in Fig. 4 is also located here.

Upper left cities are developed as not only UPA but also UCA. Additional controls of UCA are required in these cities. Many provincial prefectural capitals and core cities are located here.

On the other hand, lower right cities are neither developed UCA nor UPA. This indicates that the development of compact cities was finished. However, from the other perspective, developments slump throughout urban areas. Relatively small cities and towns are located here. Aomori city in Fig. 4 is also located here.

Lower left cities are in the most serious situation. UPA and UCA of these locations are not controlled according to intentions for compact cities. In other words, it seems that the hollowing of city centers is promoted simultaneously with suburban sprawl. Many provincial small cities are located here, even prefectural capitals, e.g. Gifu city, Kochi city, and Tottori city. The population of many small cities located here has started to decrease. Control of UCA is desired, in particular, because there is a possibility that maintenance of once developed suburban areas will become financial burdens for local governments without adequate financial resources.

The results show that it is believed that promotional policies for compact cities by the Japanese government did achieve some positive results. However, the hollowing of city centers and suburban sprawl does progress simultaneously, especially in many provincial small cities. Looking forward, prompt promotions of policy for compact cities are necessary in these types of city. On the other hand, such cities in a serious situation can look to cities of a similar urban scale and geographical condition that promote the compact city well from Table 2. Therefore, our result is fruitful for referring to compact city policies.

Table 2 Mapping results of 744 cities to design UPA and UCA based on each cluster number

UCA were being developed. ← → UCA were well controlled

UPA were well developed. ↑ ↓ UPA were declined.

Urban Promotion Aera (UPA)		Urban Contrall Area (UCA) 4 Middle-dense suburbs with development	3 Low-dense suburbs with development	2 Highly-dense suburban residential area	1 Middle-dense suburban residential area
1	Dense city center	<u>2 cities</u> Chuo-ku Sapporo city Hakata-ku Fukuoka city	<u>2 cities</u> Hyogo-ku, Kobe city Chuo-ku, Kobe city	<u>7 cities</u> Shinagawa-ku, Tokyo Sumida-ku, Tokyo Taito-ku, Tokyo Fukushima-ku, Osaka city Naka-ku Hiroshima city etc.	<u>2 cities</u> Kita-ku, Osaka city Yodogawa-ku, Osaka city
2	Highly-dense residential area	<u>146 cities</u> Toyohira-ku, Sapporo city Yamagata city, Yamagata Kanazawa city, Kanazawa Nara city, Nara Matsuyama city, Ehime Kumamoto city,Kumamoto Naha city, Okinawa etc.	<u>21 cities</u> Hakodate city, Hokkaido Nishi-ku, Sapporo city Taihaku-ku, Sendai city Kita-ku, Kyoto city Nishinomiya city, Hyogo Minami-ku, Okayama city Minami-ku, Fukuoka city etc.	<u>23 cities</u> Katsushika-ku, Tokyo Setagaya-ku, Tokyo Urayasu city, Chiba Kohoku-ku, Yokohama Shimizu-ku, Shizuoka city Amagasaki city, Osaka Itami city, Osaka etc.	<u>66 cities</u> Kawaguchi city, Saitama Urawa-ku, Saitama city Kanazawa-ku, Yokohama Higashi-ku,Hamamatsu city Minami-ku, Kyoto Minami-ku, Hiroshima Urazoe city, Okinawa etc.
3	Middle-dense developing area	<u>19 cities</u> Morioka city, Iwate Onagawa town, Miyagi Futtu city, Chiba Miura city, Kanagawa Kita-ku, Hamamatsu city Nantan city, Kyoto Hyuga city, Miyazaki etc.	<u>34 cities</u> Muroran city, Hokkaido Tomakomai city, Hokkaido Otaru city, Hokkaido Chitose city, Hokkaido Kisarazu city, Chiba Izu city, Shizuoka Ako city, Hyogo etc.	<u>1 city</u> Tsukuba city, Ibaraki	<u>2 cities</u> Toyama city, Toyama Otsu city, Shiga
4	Middle-dense urban residential area	<u>158 cities</u> Obihiro city, Hokkaido Maebashi city, Gunma Nagano city, Nagano Gifu city, Gifu Tsu city, Mie Kurashiki city, Okayama Kochi city, Kochi etc.	<u>78 cities</u> Kushiro city, Hokkaido Akita city, Akita Mito city, Ibaraki Utsunomiya city, Tochigi Fukui city, Fukui Tottori city, Tottori Nagasaki city, Nagasaki etc.	<u>1 city</u> Aomori city, Aomori	<u>14 cities</u> Showa town, Yamanashi Yaizu city, Shizuoka Yokai city, Aichi Ama city, Aichi Kuwana city, Mie Mihama-ku, Sakai city Imabari city, Ehime etc.
5	Middle-dense suburbicarian area	<u>67 cities</u> Hokuto city, Hokkaido Iwaki city, Fukushima Ota city, Gunma Komatsu city, Ishikawa Maibara city, Shiga Iwakuni city, Yamaguchi Nankoku city, Kochi etc.	<u>97 cities</u> Kitami city, Hokkaido Date city, Miyagi Ashikaga city, Tochigi Joetsu city, Niigata Fukuchiyama city, Kyoto Tamano city, Okayama Naruto city, Tokushima etc.	<u>0 city</u>	<u>3 cities</u> Ina town, Saitama Kitajima town, Tokushima Tobe town, Ehime

