Spatial distribution monitoring of isolated dwelling using building micro geodata and its issue

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Abstract

Recently, areas with very few residents in remote areas such as mountainous areas and isolated islands have appeared due to rapid declining birthrate and aging population and the population movement to urban areas in Japan. In these areas, isolated detached houses that do not have other resident buildings in the vicinity, i.e. “isolated dwellings” have appeared. An increase in isolated dwellings can be a concern in maintaining the regional community in remote areas from the viewpoint of significant decrease in cost effectiveness of maintenance and management of infrastructure, increasing risk in the event of a natural disasters due to the absence of neighboring residents, and possibility to become a vacant house in the future and so on. Continuous monitoring of the actual state of spatial distribution of isolated dwellings is an urgent task especially for the national and local governments. Although there are many previous studies aimed at grasping the actual conditions of houses in remote areas, there are no studies that try to monitor the distribution of isolated dwellings throughout Japan. Therefore, this paper attempted to monitor the spatial distribution of isolated dwellings throughout Japan by using micro geodata (MGD) of building distribution developed from digital map called residential map. First, we developed about 100 million building data in 2014 throughout Japan using the residential map. Second, about 27 million detached houses were extracted from among them. Finally, we calculated the distance from all detached houses to nearest detached houses. Then, detached houses where this distance is more than 500 m in walking distance were defined as the isolated dwellings. In other words, an isolated dwelling in this study is a detached house that does not have any other resident in the walking area. The result of extracting isolated dwellings showed that there are about 15,000 isolated dwellings throughout Japan in 2014. In addition, compared with the results of 2009, it showed that the rate of isolated dwellings increased mainly in mountains areas and remote islands although the number
of isolated dwellings decreased nationwide. Furthermore, about one third of residents in isolated dwellings were elderly people aged 65 and older. Finally, we developed a method to simulate mitigating the monetary burden of local governments by relocating residents of isolated dwellings to areas where urban functions are substantial and by demolishing them. By setting estimated annual public utility cost required for maintaining isolated dwellings and relocation promotion expenses for each municipality and comparing them, the method clarified when we can collect relocation promotion expenses. The result showed that there is a possibility that all municipalities in Japan can collect relocation promotion expenses in the eighth year if migration promotion expenses are 5 million yen per isolated dwellings, even in 10 million yen in thirteen years.

Key words: isolated dwelling; remote place; lifeline maintenance cost; relocation promotion expenses; residential map; micro geodata

1. INTRODUCTION

Depopulation has seen in several levels: national scale, metropolitan area scale, administrative boundary scale. There are thousands of studies, which report depopulation phenomena in urban area, mountainous region because of population aging and migration [1]. However, in Japan national scale population has decreased since 2007. The decrease of national population is rare case in the world. Moreover, mountainous area shares 70% of national land in Japan. Even though such a mountainous area there are inhabitant land. People makes a living in forestry, agriculture, pottery, and other nature-friendly business. However, centralization is pulling up young generation from whole of Japan. Once young generation lives in urban area for higher education or job hunting, few of them come back to original place. As a result, original inhabitant area is rapidly aging and depopulated. Finally, it would be issue as “abandoned settlements” which is difficult area to sustain. Switching unit from settlements to residential lot, “isolated dwelling” is also would be issue to maintain the living environment. Even though people living in isolated dwelling use electricity, water, sewage, gas, public roads, and other infrastructure to survive. It would be degraded of efficiency benefit by cost to maintain these infrastructures. Moreover, disaster risk would be higher under emerging situations such as flooding, landslide, earthquake, because of low accessibility to get help from neighborhood named the mutual assistance force. Isolated dwellings have high potential to be abandoned house. It means that isolated dwelling is potentially high risk for both residents and local government. Therefore, it is important to grasp spatial distribution of isolated dwelling in national scale and to address the future picture in the sense of sustainable adminiculary management.

