Regional assessment of medical care provision system by principal component analysis

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Abstract

Introduction: The Japanese government has promoted policies ensuring standardized medical care across the secondary medical care areas (SMCAs); however, these efforts have not been evaluated, making the current conditions unclear. Multidimensional indicators could identify these differences; thus, this study examined the regional characteristics of the medical care provision system for 21 SMCAs in Hokkaido, Japan, and the changes from 1998 to 2018. **Materials and Methods**: This study evaluated the characteristics of SMCAs by principal component analysis using multidimensional data related to the medical care provision system. Factor loadings and principal component scores were calculated, with the characteristics of each SMCA visually expressed using scatter plots. Additionally, data from 1998 to 2018 were analyzed to clarify the changes in SMCAs' characteristics. **Results:** The primary and secondary principal components were *Medical Resources* and *Geographical Factors*, respectively. The *Medical Resources* components included the number of hospitals, clinics, and doctors, and an area's population of older adults, accounting for 65.28% of the total variance. The *Geographical Factors* components included the number of districts without doctors and the population and a land area of these districts, accounting for 23.20% of the variance. The accumulated proportion of variance was 88.47%. From 1998 to 2018, the area with the highest increase in *Medical Resources* was Sapporo, with numerous initial medical resources (−9.283 to −10.919). **Discussion:** Principal component analysis summarized multidimensional indicators and evaluated SMCAs in this regional assessment. This study categorized SMCAs into four quadrants based on *Medical Resources* and *Geographical Factors*. Additionally, the difference in principal component scores between 1998 and 2018 emphasized the expanding gap in the medical care provision system among the 21 SMCAs.

Keywords: Medical care provision system, principal component analysis, regional characteristics

Introduction

Hokkaido, Japan's northernmost prefecture, has an expansive landmass, with its population being primarily concentrated in cities and their surroundings. As a result, there tends to be a higher concentration of medical institutions and doctors in the prefecture's urban areas.[1,2] For this reason, there are fewer medical institutions and doctors in unpopulated areas, making it difficult for residents in these areas to access medical care. To ensure the provision of medical care throughout all prefectures, Japan's Ministry of Health, Labour and Welfare (MHLW) has implemented a "medical care plan."[2] This plan was formulated based on the fundamental policy goal of providing access to care for all, and it was designed to reflect the unique conditions of each prefecture. Specifically, this medical care plan includes moving a targeted number of beds from areas with excess beds to areas where they are needed more, which is a corrective measure

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aimed at resolving the maldistribution of hospitals and beds. In that plan, secondary medical care areas (SMCAs; administrative areas encompassing several municipalities) are defined as zones working toward comprehensive access to hospitalization medical services. More specifically, these units are responsible for the corrective deployment of medical resources to individual areas.[2]

Hokkaido prefecture established a plan to develop a robust medical service system that considers the region's distinctive geographical and climate characteristics, including its expansive area, heavy snowfall, cold temperatures, expected population decline, and aging population trends.[2] The essential processes for establishing this plan include clarifying the medical resource insufficiencies in each area and identifying the necessary measures for tackling these insufficiencies. Several studies have considered single indicators, such as the number of doctors per 100,000 people[3,4] to evaluate disparities in medical care resources resulting from an uneven distribution, whereas others have combined multidimensional cross-sectional data.[5] The latter approach was adopted in this study, and the changes in the SMCA characteristics were analyzed using multidimensional indices at two time points.

A principal component analysis (PCA) simplifies the information contained within multidimensional data into low-dimensional data, with any damage to the information being limited to the greatest possible extent. By contracting multidimensional data into two- or three-dimensional data, the overall features of the dataset can be converted into a visual format that allows for simple interpretation. Nimura and Koike[6] used a PCA to extract two main components from multidimensional data related to emergency care activities and medical systems on a prefectural scale; these included "urban conditions" and "reasons for medical treatment conditions in local areas." The researchers then added the characteristics of each prefecture to a scatter plot, which they used to discuss the possibility of implementing an air ambulance system for emergency care activities. In this study, a PCA was used to better understand the current characteristics and changes over time in each SMCA in Hokkaido using various indicators related to medical services. The findings could contribute to developing a highly equitable medical care provision system. Therefore, this study aimed to clarify and visualize both the regional characteristics of Hokkaido's SMCAs and their changes from 1998 to 2018.