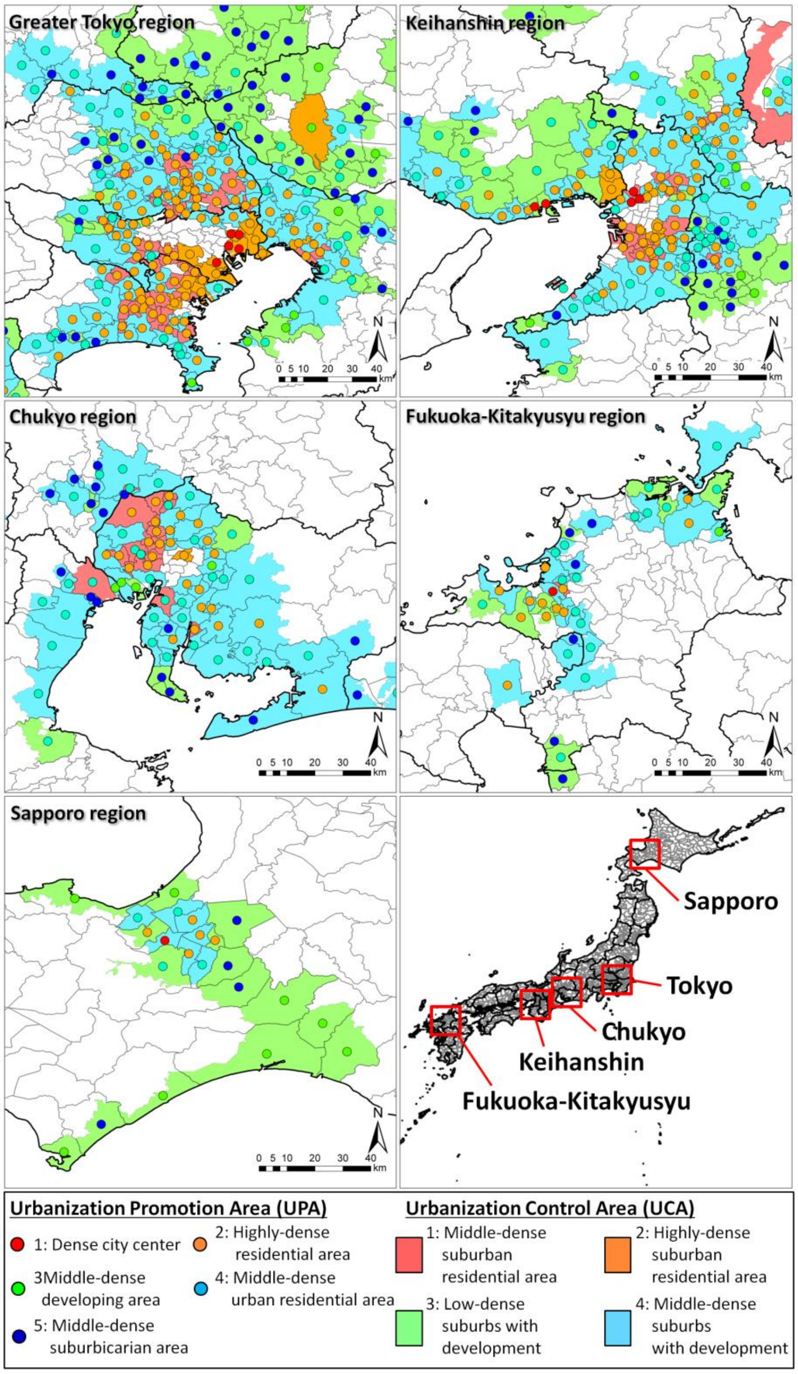


Fig. 6 Clustering results of UPA and UCA in major metropolitan areas

6 Conclusions

This study developed grid data to monitor time-series land transition quantitatively throughout Japan. In addition, a method was developed to decide the regional characteristics of each grid by x-means clustering. Moreover, situations of compact city, re-urbanization, and suburban sprawl of all Japanese cities can be monitored to integrate the grid data with city area data. It is expected that the results of this study support the development of policies promoting a compact city and its evaluation for Japanese and local governments. This study is a new approach in the field of urban planning and management because there are few studies to monitor and visualize the time-series transition of Japan using geo big data and to show supportive possibilities for concrete urban policies of compact cities.

Future work includes the development of an optimal clustering method by comparing various clustering methods. Consideration of extending the method for multi-time-series analysis is in preparation for the release of the Japanese population census in 2015. Moreover, this method can be applied in other countries if the same types of source data can be obtained. Therefore, we intend to apply our method in other countries in the future.

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