Reviewing previous researches related on isolated settlement, there are similar topics such as abundant village [2], abandoned settlements of hilly mountainous regions [3], maintain system of
marginal settlement in remote island [4]. However, many of the previous researches targets specific areas, villages, and it has not been able to grasp the state of nationwide isolated dwellings. There are a few studies worked on whole of Japan [5, 6, 7]. Okahashi (1986) classified mountainous municipalities into some clusters and found deprivation villages and Kaneki (2003) clarified spatial distribution of defunct villages based on topographic map [5, 6]. However, in any case, the aggregation unit is a relatively macro unit such as municipalities and villages, settlements, etc. There is no case analyzing the distribution of isolated dwellings in more detailed units. Therefore, in this research, we focus on the "isolated dwelling" which can be a problem in sustainable management of local government in the future for Japan, whose population reduction is becoming a serious social problem. In this research, we clarify the distribution of isolated dwellings in units of detached houses and calculate the cost of relocation of isolated dwellings based on the spatial distribution of them. As a result, this research enables us to grasp the spatial distribution for each isolated dwelling in the whole country although it was only to grasp the distribution of isolated dwellings in a single local government or village unit in previous researches. It is expected that even if it seems difficult for a single municipality to deal with it, it will be expected to show alternative proposal. Based on the above, the objectives of this research are 1) to grasp the spatial distribution of isolated dwellings throughout Japan, 2) to compare the distribution of isolated dwellings at two time points so that the spatial distribution of increase and decrease of isolated houses, and 3) to estimate the economic burden of local governments by relocation promotion for isolated dwellings in the future, and examined the possibility of site location optimization. In order to achieve the above objectives, we develop a method to grasp the spatial distribution of isolated dwellings throughout Japan by using the building MGD which has developed “residential maps (Zenrin Co., Ltd.)” that is used as a data source as precious geospatial data unrivaled
worldwide that realizes analysis on each isolated dwellings for the whole country. Moreover, by comparing the two points of 2009 and 2014 after the population decrease, the municipalities in which isolated dwellings increased were identified. Finally, we consider that the future trend of isolated dwellings in the economic burden position of the municipality by relocation of isolated dwellings.

2. METHODS

2.1. Source data

In order to grasp the spatial distribution of buildings throughout Japan, we used a digital map called "residential map" in 2014. The residential map is a digital map maintained by Zenrin Co., Ltd., and the residential map in 2014 contains about 100 million buildings throughout Japan as polygon data. We can extract only detached houses from the residential map because all building polygons have an attribute of the building uses e.g. detached houses, mixed use buildings, landmarks, offices, etc. As a result of extracting detached houses, it was found that there are about 27 million detached houses throughout Japan in 2014. In addition, the residential map has been developed by field surveys of visual observation by investigators, and it has been confirmed that the map is sufficiently reliable [8]

The Micro Population Census (MPC) is MGD that can estimate ages and genders of all resident of each building developed by Akiyama et al. (2013) [9]. This data was developed by allocating population information obtained from the Japanese population census to the residential building i.e. detached houses and apartment houses extracted from the residential map. This study used the MPC that was developed using the population census in 2010. The MPC in 2010 contains residential area, age and gender of about 50 million households and about 125 million residents
throughout Japan. Therefore, it became possible to estimate the distribution of isolated dwellings in which only elderly people live by integrating the MPC and the residential map.

2.2. Steps for spatial analysis

At first, we defined an “isolated dwelling” as a detached house is more than walking distance, far from the nearest occupied house inhabitant house. To extract isolated dwellings, these steps are followed: Step 1. Developed building point data (approximately 100 million points for all of Japan) with building attribute based on the centroid point of each building shape which extracted from ZENRIN (c) digital residential map database for whole of Japan (Fig. 1-a, b). Step 2. Extracted residential dwelling points (approx. 25.5 million points) from building point considering building attribute which shows clearly detached house with nameplate (Fig. 1-b, c.). Step 3. Searched nearest neighborhood residential dwelling point from each the residential dwelling point in Euclidian distance. If the minimum distance between residential dwelling points is more than 500 m, the residential dwelling is defined as isolated dwelling in this study.