Materials and Methods

Study design

This was a retrospective longitudinal study using public data from the MHLW. In the study, PCA was used to evaluate the current characteristics of each SMCA and determine how the SMCAs changed over 20 years.

Study area and data

This study examined 21 SMCAs in Hokkaido. The included medical areas were Minami-Oshima, Minami-Hiyama, Kita-Oshimahiyama, Sapporo, Shiribeshi, Minami-Sorachi, Naka-Sorachi, Kita-Sorachi, Nishi-Iburi, Higashi-Iburi, Hidaka, Kamikawa-Chubu, Kamikawa-Hokubu, Furano, Rumoi, Soya, Hokumo, Enmon, Tokachi, Kushiro, and Nemuro [Figure S1]. The analysis compared 1998 and 2018 data. The first set included the number of hospitals (1998),[7] the number of clinics (1998),[7] the number of hospital beds (1998),[7] the number of physicians (1998),[8] the number of doctors at each medical institution (1998),[8] overall population (1995),[9] older adult population (1995),[9] and land area (2015).[10] The 2018 data included the number of hospitals (2018),[11] the number of clinics (2018),[11] the number of hospital beds (2018),[11] the number of physicians (2018),[12] the number of doctors at each medical institution (2018),[12] overall population (2015),[10] older adult population (2015),[10] land area (2015),[10] the number of districts with no doctor (2014),[13] populations of these no-doctor districts (2014),[13] and the number of emergencies and critical care centers (2018).[14] As the standardization was conducted based on the assumption of a normal distribution of variables, the population, older adult population, and land area were analyzed using a logarithm.

Methods

A correlation matrix was used to perform the PCA on the 11 items collected from the 2018 data to identify the current characteristics of the SMCAs. Next, the proportion of variance (i.e., the accumulated proportion of variance), factor loading, and principal component scores were calculated. The principal components were labeled according to the factor loadings. The principal components score for each medical area was then visualized using a scatter plot to clarify their individual characteristics. In addition, to analyze the changes that occurred over the study period, the number of districts with no doctor, the population of the no-doctor districts, and the number of emergencies and critical care centers were excluded. The eight remaining 2018 data items were adjusted to match the 1998 dataset. A dummy variable was used to estimate the fixed effects for each year, with the 1998 data being 0 and the 2018 data 1 because the changes from 1998 to 2018 could not be assumed as having a linear relationship. A second PCA was then conducted. The principal component scores of both the 1998 and 2018 datasets were calculated and compared visually using two scatter plots. Finally, the changes that occurred over time in each medical area were analyzed according to the differences in the 1998 and 2018 principal component scores. All statistical analyses were performed using R version 4.1.1.[15]

Ethical approval

The study utilized publicly available data; thus, informed consent was not applicable.

Results

SMCA characteristics in 2018

In 2018, the primary principal components (PC1) accounted for 65.28% of the total variance, and the secondary principal components (PC2) accounted for 23.20%. Accordingly, the accumulated proportion of variance for PC1 and PC2 was 88.47%. The factor loading and principal component scores are shown in Table 1. In addition, scatter plots of factor loadings and principal component scores are shown in Figures 1 and 2, respectively. According to the factor loadings shown in Table 1 and Figure 1, the variables that affected PC1 include the number of hospitals, clinics, doctors, and beds. Based on these findings, PC1 was identified as *Medical Resources*. Furthermore, the variables that were found to affect PC2 were the number of no-doctor districts, populations of the no-doctor districts, and overall land area. Owing to these findings, PC2 was identified as *Geographical Factors*.

The score of PC1 was high in Sapporo, Kamikawa-Chubu, Minami-Oshima, and Tokachi [Table 2]. The more negative the score of *Medical Resources*, the more medical resources are available in that SMCA. Compared to Sapporo, other SMCAs had lower PC1 scores. In particular, Minami-Hiyama was the SMCA with the least medical resources.

