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# Method to Evaluate the Location of Aged Care Facilities in Urban Areas Focusing on the Equity in Terms of Users' Accessibility

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**Abstract:** The present study developed and tested a method to evaluate the location of aged care facilities from the viewpoint of whether they are equitably located for users, using the improved Median Share Ratio (MSR). By evaluating the current location of aged care facilities, it is possible to extract the districts which are short of facilities. The evaluation method was applied to Chofu and Kiyose Cities in Tokyo Metropolis, Japan, and the evaluation result of weighting and that of not weighting by elderly population were compared and discussed. Consequently, adopting the evaluation method with weighting by elderly population, it is possible to adequately examine the districts where new aged care facilities should be constructed. From this evidence, it is significant to evaluate the location of aged care facilities, using the improved MSR with weighting by elderly population in the study.

**Key words:** Aged care facility, facility location, MSR, equity, accessibility, geographical information system (GIS).

## 1. Introduction

There are various types of facilities which have respective characteristics and are individually located in suitable areas. For example, commercial establishments such as convenience stores, shopping malls and supermarkets are located in busy areas that are highly populated in order to get more customers and increase profit. In contrast, public facilities such as schools, libraries and medical facilities tend to be located in areas where many people can fairly access them. Instead of being concentrated in particular areas, the above public facilities must be located in the areas where everyone in need can access them in a fair manner.

On the other hand, in recent years, many developed countries around the world have serious problems with the aging society and declining birthrate. In the case of Japan, according to the annual report on the ageing society 2018 [1], in 2017, the total population of Japan was 126.71 million people, and percentage of the population aged 65 or over (percentage of elderly people) was 27.7%. Thus, percentage of elderly people was higher than that of young people aged under 15. Among elderly people, percentages of populations 65-74 and 75 or over were respectively 13.9% and 13.8%. In the future, as the total population decreases, the percentage of elderly people will continue to increase. As population aged 65 or over will reach its peak of 39.35 million in 2042, the percentage of elderly people will increase. In 2015, there were 2.3 persons aged 15-64 (production-age) per person aged 65 or over. However, in 2065, there will be 1.3 persons aged 15-64 per person aged 65 or over.

Furthermore, according to the annual report on the ageing society 2018 [1], the percentage of elderly people in Japan was at a lower rank until the 1980's, at a medium rank in the 1990's, and at the highest rank in 2005. Calculating the ageing rate on the basis of the number of years required for it to double since it has exceeded 7%, in the case of Japan, it exceeded 7% in

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1970, and reached 14% in 1994, 24 years later. However, at that point in time, the growth rate slowed down. Thus, in Japan, population aging is advancing faster than other countries around the world. In recent Japan, national measures for the ageing society are proposed and adopted based on the Basic Act on Measures for the Ageing Society (1995). As one of such measures against population aging, it is essential to progress the construction of aged care facilities corresponding to needs of each area in recent Japan.

Additionally, according to the surveys conducted by the Ministry of Health, Labour and Welfare (MHLW) in Japan [2, 3], in 2016, though the number of aged care facilities and its capacity are increasing, the utilization rate of such facilities remains at the same level and the lack of facilities has not been addressed. The reason for this is that Japan is aging at a pace unparalleled in other countries. Though a financial subsidy is provided by the national and local governments for the construction of aged care facilities, the amount of such a subsidy cannot be greatly increased due to the need for more childcare and medical facilities as well. Accordingly, it is not expected that the number of aged care facilities will greatly increase in the future. Therefore, the construction of new aged care facilities should be prioritized in districts with greater needs. In order to make this possible, first of all, it is necessary to accurately grasp the districts which are short of aged care facilities.

Based on the background mentioned above, using Geographic Information Systems (GIS), an applied statistical method and public open data related to aging population and aged care facility, the present study aims to develop a method to quantitatively evaluate the locations of aged care facilities focusing on the equity in terms of users' accessibility in urban areas within Japan. By evaluating the current location of aged care facilities, it is possible to extract the districts which are short of facilities, and it will assist the policy and decision makers in planning new aged care facilities.

## 2. Related Work

The present study develops and tests a new method to evaluate the location of aged care facilities. Therefore, the present study is related to three study fields, namely: (1) studies related to facility location problem, and (2) studies related to the siting of health care facilities. The following will introduce the major preceding studies in the above two study areas, and demonstrate the originality of the present study in comparison with the others.

In (1) studies related to facility location problem, Voogd [4] developed a multicriteria evaluation (MCE) for urban and regional planning. Based on this, targeting various facilities, there were a lot of studies related to facility location problem using MCE and GIS. In recent years, Sánchez-Lozano et al. [5, 6] and Tahri et al. [7] developed methods for the evaluation of solar farms locations. Szurek et al. [8], Asakereh et al. [9] and Villacreses [10] developed methods to evaluate the suitability of wind farm locations. Uddin et al. [11] and Asborno et al. [12] developed methods to evaluate the locations of transportation facilities. Additionally, for disaster management, Pourghasemi et al. [13], Feizizadeh et al. [14], Günther et al. [15], Ahmed [16], Dragićevića et al. [17], Erener et al. [18] and Nsengiyumva et al. [19] developed methods for landslide susceptibility assessment.

In addition to the above studies, there are some preceding studies adopting *p*-median problem using GIS. For example, Ndiaye et al. [20] and Satoh et al. [21] respectively developed methods to evaluate the locations of schools. Baray et al. [22] and Tsukahara et al. [23] respectively developed methods to evaluate the locations of hospitals and aged care facilities. Dzator et al. [24] and Jánošíková et al. [25] applied *p*-median problem to derive the optimum location of ambulances.

On the other hand, there are some studies related to facility location problem adopting economic methods. Tanaka et al. [26] applied the Quintile Share Ratio (QSR), which is an indicator showing the degree of bias in income, to the facility locational analysis for linear cities which are theoretical line-formed cities. The QSR is an inequity measure of income distribution defined as the ratio of total income received by the 20% of the population with the highest income (top quintile) to that received by the 20% of the population with the lowest income (lowest quintile). Additionally, with the QSR as a reference, Tanaka et al. [27] modified the definition of a well-known inequity measure, the QSR, and newly defined the Median Share Ratio (MSR) as the ratio of the average distance among the top half of the population with longer distance to a facility to that among the bottom half of the population with shorter distance to a facility. Furthermore, Tanaka et al. [27] used the MSR, which is an equity measure, to develop a facility location evaluation model in a linear city with one or two facilities, as well as a uniformly distributed population. Furuta et al. [28] used a method that generalized the QSR and pro-posed a solution to optimize multiple facility locations in cases where the demand and candidate facility locations are discrete. Referring these theatrical studies, Tuskahara et al. [29] developed a concrete method to evaluate the location of aged care facilities in real cities using MSR.