Detecting the spatial distribution of the isolated dwellings, we need to calculated distances from each detached house to the nearest residential building. Ideally, these distances should be calculated in network distance. However, it is not easy because development of Japanese digital road network dataset is insufficient for rural and mountainous area. Morita et al. (2015)[10] calculated ratio of road network
distance to Euclidian distance ($R_r$) for 112 Japanese cities and national average using road network data for all over Japan. Therefore, this study applied each ratio for the 112 cities and for other cities and villages national average ratio. As a results, distance from each detached house to the nearest residential building which was approximated the network distance ($S_1$) is obtained by equation (1).

$$S_1 = S_2 / R_r \quad (1)$$

where $S_2$ represents the Euclid distance from each detached house to the nearest residential building, and $R_r$ represents the ratio of network distance to Euclidean distance referred Morita et al (2015) [10].

On the other hand, Nagata et al. (2015) defined the walking distance of Japan as 500 m in their study about Japanese food desert problem [11]. In addition, there are many previous studies that defined the walking distance as 500 m not only in Japan [12, 13] but also outside Japan [14]. Therefore, this study also defined walking distance as 500 m, and defined the detached house whose $S_1$ is over 500 m as an isolated dwelling.

3. RESULTS

3.1. Spatial distribution of isolated dwellings

Total number of isolated dwelling decreased from 17,106 in 2009 to 15,052 in 2014 in Figure 2. Aggregated isolated dwelling by boundaries of each local government are illustrated in Figure 3. The red colored area in Figure 3 shows that local government boundaries which has more than 50 isolated dwellings are located in Eastern part of Hokkaido and North part of Hokkaido in Hokkaido region and mountainous area of Tohoku, Chugoku, Shikoku, and Kyusyu regions in both years. Figure 4 shows percentage of isolated dwellings in detached houses by municipalities in 2009 and 2014. The percentages are zero at the Tokyo metropolitan area including Tokyo and Yokohama city, Chukyo
metropolitan area including Nagoya city, Keihanshin metropolitan area including Kyoto, Osaka and Kobe city and other populated cities. It is less than 1.0 % at almost all municipalities of Japan except Hokkaido region in both years. The highest percentage in 2014 is 10.46 % of Toyokoro town in Hokkaido. Although Toyokoro town is located at the Tokachi river estuary, flat area is limited because hilly area divided flat area. That geographical condition would be supported the higher percentage of isolated dwelling. Except Hokkaido, 6.08 % of Shiiba village in Miyagi Prefecture is the highest percentage. Shiiba village is located in the mountains and there is no train station and accessibility is very limited.

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Insert Figure 2 a-b.

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Insert Figure 3

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Insert Figure 4

However, Hokkaido region, especially in eastern and northern regions might have different reasons
why that many isolated dwellings located from other regions. Because these regions have been
developed as settlements of Tondenhei (the soldiers for developing and guarding Hokkaido), each land
lot is wider than other regions of Japan. For instance, average farmland in Hokkaido is approximately
26 ha, while, national average of Japan except Hokkaido is approximately 1.9 ha [15]. Considering
more than 10 times large farmland in Hokkaido, isolated dwellings that defines by 500 m radius in
Hokkaido possibly are overestimated. It suggests that further study needs to adjust the distance
considering geographical characteristics. Figure 5 shows differences of isolated dwelling percentage
between 2009 and 2014. Almost of the local government in Japan presents -1.0 % to 1.0 of difference
of one. Table 1 listed top ten local governments with a large increase in change of isolated dwelling
rates. In the local governments listed in Table 1, there are local governments where the isolated
dwelling rate in 2014 was over 2.5% despite the fact that there were no isolated dwellings in 2009. In
such a local government, it is considered that an isolated dwelling was detected because the house
became a vacant house or the house demolished between 2009 and 2014 in the place where the housing
density was relatively low.