Changes over time

For changes over time, PC1 accounted for 69.58% of the total variance, with PC2 accounting for another 13.06%. Accordingly, the accumulated proportion of variance was 82.64%. The factor loading and principal component scores (volume of change) are shown in Tables 3 and 4, respectively.

In addition, scatter plots of the factor loadings and principal component scores of each SMCA are shown in Figures 3 and 4, respectively. Based on these factor loadings, PC1 was again labeled as *Medical Resources* [Table 3, Figure 3]. For PC2, both land area and the year-dummy variables had contributions. Thus, PC2

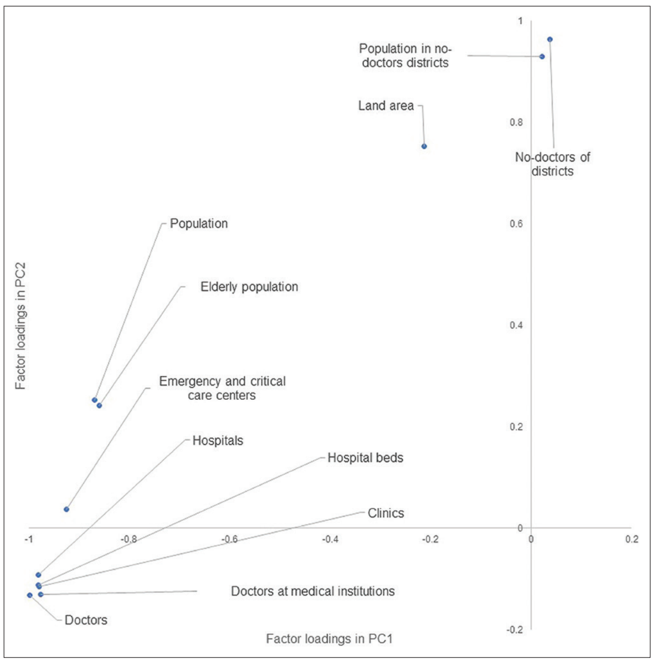

Figure 1: Factor loadings of each variable in 2018

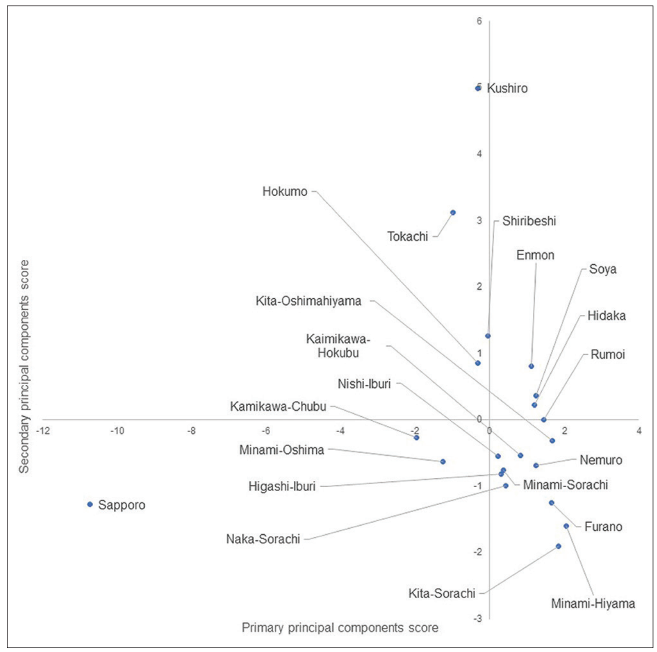

Figure 2: Primary and secondary principal components score of SMCAs in 2018. Primary principal components score is labeled as "medical resources" and secondary components score labeled as "geographical factors"

Table 1: Factor loadings of characteristics of each secondary medical care area in 2018