In (2) studies related to the siting of health care facilities, Kondo et al. [30] developed a planning model for medical facilities in addition to road network considering accessibility and connectivity in large cities. Gu et al. [31] identified optimal locations for preventive health care facilities so as to maximize participation. Shariff et al. [32] used maximal covering location problem (MCLP) to determine good locations for the health care facility so that the population coverage is maximized. Crecente et al. [33] proposed a methodology for the location of thalassotherapy resorts to promote sustainable tourism. Beheshtifar et al. [34] applied a multi-objective model that combined GIS analysis with a multi-objective genetic algorism (GA) to determine the optimal number and locations of new health care facilities. Zhang et al. [35] examined the problem of where health care facilities should be located to raise the total accessibility for the entire population in highly developed cities, using a multi-objective GA. Oppio et al. [36] proposed an evaluation system to be applied for the site selection of new hospitals. Segall et al. [37] applied data envelopment analysis (DEA) to select the candidate town for location of a health care facility.

Regarding studies related to (1), there are a lot of preceding studies using MCE to evaluate the locations of various facilities, and Tsukahara et al. [23, 29] just targeted aged care facility. Additionally, though Tanaka et al. [26] and Furuta et al. [28] focused on the equity to propose the evaluation method for facility location, it has been applied to theoretical city modelling exercises and not to any real cities. In the above studies, equity was an indicator to show the degree of the accessibility to facilities for users. Additionally, regarding studies related to (2), though most of the studies target medical facilities, there are very few preceding studies related to aged care facilities.

Therefore, with the results of the preceding studies mentioned above as a reference, the present study will demonstrate the originality and significance by considering the lack of aged care facilities, which has become a serious social issue as mentioned in the previous section, and developing a new method to quantitatively evaluate current location of aged care facilities focusing on the equity in terms of the accessibility to facilities for users in a real city. Additionally, based on the evaluation results, the present study will extract the districts which are short of facilities and propose the places where new facilities should be constructed.

## 3. Evaluation Method

### *3.1 Previous Method*

In order to develop a new method to evaluate the location of aged care facilities in a real city, and focus on the equity which is an indicator to show the degree of the accessibility to facilities for users, the present study improves the MSR. Figs. 1 and 2 respectively show the examples of a linear city and a real city. According to Tanaka et al. [26, 27], the MSR in the case where one facility exists in a linear city as shown in Fig. 1 is derived by the following procedures:

(i) Deduce the cumulative distribution function $F_X(x)$ of the distance *X* to the facility;

(ii) Specify the median $m$ of the distance *X* at which $F_X(m) = 0.5$;

(iii) Find the probability density function $f_X(x)$ of the distance *X* to the facility;

(iv) Calculate the mean value $v_H$ of the interval where the distance is longer than the median $m$, and the mean value $v_L$ of the interval where the distance is shorter than the median $m$;

(v) The MSR can be calculated by dividing $v_H$ by $v_L$.

The cumulative distribution function $F_X(x)$ and the probability density function $f_X(x)$ have a relationship expressed by Eq. (1). The MSR can be calculated using probability density function $f_X(x)$ as shown in Eq. (2). From Eq. (2), it can be judged that facilities are fairly located as the MSR value is lower. Incidentally, the constant $l$ in Eq. (2) is the distance from the facility to the furthest district.

$$f_X(x) = \frac{d}{dx} F_X(x) \quad (1)$$

$$\mathrm{MSR} = \frac{v_H}{v_L} = \frac{\int_m^l x f_X(x) dx}{\int_0^m x f_X(x) dx} \quad (2)$$

*3.2 Developed Method*

As Tsukahara et al. [29] described, there are some differences between a linear city and a real city, comparing Figs. 1 and 2. Therefore, it is necessary to improve the MSR to be suitable for a real city in the present study. At first, distance *X* must be considered as area. In a linear city, as shown in Fig. 1, the distance was treated as a line segment. However, in a real city, as shown in Fig. 2, since the aggregate of line segments is a distance, the distance *X* can be regarded as the area *S*(*x*) with a radius of distance *x*. Therefore, $F_X(x)$ and $f_X(x)$ are respectively expressed by Eqs. (3) and (4).

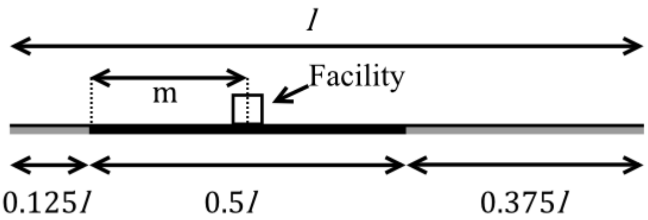



**Fig. 1 Example of a linear city.**

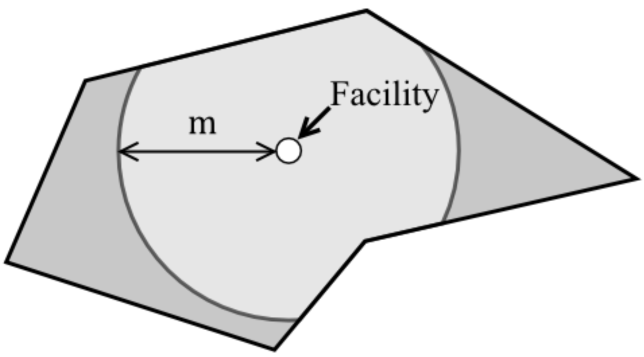



**Fig. 2 Example of a real city.**

$$F_X(x) = \frac{\int_0^x S(t)dt}{\int_0^l S(s)ds} \tag{3}$$

$$f_X(x) = \frac{S(x)}{\int_0^l S(s)ds} \tag{4}$$

Second, the number of facilities increases from 1 to $n$. In this case, the area $S(x)$ is the sum of the areas which are away from each facility by distance $x$. Assuming that the user uses the nearest facility, Voronoi tessellation is performed with each facility as a kernel point, and the sum of area of each Voronoi polygon is the area $S(x)$ (Eq. (5)).

$$S(x) = S_1(x) + \cdots + S_n(x) \tag{5}$$

Finally, it is necessary to reflect the deviation of the distance from the facility by the population in Voronoi domain. When weighting by the population, the product of the number of users $p_i(x)$ and the distance $x$ from the facility is the area of the Voronoi polygon $i$ $S_i(x)$ (Eq. (6)).

$$S_i(x) = p_i(x)x \tag{6}$$

In Section 5, the evaluation results in the cases of weighting and not weighting by the population will be compared. Based on the comparison result, in Section 6, the validity of the evaluation method using the improved MSR with weighting by the population will be verified.