Insert Figure 5

Insert Table 1
3.2. Comparison of isolated dwellings rate and aged rate

As mentioned above, although the number of isolated dwellings has decreased slightly as a total number, rapidly change of isolated dwellings was confirmed by local governments’ boundaries. In other words, it can be said that there is a necessity to observe isolated dwellings by region rather than seeing it nationwide. Next, in order to grasp the characteristics of the residents of the isolated dwellings, Figures 6 and 7 show the relationship between the aging population and isolation dwelling ratio by municipalities, and the difference of isolated dwelling rate from 2009 to 2009, respectively.

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Insert Figure 6

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Insert Figure 7

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There are no effective relationships between aging rate and the difference of isolated dwelling rates by municipality. It is considered that the number of isolated dwellings based on geographical characteristics such as Hokkaido as described above is larger than the aging rate. Furthermore, in order to examine the influence of individual phenomenon factors, in order to analysis on a more detailed scale, each building was analyzed using the MPC. Specifically, we estimated the distribution of isolated dwellings in which only elderly people live by integrating the MPC and the residential map.
According to Table 2, about one-third of the residents were aged people over 65 years old in isolated dwellings. Hence, it was suggested that the possibility of aged people living in isolated dwellings is higher than that of non-isolated dwellings. This suggests that the risk of disasters is high. Isolated dwellings are a geographically inconvenient place, so it takes time to go to the rescue and deliver relief supplies after a disaster occurs. Also, because there are no residents in the vicinity, mutual support cannot be obtained at the time of a disaster. Therefore, there is a high possibility that necessary support cannot be obtained at the time of disaster occurrence.

4. POSSIBILITY OF LOCATION OPTIMIZATION

We proposed relocation measure of isolated dwelling resident to collective living area at the same municipality. Proposed idea would expect to reduce financial burdens off local government where isolated dwelling locates. This idea is supported by the location optimization plan. In 2004, amended the act on Special Measures Concerning Urban Regeneration makes it possible to design the location optimization plan that is promoting for compact city by local government [16]. The location optimization plan is a master plan to attract urban function: hospital, welfare, commercial facility, road network and dwellings by collective investigation. Executing relocation of isolated dwelling is expected to substitute relocation promotion expenses for future lifeline; road network and water supply pipe maintenance expenses and to save lifeline maintenance fee of local government. Based on the
above, we estimated lifeline expenses for mainlining all isolated dwellings in Japan for the future at each local government level. At the same time, we calculated total relocation expenses to suppose relocation promotion expense per household.

4.1. Estimation of total utility expenses to keep lifeline for isolated dwelling

Calculating expenses to maintain isolated dwelling, cost of road and water supply is considered. Because some of other lifelines manages by private sectors such as electricity, gas, internet, and telephone network. Moreover, sewage system is very diverse compared to water supply system. This study takes unified indices to estimate maintain cost for whole of country. Therefore, this study defined annual minimum cost \( c_i \) of local government \( i \) as the following equation (2).

\[
c_i = d_i(w + r_1 + r_2)
\]

where \( c_i \) represents minimum annual total utility expenses to keep lifeline for isolated dwelling \( i \) [bln. JPY/year]; \( d_i \) represents distance in meter from isolated dwelling \( i \) to nearest residence [m]; \( w \) represents estimated annual replacement cost of water supply pipe per meter [JPY/m/year], \( r_1 \) represents annual maintenance cost of municipality roads (cleaning fee for road surface) per meter [JPY/m/year], \( r_2 \) represents maintenance cost of municipality roads (road construction expenses) per meter [JPY/m/year]. \( w \) which was derived by multiplying annual replacement cost of water supply pipe per meter; 32147 [JPY/m] [17] by replacement rate of water supply pipe in 2013; 0.79 % [18] is 253.96 [JPY/m/year]. \( r_1 \) which was derived by multiplying unit cost; 145 [JPY/m2] [17] by minimum road width [3 m] regulated by Government Order on Road Design Standards Article 5, paragraph 4 [19] is 435 [JPY/m/year]. \( r_2 \) is consist from the cost of the cut-and-overlay asphalt work is done for improving road pavement for every ten years (1526 [JPY/m2] [17] and the cost of replacing asphalt...
paving for every twenty years (3406 [JPY/m²]) [17]. Since the update time is unknown, it smoothed as annual cost. \( r_2 \) which was derived from the following equation (3). 3 [m] in the equation (3) comes from minimum road width as mentioned.

\[
 r_2 = (1526 \text{ [JPY/m²]} \times 1/10) \times (3406 \text{ [JPY/m²]} \times 1/20) \times 3 \text{ [m]} = 968.7 \text{ [JPY/m/year]} \tag{3}
\]

Substituting the following values in equation (2), \( c_i \) is derived \( c_i = d_i (w + r_1 + r_2) = 1657.66 \cdot d_i \).