Variables	PC1 Medical resources	PC2 Geographical factors
Number of hospitals	-0.981	-0.091
Number of clinics	-0.979	-0.115
Number of doctors	-0.975	-0.131
Number of doctors at medical institutions	-0.976	-0.130
Number of hospital beds	-0.980	-0.111
Population	-0.869	0.253
Land area	-0.212	0.753
Elderly population	-0.860	0.242
Number of no-doctors districts	0.038	0.963
Population in no-doctors districts	0.022	0.930
Number of emergency and critical care centers	-0.924	0.037

Note. PC1, primary principal component; PC2, secondary principal component was labeled as *Land Area*. Figure 4 and Table 4 show the changes in the principal component scores from 1998 to 2018. From 1998 to 2018, the overall coordinate point moved in the positive direction along the PC2 land area axis. The Sapporo region moved noticeably in the negative direction along the PC1 Medical Resources axis. This trend reveals that medical resources have been relatively concentrated in Sapporo over the last 20 years. Moreover, several SMCAs, including Kita-Oshimahiyama, Nishi-Iburi, Higashi-Iburi, Kamikawa-Chubu, Furano, Soya, Hokumo, Tokachi, Kushiro, and Nemuro, moved in the negative direction along the PC1 axis [Figure 5]. Therefore, the medical resources in these SMCAs were found to have increased slightly over the 20-year study period. In contrast, Minami-Oshima, Minami-Hiyama, Shiribeshi, Minami-Sorachi, Naka-Sorachi, Kita-Sorachi, Hidaka, Kamikawa-Hokubu, Rumoi, and Enmon, moved in the positive direction along the PC1 axis, suggesting that the medical resources in these areas decreased over the two decades examined [Figure 5].

Table 2: Principal component scores of each secondary medical care area in 2018

Secondary medical care area	PC1 Medical resources	PC2 Geographical factors
Minami-Oshima	-1.257	-0.636
Minami-Hiyama	2.057	-1.601
Kita-Oshimahiyama	1.680	-0.313
Sapporo	-10.718	-1.278
Shiribeshi	-0.045	1.262
Minami-Sorachi	0.373	-0.767
Naka-Sorachi	0.359	-0.991
Kita-Sorachi	1.838	-1.904
Nishi-Iburi	0.222	-0.549
Higashi-Iburi	0.298	-0.814
Hidaka	1.209	0.223
Kamikawa-Chubu	-1.953	-0.268
Kaimikawa-Hokubu	0.825	-0.540
Furano	1.663	-1.252
Rumoi	1.453	0.002
Soya	1.244	0.363
Hokumo	-0.309	0.849
Enmon	1.113	0.800
Tokachi	-0.981	3.117
Kushiro	-0.311	4.991
Nemuro	1.251	-0.696

Note. PC1, primary principal component; PC2, secondary principal component

Table 3: Changes in the factor loadings from 1998-2018

Variables	PC1 Medical Resources	PC2 Land Area
Number of hospitals	-0.974	-0.150
Number of clinics	-0.983	-0.135
Number of doctors	-0.972	-0.153
Number of doctors at medical institutions	-0.972	-0.152
Number of hospital beds	-0.975	-0.175
Population	-0.867	0.292
Land area	-0.203	0.863
Older adult population	-0.844	0.367
Year dummy variable (1998=0, 2018=1)	-0.023	0.305

Note. PC1, primary principal component; PC2, secondary principal component

Discussion

Interpretation of the SMCAs' current characteristics

This study revealed the current characteristics of SMCAs in Hokkaido, Japan, and their changes over time. Furthermore, the PCA outlined these characteristics in a manner that included multidimensional indicators. In the scatter plot of the principal component scores [Figure 1], negative trends in the PC1 (Medical Resources) correlated with greater amounts of medical resources available. In contrast, positive trends in PC2 "geographical factors" were correlated with poor geographical conditions in the SMCAs. Based on these scatter plots, the study area was divided into four quadrants around the origin [Figure 6].