The present study used ArcGIS Pro Ver. 2.0 provided by the Environmental Systems Research Institute, Inc. (ESRI) as GIS. Utilizing specific functions of this GIS, the following sections will process the data related to aging population and aged care facility in the digital map format, evaluate the location of aged care facilities, and visualize the evaluation results on the digital maps.

### *3.3 Application of Developed Method*

As the situations are different in every region, it is impossible to compare the equity of the facility locations among multiple regions using the previous MSR which was introduced in Section 3.1. Because area, population and number of facilities are different in every region, and these differences have an enormous influence on the evaluation results. Therefore, in order to eliminate these influences and compare the equity of the facility locations using the MSR values among multiple regions, the present study proposes to adopt the ratio of the evaluation results of current and reference locations focusing on the MSR value.

The former is the present location, and the latter is the location with the best MSR value (the lowest MSR value) and the best equity for users in the region. The area, population and number of facilities of the latter are same with the former, and there is the difference of the facility locations between these two locations. Therefore, based on the reference location, it is possible to evaluate the current location from the viewpoint of whether the facilities are equitably located for users. Additionally, as only the locations are different, it is also possible to compare the equity of the facility locations among multiple regions, ignoring the influences caused by the differences of area, population and number of facilities.

A reference location is determined to have the best MSR value, based on the simulation results in which the same number of facilities as the current location is randomly placed in the center of each district in the evaluation target area. The 5,000 times of simulations are conducted just in the case of not weighting by the population. Referring the preceding studies related to facility location problem, the number of simulations is generally 1,000-5,000 times. The same reference location is also adopted in the case of weighting by the population.

## 4. Selection of Evaluation Targets and Data Processing

### *4.1 Selection of Evaluation Target Age Group*

According to the annual report on the ageing society

2018 [1], life expectancy at birth is 80.98 years old for men and 87.14 years old for women in 2016. By 2065, it will be 84.95 years old for men and 91.35 years old for women, exceeding 90 years for women. Additionally, according to Hashimoto [38], Japan boasts the highest healthy life expectancy in the world with 71.19 years old for men and 74.21 years old for women, suggesting that people in Japan remain active for a relatively long period. In consideration of these circumstances, in present Japan, elderly people aged 75 or over are called as "the latter-stage elderly people" according to the regulations in social welfare services. Therefore, as elderly people aged 75 or over have a high possibility to become the users of aged care facilities, the present study targets this age group.

### *4.2 Selection of Evaluation Target Area*

For the evaluation target area in the present study, Chofu and Kiyose Cities in Tokyo Metropolis, Japan are selected. The two cities are located in the suburban area of Tokyo Metropolis as shown in Fig. 3. According to the survey on the aging population in Chofu City [39], in Chofu City, the aging population (age 65 or over) has already exceeded the youth population (under age 15), and the former population is expected to increase in the future. Equivalent to 10% of the total population, 23,545 people, fit in the current age range of the present study subject which is 75 and over. The tendency is similar with the one of the whole Tokyo Metropolis. Additionally, according to the Population Vision of Kiyose City [40], the tendency of aging population in Kiyose City is almost similar with the one of Chofu City. However, the population and rate of the latter-stage elderly people are 10,719 people and 14%, and the population aging advances above the average of Tokyo Metropolis.

In the present study, evaluation will be conducted in the unit of 105 and 43 districts within Chofu and Kiyose Cities. The present study targets 36 and 21 aged care facilities at which elderly people in need usually stay in Chofu and Kiyose Cities, and excludes the ones in neighboring other cities. According to Japanese regulations in social welfare services, it is necessary for elderly people to enter the aged care facilities in the cities where they live.

### *4.3 Data Processing*

4.3.1 Data Processing

The utilized data and the utilization method of the data in the present study are shown in Table 1.

4.3.2 Distribution Maps of Aging Population and Aged Care Facilities

Figs. 4 and 5 show the distributions of the elderly population over 75 years old in Chofu and Kiyose Cities. Figs. 6 and 7 show the distributions of aged care facilities in the two cities and the Euclidean distance between the center of district and the nearest aged care in the case of current location. As shown in Fig. 4, in Chofu City, the southern and eastern parts have high aging populations and there are old housing complexes in most of these areas. Additionally, as shown in Fig. 5, in Kiyose City, the southwestern part has high aging

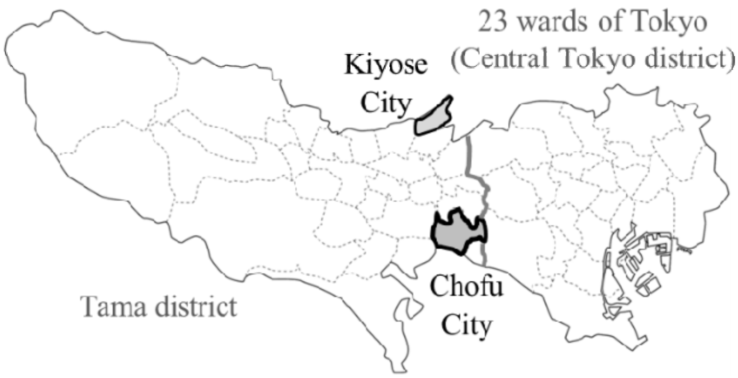



**Fig. 3 Locations of Chofu and Kiyose Cities in Tokyo Metropolis.**

**Table 1 List of utilized data.**

| Utilized data | Utilization method of data |
|---|---|
| Population by age<br>(National Census 2010 by the Statistics Bureau) | Creation of the distribution map of the aging population in the unit of districts |
| Local care resources<br>(Regional figures—Chofu City, Tokyo Metropolis by the Japan Medical Association) | Creation of the distribution map of aged care facilities |