When the number of isolated dwelling is \( n \) at local government \( i \), total lifeline cost to maintain isolated dwelling for \( t \) years (\( C_i \)) was derived equation (4):

\[
 C_i = t \sum_{i=1}^{n} c_i = t \sum_{i=1}^{n} (1657.66 \cdot c_i) = 1657.66 \cdot t \sum_{i=1}^{n} d_i \tag{4}
\]

4.2. Supposition of relocation promotion expenses

We assume that once local government \( i \) gives every isolated dwelling house hold uniformly relocation promotion expense as lump sum, all the isolated dwelling households at local government \( i \) will leave isolated dwelling to estimate total relocation promotion expense (\( M_i \)). \( M_i \) represents in equation (5):

\[
 M_i = n_i m_i \tag{5}
\]

where \( n_i \) represents the number of isolated dwelling located at local government \( i \), and \( m_i \) represents relocation promotion expense for each isolated dwelling household. In this study, \( m_i \) is set several levels: 2.5, 50, 10, 25, 50, 100 million JPY (mln. JPY).

4.3. Balance of \( C_i \) and \( M_i \)

\( M_i \) is lump sum, while \( C_i \) is accumulated cost of annual minimum cost when isolated dwelling household remains. Our study check the timing when \( M_i \) and \( C_i \) balance each other out at local government \( i \). In case, all the isolated dwelling households have relocated at first year, local
government $i$ can achieve cost recovery, when $C_i$ exceeds $M_i$. Figure 8 a. presents a result of estimated public works expenditure by municipality. The national total of estimated lifeline cost was 21.77 billion JPY. The most expensive municipality was Betsukai town, Hokkaido, with the number of isolated dwellings: 300, and estimated lifeline cost: 558 million JPY. Except Hokkaido, the highest municipality was Iwaki City, Fukushima Prefecture, with the number of isolated homes: 146, and estimated lifeline costs: 187 million JPY. In local governments where the total estimated lifeline cost is high, it is a feature that the number of isolated dwellings shown in Figure 2 is large.

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Insert Figure 8 a-b
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Next, Figure 8 b. shows the average estimated lifeline cost per isolated dwelling by municipality. The national average was 1.4461 million JPY. The highest municipality was Tokashiki village in Okinawa Prefecture, and the total lifeline cost was 17.77 million JPY for a single isolated dwelling. Here, Tokashiki village in Okinawa Prefecture is a remote island, and the distance to the nearest neighboring dwelling is 10.72 km, which is the second most distant place even if it is nationwide. Among the municipalities with multiple isolated dwellings, the most expensive municipality is Kamikitayama village in Nara Prefecture, and estimated total lifeline costs was 6.23 million JPY for 3 isolated dwellings. Regions where the average is high were geographically isolated areas such as remote islands and mountainous areas.
As section 4.2 mentioned, $m_i$ is set several levels: 2.5, 50, 10, 25, 50, 100 million JPY (mln. JPY).