Quadrant 1 was labeled "medical areas with scarce medical resources and poor geographical conditions" and included Hidaka, Rumoi, Soya, and Enmon. These findings suggest that the SMCAs in Quadrant 1 had significant gaps in their medical care services compared to other areas. Quadrant 2 was labeled "medical areas with sufficient medical resources and poor geographical conditions" and included the four medical areas of Shiribeshi, Hokumo, Tokachi, and Kushiro, with their land area being inferred as a relative factor in their classification. These results suggest that geographical access is crucial when constructing a medical service system. Quadrant 3 was labeled "medical areas containing sufficient medical resources and good geographical conditions" and included Sapporo, Kamikawa-Chubu, and Minami-Oshima. Finally, Quadrant 4 was labeled "medical areas

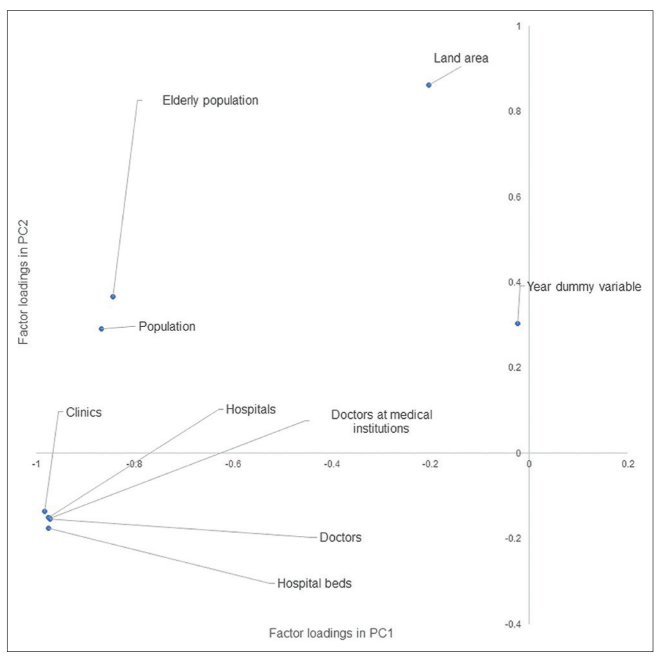

Figure 3: Factor loadings of each variable in the period of 1998–2018. Primary principal components score is labeled as "medical resources" and secondary components score labeled as "land area"