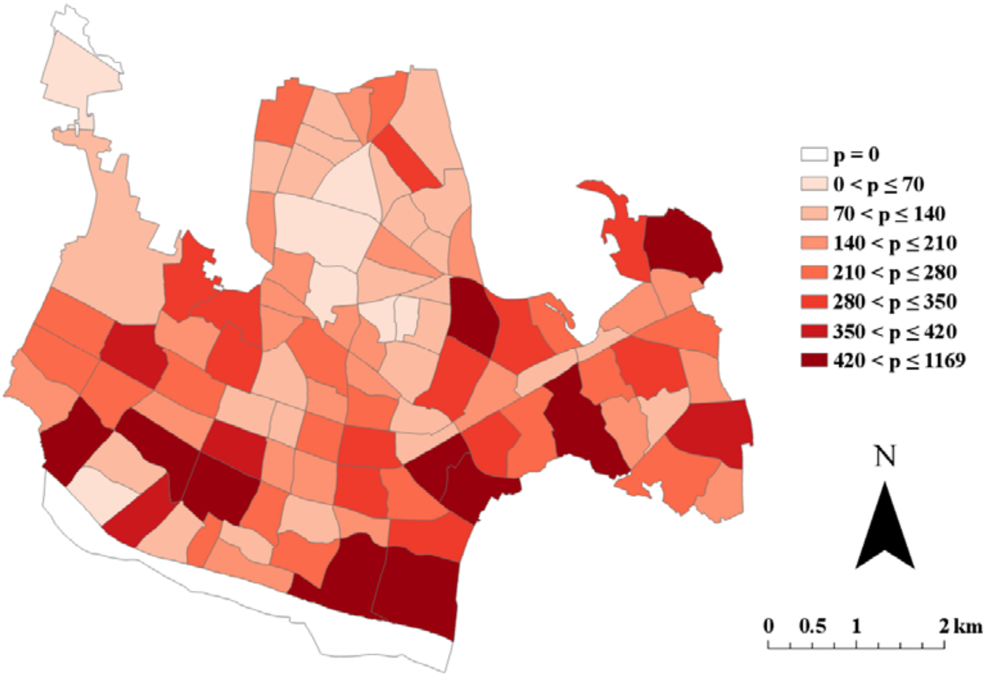



**Fig. 4 Distribution of the elderly population over 75 years old (Chofu City).**

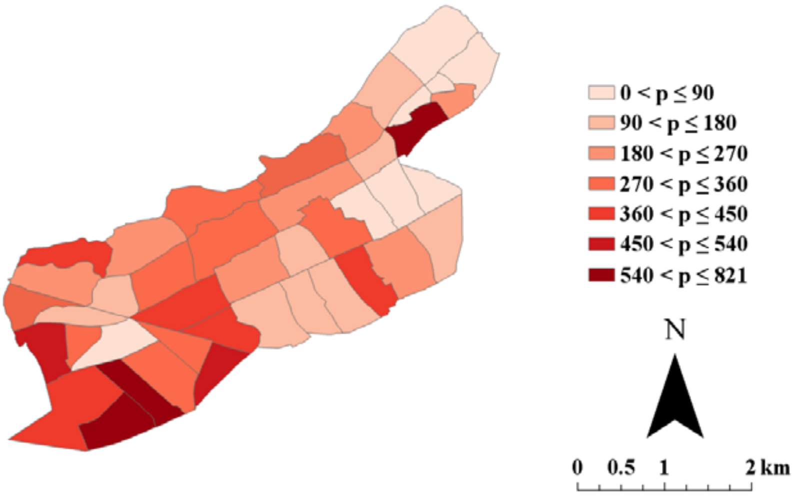



**Fig. 5 Distribution of the elderly population over 75 years old (Kiyose City).**

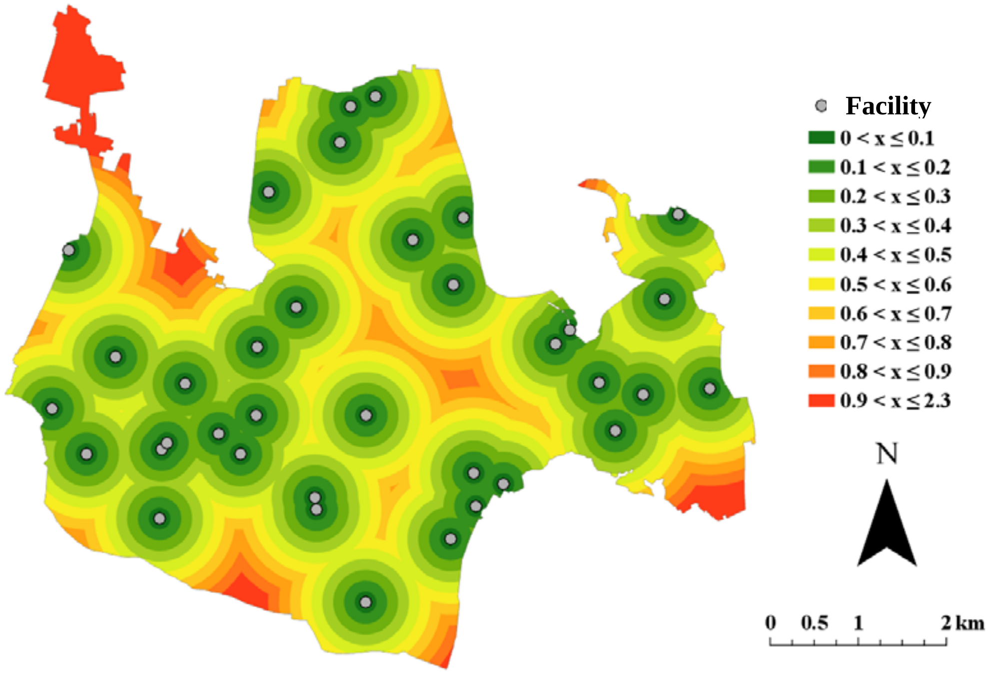



**Fig. 6 Distribution of aged care facilities and distance between the center of district and the nearest aged care facilities (km) in the case of current location (Chofu City).**

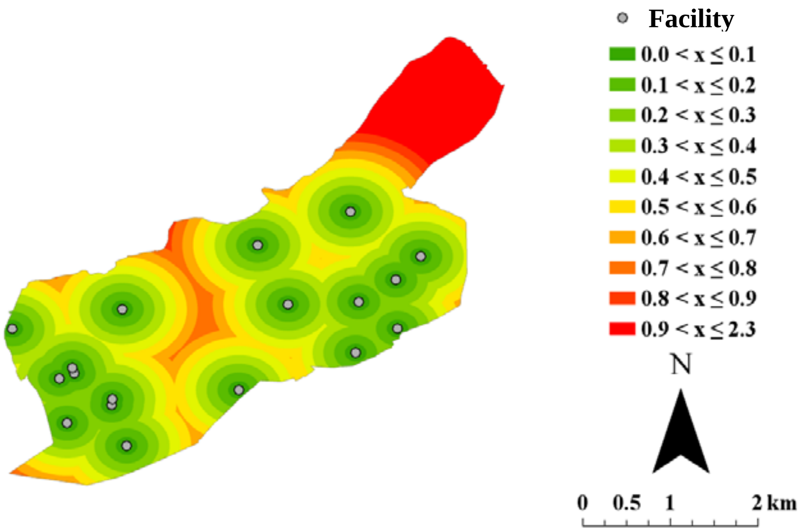



**Fig. 7 Distribution of aged care facilities and distance between the center of district and the nearest aged care facilities (km) in the case of current location (Kiyose City).**

population and there are old housing complexes in this area. As indicated in Fig. 6, in Chofu City, aged care facilities are distributed throughout the entire city excluding the central part. Additionally, as shown in Fig. 7, in Kiyose City, there are no aged care facilities in the northeastern part. Furthermore, in response to the evaluation method in the present study in Section 3.2, Euclidean distance is adopted for buffer analysis in Figs. 6 and 7.