Figure 9 illustrated balanced year of $C_i$ and $M_i$ for all municipalities. When $m_i$ is one million JPY, it takes two years to cost recovery since providing $m$, as same as in the case of 2.5 mln. JPY takes 4 years, 5 mil. JPY takes 8 years, 10 mln. JPY takes 13 years, 25 mln. JYP takes 30 years, 50 mln. JPY takes 61 years, and 100 mln. JPY takes 121 years. As an example, we focus on the 10 mln. JPY case. In this case, it takes 13 years’ maximum to recover relocation promotion expenses in Figure 10. After 10 years, almost all the local governments can achieve locational cost recovery. On the other hand, ten years are not enough to achieve the recovery for some local governments. That is reasons why the number of isolated dwelling ($n_i$ of equation (5)) is more than other local governments in these local governments. For example, there are many red colored municipalities in Ibaraki prefecture, where agricultural land is spreading in the Kanto plain. Since the characteristics of rural land use, with the uniform index of 500 m, the possibility that it could not be evaluated remained. Against this point, it was also indicated as a subject to reconsider the distance that define an isolated dwelling for each municipality. To achieve this, it is need to investigate distance of each dwelling for each municipality and living sphere for each resident. Based on these spatial analysis, when discussing the relocation
project by considering the cognitive distance of the residents, it is expected that the effect of promoting
the consensus building between the residents and the local government office. According to Figure 11,
many local governments could achieve to cost recovery during five to seven years. If almost all the
local governments which has isolated dwellings could secure 0.3 billion JPY as a budget for relocation
promotion, they would reduce economic burden to maintain lifeline for isolated dwelling.

According to the past cases relating to residence relocation projects, the history of relocation is various,
such as disaster, brought by family members, difficulty of survive. However, it has been pointed out
that challenges are involved in rebuilding life base, such as continuing the occupation and rebuilding
the human network after relocation. Island-wide evacuation of Miyakejima Island due to volcanic
eruption in 2000 and Group Relocation for Disaster Mitigation after Great East Japan earthquake in
2011 are examples of large relocation. There were relocations beyond the sea and beyond the
prefecture. In these cases, there were difficulties in reconstructing all living bases such as school
attendance, employment place, and hospital visit and so on. In this time, we assumed relocation to the
same municipality, but we will need to discuss specific migration destination in the future work.

5. CONCLUSIONS

This study aimed to grasp spatial distribution of isolated dwelling in national scale and to address
the future picture in the sense of sustainable management of local government. To achieve the above
objects, we firstly developed isolated dwelling database using building MGD for all of Japan. Then, we
did trial calculation to estimate both relocation promotion expenses and life line maintenance cost for isolated dwelling for each local government. As a results, with several grades of lump sum for relocation, it takes from 2 to 121 years to achieve cost recovery. In the case of 10 mln. JPY as lump sum, almost all the local governments which have isolated dwelling could achieve cost recovery within ten years. Although these trial calculation is based on ideal condition, this study show a trial calculation to relocate isolated dwelling residents. Further study is needed to close research result to reality.

- Examination of an appropriate extraction method for isolated dwellings of buildings (home office highly likely to have settlement population) other than detached houses with nameplate.
- Calculation of relocation promotion expenses according to isolation distance of isolated dwellings (in this study, although focusing on fairness within municipalities, it was made uniform)
- with considering on geographical condition and life range pattern of residents to define isolated dwellings for each local government.
- Depending on the financial situation of each municipality, it is necessary to consider promotion expenses within the amount that can afford.
- Interview with municipalities on problem consciousness concerning isolated dwellings and results of
We would like to study in the future on how to effectively utilize the data and method of this research in order to establish policies and isolation houses in municipalities and gradual relocation plan.

**Compliance with Ethical Standards**

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**Conflicts of Interest:** The authors declare that they have no conflict of interest.
REFERENCES


Tables

Table 1. Top 10 local governments with a large increase in change of isolated dwelling rates.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Isolated dwelling rate (%)</th>
<th>2009</th>
<th>2014</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horonobe, Hokkaido</td>
<td></td>
<td>0.00</td>
<td>8.39</td>
<td>8.39</td>
</tr>
<tr>
<td>Horokanai, Hokkaido</td>
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<td>0.00</td>
<td>7.23</td>
<td>7.23</td>
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<tr>
<td>Koshimizu, Hokkaido</td>
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<td>5.04</td>
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<td>Shiiba, Miyazaki</td>
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<td>3.24</td>
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<tr>
<td>Satoma, Hokkaido</td>
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<td>3.79</td>
<td>4.78</td>
<td>0.99</td>
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Table 2. Comparison of aging rate and single household rate between isolated and non-isolated dwelling.