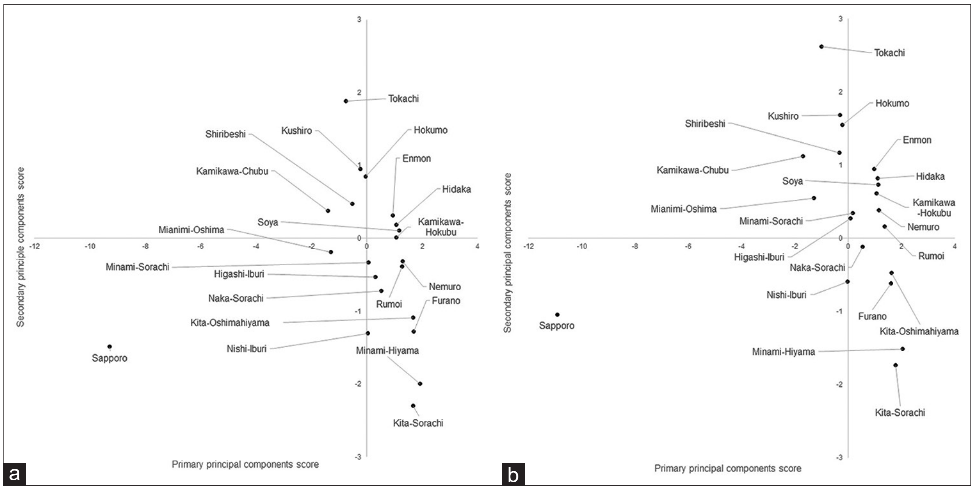

Figure 4: Principal components score of SMCAs in (a) 1998 and (b) 2018

Table 4: Changes in principal component scores in SMCAs from 1998-2018

SMCA	1998		2018		Changes	
	PC1 Medical resources	PC2 Land area	PC1 Medical resources	PC2 Land area	PC1 Medical resources	PC2 Land area
Mianimi-Oshima	-1.306	-0.192	-1.290	0.549	0.016	0.741
Minami-Hiyama	1.917	-2.004	2.043	-1.516	0.126	0.488
Kita-Oshimahiyama	1.673	-1.091	1.616	-0.474	-0.057	0.617
Sapporo	-9.283	-1.491	-10.919	-1.045	-1.636	0.446
Shiribeshi	-0.515	0.473	-0.342	1.168	0.173	0.695
Minami-Sorachi	0.065	-0.332	0.163	0.343	0.098	0.675
Naka-Sorachi	0.524	-0.726	0.544	-0.115	0.02	0.611
Kita-Sorachi	1.679	-2.307	1.786	-1.736	0.107	0.571
Nishi-Iburi	0.038	-1.304	-0.027	-0.594	-0.065	0.71
Higashi-Iburi	0.307	-0.534	0.071	0.267	-0.236	0.801
Hidaka	1.069	0.185	1.095	0.816	0.026	0.631
Kamikawa-Chubu	-1.404	0.372	-1.693	1.121	-0.289	0.749
Kamikawa-Hokubu	1.061	0.011	1.070	0.613	0.009	0.602
Furano	1.696	-1.282	1.607	-0.618	-0.089	0.664
Rumoi	1.275	-0.393	1.361	0.162	0.086	0.555
Soya	1.164	0.104	1.128	0.733	-0.036	0.629
Hokumo	-0.045	0.841	-0.215	1.552	-0.17	0.711
Enmon	0.933	0.310	0.980	0.943	0.047	0.633
Tokachi	-0.745	1.881	-1.007	2.622	-0.262	0.741
Kushiro	-0.226	0.944	-0.302	1.685	-0.076	0.741
Nemuro	1.303	-0.322	1.152	0.381	-0.151	0.703

Note. SMCA, secondary medical care area; PC1, primary principal component; PC2, secondary principal component

with scarce medical resources and relatively good geographical conditions" and included the largest number of medical areas of the four quadrants (i.e., Minami-Hiyama, Kita-Osimahiyama, Minami-Sorachi, Naka-Sorachi, Kita-Sorachi, Nishi-Iburi, Higashi-Iburi, Kamikawa-Hokubu, Furano, and Nemuro). For these medical areas, the main characteristics observed included having depopulated areas, relatively scarce medical resources, small populations, and small land areas. According to previous policies and studies, the policy that increased the number of physicians between 1998 and 2008 did not, unfortunately, lead to an equal geographical distribution of physicians in Japan,[3] with an urban-rural disparity in physician distribution increasing from 2000 to 2014.[16] Regarding geographical access in the field of stroke care, Fujiwara *et al*.[17] evaluated geographical accessibility by calculating the population of people aged 65 years and over living in various medical areas who had to travel at least 30 to 60 min to reach these medical facilities. Their results indicated that the percentage of people aged 65 years and older who lived within 30 min of a facility offering mechanical thrombectomy in Sapporo, Kamikawa-Chubu, and Minami-Oshima were 93.5%, 92.6%, and 81.1%, respectively. These were the top three of the 21 SMCAs.[17] Notably, all three of these SMCAs are in Quadrant 3, and they are areas rich in both medical resources and geographic accessibility. Similarly, in Quadrant 1, Hidaka, Rumoi, Soya, and Enmon lacked facilities offering mechanical thrombectomy within 30 min.[17] In contrast, only 39.9% of people in Shiribeshi