## 5. Evaluation

### *5.1 Evaluation in Chofu City*

This section will introduce the evaluation results without and with weighting by the elderly population over 75 years old in Chofu City, using Eqs. (5) and (6) in Section 3.2.

5.1.1 Evaluation for the Case of Not Weighting by Elderly Population

Fig. 8 describes the graphs of the cumulative distribution function $F_X(x)$ and the probability density function $f_X(x)$ in the case of not weighting by elderly population. Table 2 shows the results of calculating the median $m$, the mean value $v_H$, the mean value $v_L$ and the MSR value of current and reference locations by using the data in Fig. 8. As is clear from Table 2, all values of reference location are lower than those of current location.

5.1.2 Evaluation for the Case of Weighting by Elderly Population

Fig. 9 describes the graphs of the cumulative distribution function $F_X(x)$ and the probability density function $f_X(x)$ in the case of weighting by elderly population. Table 3 shows the results of calculating the median $m$, the mean value $v_H$, the mean value $v_L$ and the MSR value of current and reference locations by using the data in Fig. 9. As is clear from Table 3, all

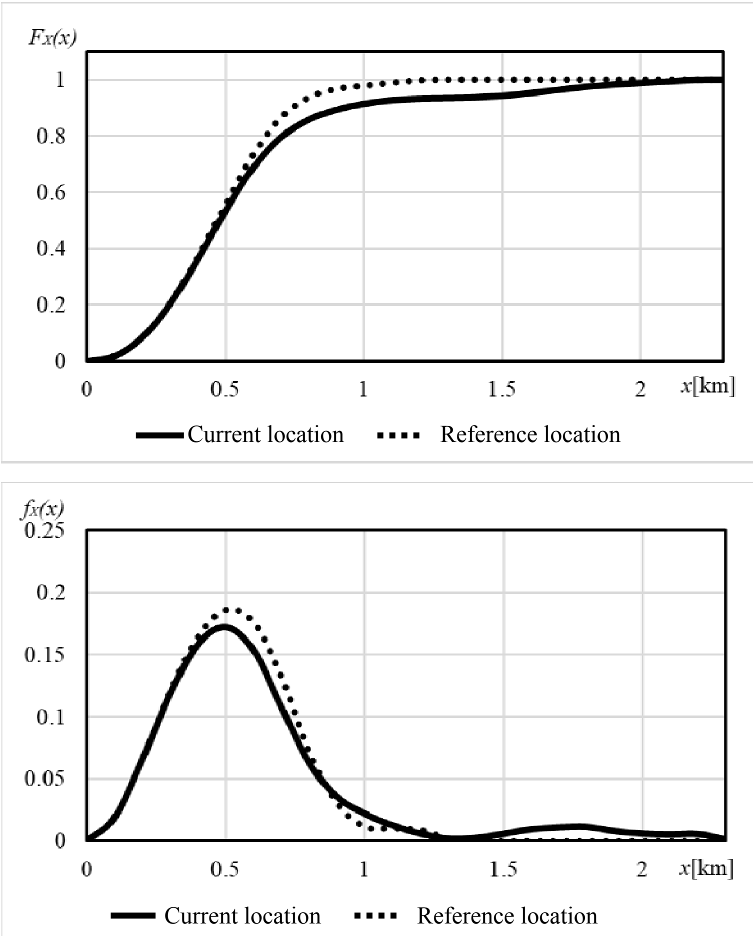



**Fig. 8 Cumulative distribution function $F_X(x)$ and probability density function $f_X(x)$ without weighting by elderly population (Chofu City).**

**Table 2 Evaluation result of the MSR without weighting by elderly population (Chofu City).**

| | MSR | $m$ (km) | $v_H$ | $v_L$ |
|---|---|---|---|---|
| Current location | 2.30765 | 0.37581 | 0.30257 | 0.13112 |
| Reference location | 1.75077 | 0.41032 | 0.25144 | 0.14362 |
| Current location/reference location | 1.31808 | 0.91589 | 1.20335 | 0.91296 |

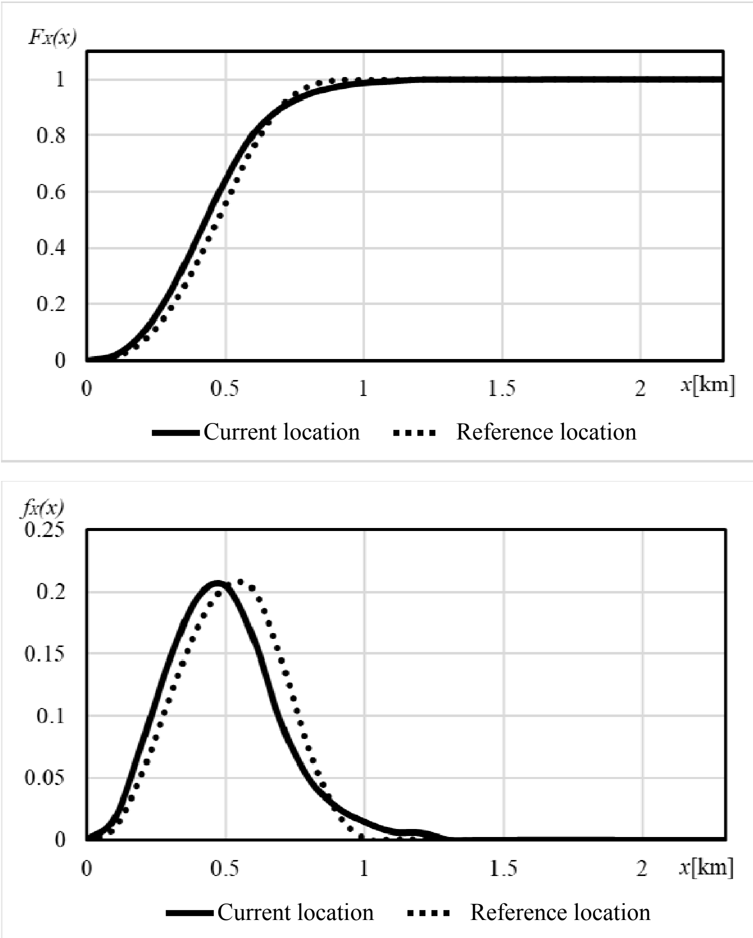



**Fig. 9 Cumulative distribution function $F_X(x)$ and probability density function $f_X(x)$ with weighting by elderly population (Chofu City).**