<table>
<thead>
<tr>
<th></th>
<th>Isolated dwelling</th>
<th>Non-isolated dwelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of residents</td>
<td>31,856</td>
<td>126,249,157</td>
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<tr>
<td>Number of residents over 65 years old</td>
<td>10,819</td>
<td>24,914,140</td>
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<tr>
<td>Aging rate [%]</td>
<td>33.96</td>
<td>19.73</td>
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<tr>
<td>Household Number</td>
<td>8,686</td>
<td>25,536,883</td>
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<td>Single household Number</td>
<td>847</td>
<td>2,606,494</td>
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<td>Single household rate [%]</td>
<td>9.75</td>
<td>10.21</td>
</tr>
</tbody>
</table>
Figure legends

**Fig 1 a-c** Steps of extraction of residential MGD. **Figure 1 a.** Digital residential map. **Figure 1 b.** Building point data. **Figure 1 c.** Residential point data.

**Fig 2 a-b** Location of isolated dwellings. **Figure 2 a.** For the year of 2009. **Figure 2 b.** For the year of 2014.

**Fig 3 a-b** Number of isolated dwelling by boundaries of local government. **Figure 3 a.** For the year of 2009. **Figure 3 b.** For the year of 2014.

**Fig 4 a-b** Percentage of isolated dwelling in detached house by boundaries of local government. **Figure 4 a.** For the year of 2009. **Figure 4 b.** For the year of 2014.

**Fig 5** Difference of isolated dwelling percentage between 2009 and 2014.

**Fig 6** Scattering plot for aging rate and isolated dwelling rate by municipalities.

**Fig 7** Scattering plot for aging rate and difference of isolated dwelling rate by municipalities.

**Fig 8 a-b** Estimated total utility expenses in 2014 by municipalities. **Figure 8 a.** Estimated total utility expenses by municipalities [bln. JPY]. **Figure 8 b.** Average estimated total utility expenses of isolated
dwelling [mln. JPY/house hold].

**Fig 9** Balanced year of $C_i$ and $M_i$ for all municipalities.

Note: when $m_i$ is one million JYP, it takes two years to cost recovery since providing m, as same as in the case of 2.5 mln. JPY takes 4 years, 5 mil. JPY takes 8 years, 10 mln. JPY takes 13 years, 25 mln. JYP takes 30 years, 50 mln. JPY takes 61 years, and 100 mln. JPY takes 121 years.

**Fig 10** Balanced year of $C_i$ and $M_i$ for all municipalities in a case of 10 mln. JPY.

Note: this map shows the case of 10 mln. JPY for $m_i$. Blank municipality is out of calculation because of no isolated dwelling.

**Fig 11** Histogram of estimated total utility expenses in municipalities that has isolated dwelling.
Percentage of isolated dwelling in 2009 (%)
- 0.0
- 0.0 - 1.0
- 1.0 - 2.5
- 2.5 - 5.0
- > 5.0

Percentage of isolated dwelling in 2014 (%)
- 0.0
- 0.0 - 1.0
- 1.0 - 2.5
- 2.5 - 5.0
- > 5.0
Difference between 2009 and 2014 (%)

-1.0 - 0.0
0.0 - 1.0
1.0 - 2.5
> 2.5

Percentage of isolated dwelling in 2014 [%]

Aging ratio in 2010 [%]

Difference of isolated dwelling rate between 2009 and 2014 [%]
Relocate promotion expenses for each isolated dwelling (JPY)

- 1 mln.
- 2.5 mln.
- 5 mln.
- 10 mln.
- 25 mln.
- 50 mln.
- 100 mln.

Number of municipalities which achieved relocation promotion expenses recovery

Elapsed year since the promotion started (Year)
Year of relocation promotion cost recovery achieve (year)

- 0 (first year)
- 1 - 3
- 3 - 5
- 5 - 10
- > 10

*relocation promotion cost = 10 mln. JPY