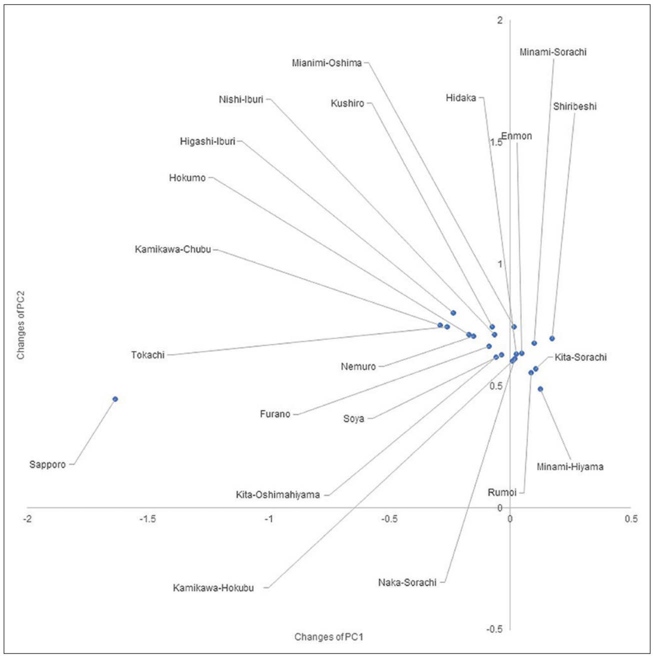

Figure 5: Changes in primary and secondary principal components score from 1998 to 2018

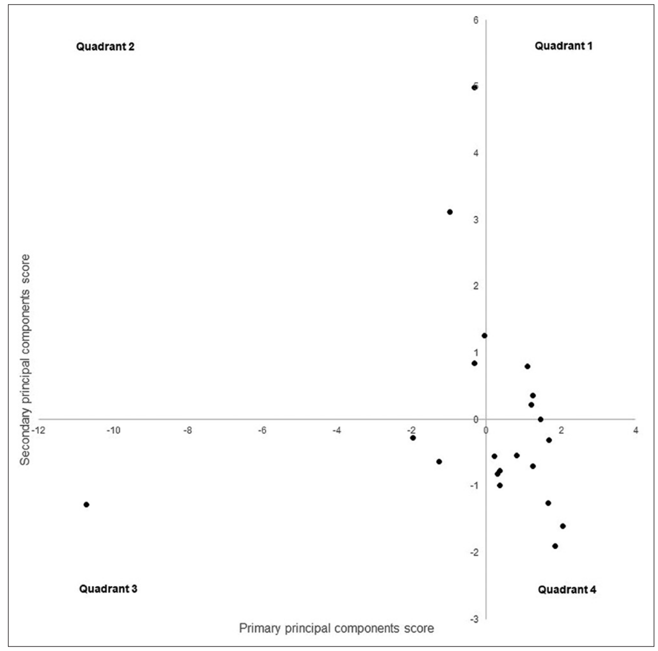

Figure 6: Figure 6 was based on Figure 1. Quadrant 1 means that medical areas with scarce medical resources and poor geographical conditions, quadrant 2 means that medical areas with sufficient medical resources and poor geographical conditions, quadrant 3 means that medical areas containing sufficient medical resources and good geographical conditions, quadrant 4 means that medical areas with scarce medical resources and relatively good geographical conditions

could receive mechanical thrombectomy treatment within 30 min, whereas in Kushiro, 74.6% of people could receive the treatment within 30 min, yet they are both in Quadrant 4,[17] indicating that these two SMCAs are represented by their boundary with Quadrant 1. Although they have poor geographical conditions, the regions have relatively good medical resources. The SMCAs in Quadrant 4 were complicated, with similar indicators ranging from 0% to 79%.[17] These regions may be affected by the small size of the country and the availability of medical resources in neighboring SMCAs. However, this study did not consider data from adjacent regions. Moreover, a previous study identified the need to realistically redefine no-doctor districts.[18] The number of no-doctor districts and their populations included in this study may have underestimated people with poor access to medical resources. Therefore, an analysis that includes accessibility to medical resources in neighboring SMCAs is required for more detailed characterization.