**Table 3 Evaluation result of the MSR with weighting by elderly population (Chofu City).**

| | MSR | $m$ (km) | $v_H$ | $v_L$ |
|---|---|---|---|---|
| Current location | 2.35143 | 0.42796 | 0.33063 | 0.14061 |
| Reference location | 1.83212 | 0.47205 | 0.30556 | 0.16678 |
| Current location/reference location | 1.28345 | 0.90661 | 1.08205 | 0.84308 |

values of reference location are lower than those of current location. Comparing Tables 2 and 3, all values in the case of weighting by elderly population are lower than those in the case of not weighting by elderly population introduced in the previous section.

## *5.2 Evaluation in Kiyose City*

In the same way with the previous section, this section will introduce the evaluation results without and with weighting by the elderly population over 75 years old in Kiyose City, using Eqs. (5) and (6) in Section 3.2.

### 5.2.1 Evaluation for the Case of Not Weighting by Elderly Population

Fig. 10 describes the graphs of the cumulative distribution function $F_X(x)$ and the probability density function $f_X(x)$ in the case of not weighting by elderly population. Table 4 shows the results of calculating the median $m$, the mean value $v_H$, the mean value $v_L$ and the MSR value of current and reference locations by using the data in Fig. 10. As is clear from Table 4, except for the mean value $v_L$, the values of reference location are lower than those of current location.

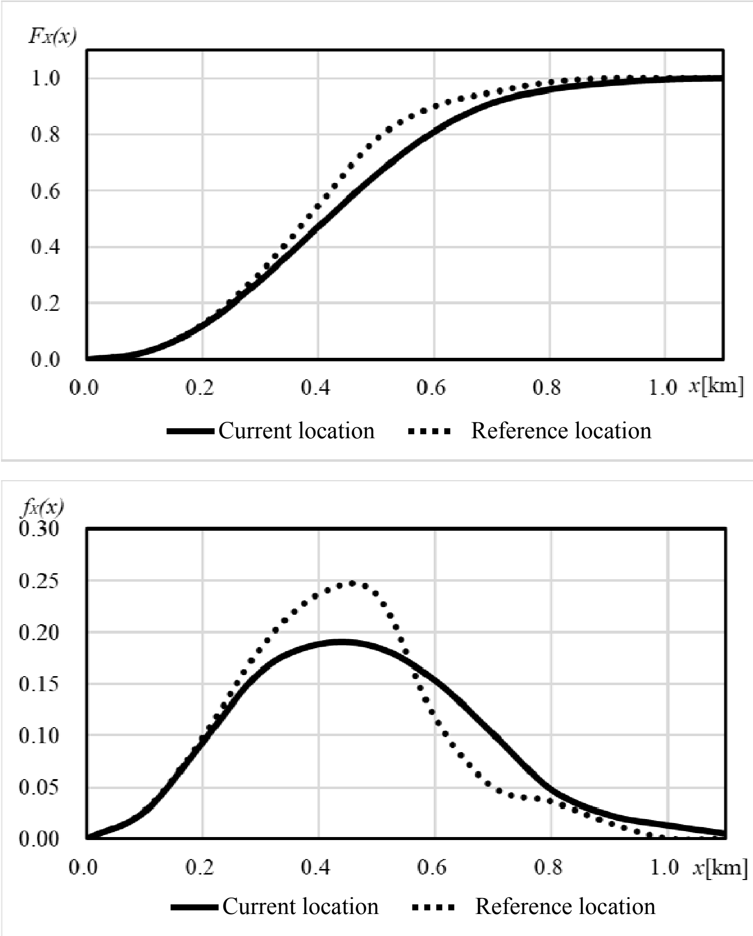


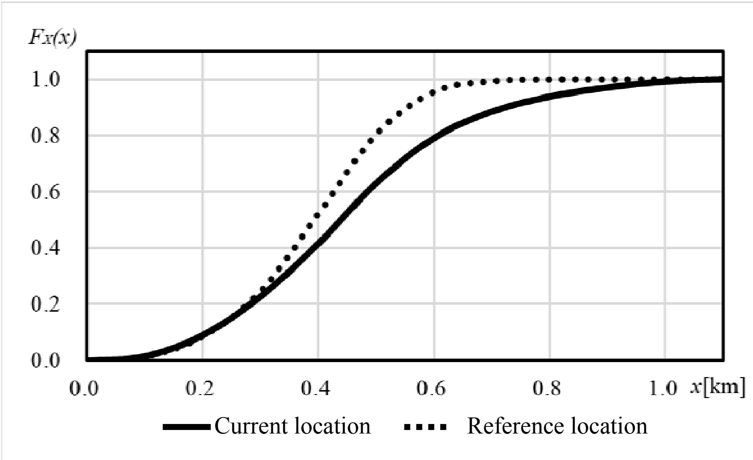

**Fig. 10 Cumulative distribution function $F_X(x)$ and probability density function $f_X(x)$ without weighting by elderly population (Kiyose City).**

**Table 4 Evaluation result of the MSR without weighting by elderly population (Kiyose City).**

| | MSR | $m$ (km) | $v_H$ | $v_L$ |
|---|---|---|---|---|
| Current location | 2.17582 | 0.41448 | 0.28548 | 0.13121 |
| Reference location | 1.85870 | 0.37852 | 0.25813 | 0.13888 |
| Current location/reference location | 1.17061 | 1.09500 | 1.10595 | 0.94477 |

5.2.2 Evaluation for the Case of Weighting by Elderly Population

Fig. 11 describes the graphs of the cumulative distribution function $F_X(x)$ and the probability density function $f_X(x)$ in the case of weighting by elderly population. Table 5 shows the results of calculating the median $m$, the mean value $v_H$, the mean value $v_L$ and the MSR value of current and reference locations by using the data in Fig. 11. As is clear from Table 5, except for the mean value $v_L$, the values of reference location are lower than those of current location. Comparing Tables 4 and 5, all the ratios of the evaluation results of current and reference locations in the case of weighting by elderly population are higher than those in the case of not weighting by elderly population introduced in the previous section. The MSR values of both locations and $v_H$ of reference locations are higher in the former case rather than the latter case.