Changes over time

The changes in the SMCA characteristics that occurred between 1998 and 2018 were clarified using differences in their principal component scores between these two periods. According to the trends found for the difference in PC1 (Medical Resources), in each medical area, Kita-Oshimahiyama, Sapporo, Nishi-Iburi, Higashi-Iburi, Kamikawa-Chubu, Furano, Hokumo, Tokachi, Kushiro, and Nemuro had a negative result. This means that the medical resources in these areas have increased over the last 20 years. In particular, although Sapporo was defined as having good medical resources and good geographical conditions in 1998, it has the largest negative trend. Conversely, the medical resources of Minami-Hiyama, which was identified as having scarce medical resources and poor geographical conditions in 1998 saw a decrease over the study period. Based on these results, gaps in medical resources in Hokkaido and its various regions have progressed over the last 20 years. This result is consistent with previous studies that have examined and outlined the concentration of medical resources in urban areas.[16] Hara *et al.*[16] reported that although the total number of doctors increased from 2000 to 2014 in Japan, the disparity in the number of doctors per healthcare demand expanded between urban and rural areas. Moreover, Ishikawa revealed that from 1996 to 2016, fewer doctors migrated from areas with high physician densities to areas with low physician densities than the reverse; that is, more doctors migrated to areas that already had high physician densities.[19] In this case, Sapporo had high physician density at the baseline compared to other SMCAs, yet medical resources, including the number of doctors, increased in the study period. Although this study focused on a single prefecture, the result was consistent with the overall trend in Japan. These findings suggest the need for policies to set the required number of doctors and the number of hospitals and beds to better equalize medical resources.

The PC2 (Land Area) trend showcased a positive trend overall, with the trend being caused by the year-dummy variable. There were no changes observed in the land area over the 20-year study period because the year-dummy variable changes were fixed regardless of the conditions of each medical area. Although the variations in the PC2 (Land Area) trend's change in volume are a result of changes in both the general and elderly populations if a logarithm is used to analyze the actual population, the change in the volume for these two data items is likely to be high because of increases in the older adult population. Accordingly, medical areas that demonstrated a positive trend had an increase in their older adult populations, which was interpreted as an increase in the demand for medical care.

Limitations

This study has several limitations. First, the principal component scores are limited to evaluating the relative relationships within Hokkaido prefecture because they are only relative values. However, the study expands on current assessments of relative medical resources in other prefectures and contributes data that will help in the effective reallocation of medical resources. Second, the geographical access data in this study were insufficient compared with the medical resource data. This is because the study only used publicly available data on the internet in the analysis. Future studies that include a wider range of data are thus necessary to construct a more comprehensive system for equal distribution of medical services.

Conclusions

This study aimed to clarify the current conditions and changes over time in the medical services within SMCAs in the Hokkaido prefecture. In addition, this research visualized the multidimensional data related to these SMCAs' medical services using PCA to reduce this data to a composite index.

Scatter plots were used to visualize the distribution of the current medical care provision systems at each SMCA. A four-quadrant interpretation of these data found that the medical service system was insufficient in various SMCAs, excluding Sapporo, Kamikawa-Chubu, and Minami-Oshima. In addition, the observations of the changes over the last 20 years revealed that the concentration of medical resources in Sapporo increased.

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Conflicts of interest

There are no conflicts of interest.

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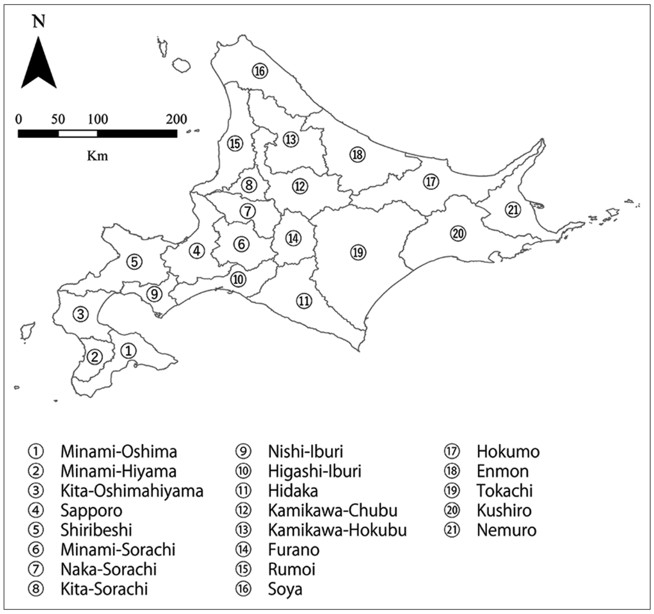

Figure S1: Fig S1 shows 21 secondary medical care areas in Hokkaido, Japan