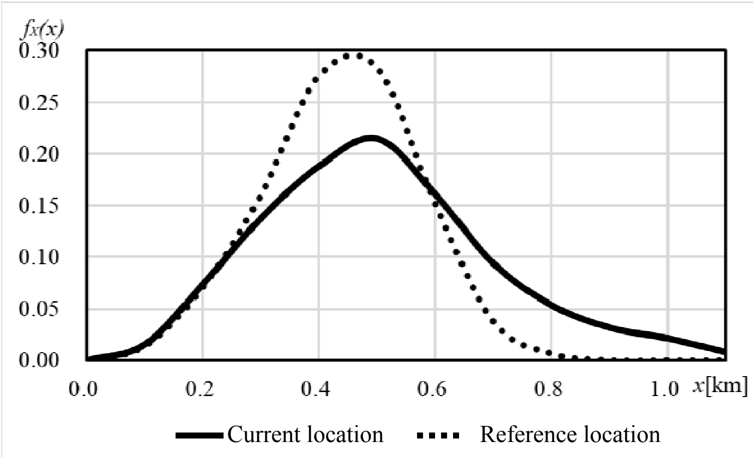




**Fig. 11 Cumulative distribution function $F_X(x)$ and probability density function $f_X(x)$ with weighting by elderly population (Kiyose City).**

**Table 5 Evaluation result of the MSR with weighting by elderly population (Kiyose City).**

| | MSR | $m$ (km) | $v_H$ | $v_L$ |
|---|---|---|---|---|
| Current location | 2.00136 | 0.43784 | 0.30428 | 0.15203 |
| Reference location | 1.54397 | 0.39168 | 0.24558 | 0.15906 |
| Current location/reference location | 1.29624 | 1.11785 | 1.23902 | 0.95586 |

### *5.3 Proposal of the Suitable Districts for New Aged Care Facilities Based on the Evaluation Results*

Based on the evaluation result for the case of weighting by elderly population described in Section 5.1.2, the districts for planning new aged care facilities will be extracted in Chofu City. Fig. 12 shows the MSR values in the unit of districts in Chofu City. As clearly shown in Fig. 12, it is possible to propose the suitable districts for new aged care facilities in the northwestern and southeastern parts whose MSR values are very high.

In the same way with Chofu City, based on the evaluation result described in Section 5.2.2, the districts for planning new aged care facilities will be extracted in Kiyose City. Fig. 13 shows the MSR values in the unit of districts in Kiyose City. As clearly shown in Fig. 13, it is possible to propose the suitable districts for new aged care facilities in the northeastern part whose MSR value is very high.

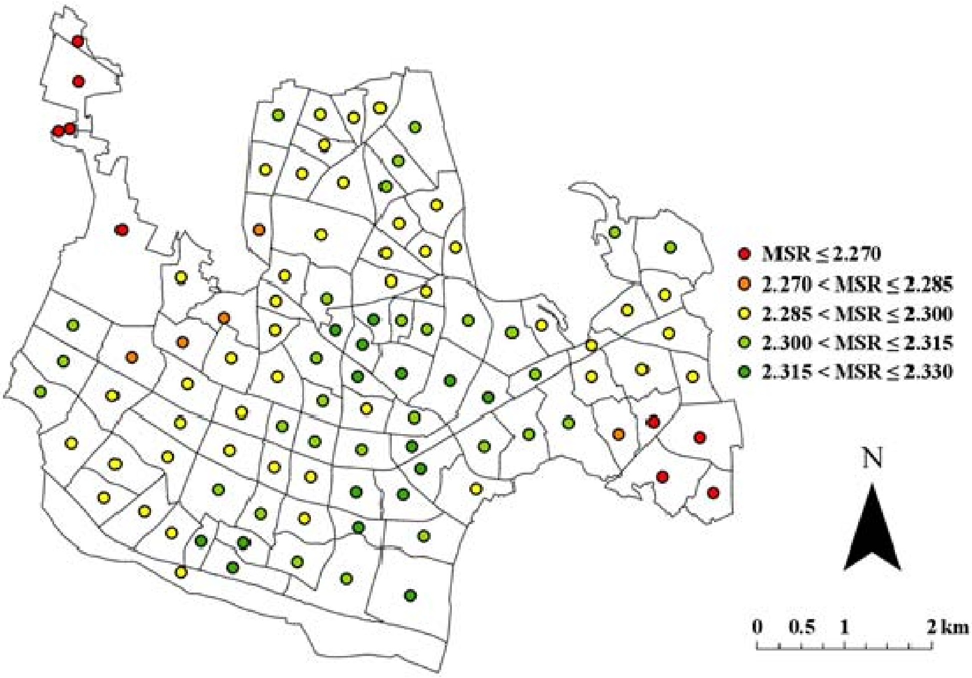



**Fig. 12 MSR values in the unit of districts (Chofu City).**

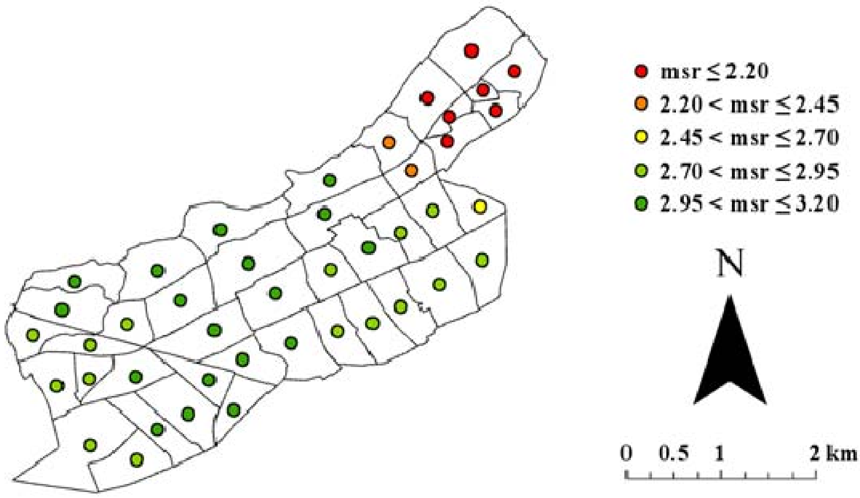



**Fig. 13 MSR values in the unit of districts (Kiyose City).**

## 6. Discussion

In this section, the evaluation results in the previous section will be compared and discussed, and the validity of the evaluation method using the improved MSR with weighting by elderly population will be verified.

*6.1 Chofu City*

First, based on Tables 2 and 3, the evaluation result of weighting and that of not weighting by the elderly population over 75 years old are compared. It is clear that all values are lower and the mean value $v_H$ of current location is tremendously lower in the latter case than the former case. From these, all of the ratios of the evaluation results of current and reference locations are also lower in the latter case than the former case. The reason for this is that there is the peak of probability density function $f_X(x)$ at the distance of 1.5-2.0 km which can not be seen in the former case. Comparing Figs. 4 and 6, in the northwestern and southeastern parts, there are the districts which are 1.5-2.0 km away from the nearest facilities and have very few elderly populations over 75 years old. Additionally, at the distance of 0.5 km, the values of probability density function $f_X(x)$ are the highest. Comparing Figs. 8 and 9, the value is remarkably higher in the former case than the latter case. In the northwestern and southwestern parts, there are the districts which are 0.5 km away from the nearest facilities and have many elderly populations over 75 years old.

Consequently, comparing the evaluation result of weighting and that of not weighting by elderly population, it is evident that the evaluation method using the improved MSR with weighting by the elderly population over 75 years old appropriately reflected the influence of the distribution of such an elderly population. Therefore, based on the result in Section 5.3, in order to pull down the ratio of the MSR value of current and reference locations, it is necessary to examine the construction of new aged care facilities in the northwestern and southeastern parts whose MSR values are very high.

### 6.2 Kiyose City

In the same way with Chofu City, based on Tables 4 and 5, the evaluation result of weighting and that of not weighting by the elderly population over 75 years old are compared. It is clear that the median $m$, the mean value $v_H$, and the mean value $v_L$, of current location are higher in the latter case than the former case.

Additionally, comparing Figs. 10 and 11, there is not a large difference of waveforms between probability density functions $f_X(x)$ of current location in the cases of weighting and not weighting by the elderly population over 75 years old. However, some small differences of waveform between the probability density functions $f_X(x)$ of current location in the above two cases can be seen at the distances of 0.3 km, 0.5 km and 0.8-1.0 km.

Comparing Figs. 5 and 7, regarding the distance of 0.3 km, in the northeastern and southwestern parts, there are the districts which are 0.3 km away from the nearest facilities and have very few elderly populations over 75 years old. This contributes to the low value of the probability density functions $f_X(x)$ at the distances of 0.3 km in the case of weighting by elderly population. Regarding the distance of 0.5 km, in the central and southwestern parts, there are the districts which are 0.5 km away from the nearest facilities and have few elderly populations over 75 years old. Regarding the distance of 0.8-1.0 km, in the northeastern part, there are the districts which are 0.8-1.0 km away from the nearest facilities and have many elderly populations over 75 years old. As a result, in the case of weighting by elderly population, the values of the probability density functions $f_X(x)$ are high at the distance of 0.8-1.0 km, and it causes the high mean value $v_H$.

Consequently, as well as Chofu City, comparing the evaluation result of weighting and that of not weighting by elderly population, it is evident that the evaluation method using the improved MSR with weighting by the elderly population over 75 years old appropriately reflected the influence of the distribution of such an elderly population. Therefore, in order to pull down the ratio of the MSR value of current and reference locations, it is necessary to examine the construction of new aged care facilities in the northeastern part whose MSR value is very high.

### 6.3 Limitations of the Developed Method

Referring to Tables 2-5, in Chofu and Kiyose Cities, the MSR values of reference location are lower than those of current location in both cases of weighting and not weighting by the elderly population over 75 years old. From this, it is evident that the reference location is reasonable in these two cases assumed in the evaluation method of the present study. In the case of reference location, though the MSR value is weighted by elderly population, a few of the aged care facilities are located in districts where elderly people over 75 years old do not live. Additionally, though the parallel distributed processing was conducted using plural high-efficiency computers, it takes a huge amount of calculation time to detect the location with the best MSR value. Therefore, it is necessary to devise and improve the method to determine a reference location.

Thus, the present study evaluated the location of aged care facilities, by applying the improved MSR to Chofu and Kiyose Cities, and using the public open data related to elderly population over 75 years old and aged care facility, and the evaluation method has high spatial reproducibility. Moreover, the evaluation method is based on the above public open data and public information as described in Section 4. Therefore, by obtaining population data and geospatial data similar to those of the present study, the evaluation method can also be applied to other areas in the past and future. Accordingly, it can be said that the evaluation method has high time reproducibility as well as spatial reproducibility.

However, though it is desirable to consider the capacity of existing and planned aged care facilities in the evaluation method developed in the present study, such data are not accessible to the public in the present Japan. If the data related to the capacity of existing aged care facilities are obtained, it is possible to raise the accuracy of the evaluation method in the present study.

## 7. Conclusion

The present study developed and tested a method to evaluate the location of aged care facilities from the viewpoint of whether they are equitably located for users. In order to improve the MSR, which has been applied only to a linear city in the preceding studies, to apply it to a real city, the present study changed a distance to an appropriate shape, targeted multiple facilities, and reflected the deviation of the distance from the facility by the population. Moreover, as the ratio of the evaluation results of current and reference locations focusing on the MSR value can be calculated, it made possible to compare the equity of the facility locations among multiple regions.

As a model case of evaluation in the present study, the improved MSR with and without weighting by the elder population over 75 years old is applied to Chofu and Kiyose Cities in Tokyo Metropolis, Japan. Based on the evaluation results, it is possible to adequately examine the districts where new aged care facilities should be constructed in the case of weighting by elderly population. From this evidence, it is significant to weight the distance by elderly population to evaluate the location of aged care facilities using the improved MSR in the present study. As the evaluation method is based on public open data and public information, by obtaining population data and geospatial data similar to those of the present study, evaluations can be conducted in other areas as well as for the past and future. Therefore, the evaluation method in the present study has a high temporal reproducibility as well as spatial reproducibility.

The future research issue is to raise the accuracy of the evaluation method in the present study, and reduce the amount of calculation time to detect the reference location with the best MSR value, as mentioned in Section 6.3. For these, it is necessary to devise and improve the method to determine a reference location in case of weighting by elderly population, and ameliorate the method of parallel distributed processing. After that, it is essential to apply the improved evaluation method to other areas to verify the validity.

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