Compact City Model Analysis for a Metropolitan Area using GIS Relationship between Population and Land Use

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Abstract**—** This study aims to evaluate a compact city model by considering the relationship between different types of land use and population. Urbanization promotion areas in Aomori, Sendai and Sapporo metropolitan areas were studied. All areas are implementing the compact city model in the northern part of Japan; however, they correspond to small, middle and large scale sizes respectively. In this study GIS is used to manipulate the geographical data. The main results of this study are: (1) The compact city model was validated using a residual Kriging model and a compactness index using land use transformation and population density data. (2) There is a commuter belt in both the Sendai and Sapporo Metropolitan areas as shown by population density according to the residual Kriging model. (3) The compactness index was useful in validating the compact city model in the different metropolitan areas, and also in contrasting the model implementation in different time periods. (4) Although Sendai and Sapporo promote residential areas, it is necessary to improve the mixed use of land and commuter belt areas in order to incrementally increase the index of compactness.

Keywords**—** Compact city, Japanese local city, Kriging model, land use changes, population density.

I. Introduction

1.1. Background and purpose

In contrast with European and American countries, most large cities in Asia have a high population density [1]. It is important for each government and city planner to consider how to improve living conditions because inadequate urban planning results in problems such as environmental degradation, disease, lack of green spaces and unintended changes to the local topography. According to Yamamoto, Japan lacks green spaces in comparison to other large cities in developed nations [2]. Therefore, it is important for scientists, architects and geographers to consider how to create or improve new kinds of city models such as compact [3], smart [4], green cities [5], etc.

Squires (2002) defines a Metropolitan Area (MtA) as a region with high population density in the urban core and a less populated perimeter, sharing industry, infrastructure and housing. The Statistics Bureau of Japan also defines an MtA as an area consisting of a central city or central cities and the surrounding area (cities, towns and villages). In Japan there are 14 MtAs, including three major MtAs and other local MtAs. Local MtAs include the Hokkaido, Tohoku, Hiroshima and Fukuoka regions.

For this study, MtAs in Aomori, Miyagi and Hokkaido prefectures were considered, first of all because they are all in northern Japan, and because they share specific problems related to weather and historical and physical features. Information is processed through a Geographic Information System (GIS) which combines hardware and software useful to manipulate, store, retrieve, view and analyze large spatial databases [6]. The purpose of this study is to describe how compactness indexes have changed over time for three Japanese cities (Aomori, Sendai and Sapporo MtA) to see if they follow the objectives of a compact city.

1.2. Related work

A. Population density estimation

Scientists are developing different methods to predict geographical information in different fields. Methods applied to social physics [7], agriculture [8], climatology [9] and those related to decreasing population density [10] are examples of their broad coverage. Some models follow the probability theory, and predictions are accompanied with estimates of prediction errors. Those models can be grouped based on: Smoothing effect, proximity effect, convexity effect and support size. The latter effects predict at certain points or for certain blocks and are called area-based and point-based [11]. Point-based methods, which depend initially on geographic coordinates, use zone centroids as control points. Later, a window is positioned over each control point and the source zone population is allocated to grid cells falling inside this window using unique weighting based on the distance decay function between the source zone centroid and the grid cell. On the other hand, area-based methods use the zone itself as the unit of operation and this method is more concerned with volume preservation [12]. However, if the boundaries are not symmetrical, the location of the centroid can be affected, and as

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a result interpolation may be biased [13]. For this reason, this study works with 100m mesh, to provide higher accuracy than the original area.

Some methods have been developed to handle point-based methods, for example, interpolating polynomials, Kriging, distance-weighting methods, etc. For Kriging methods, if the source zones can be reduced to point sources and the population distribution can be described with a semi-variogram [14], this method is the best linear unbiased estimation [15]. The Kriging model is also known as BLUP (Best Linear Unbiased Predictor), and is used in various studies [16], [17]. In order to calculate the best predictor for unknown quantities, it is important to calculate the best linear unbiased predictor [18].

B. Compact city

The compact city model focuses on population density, activity concentration, public transportation intensification and city size and access conditions [19][20]. In the early 1980s, K. Lynch suggested a model where cities are like a galaxy of separate medium-sized communities, surrounded by large swaths of green space and connected by major roads [21]. He mentioned that the compact city should be located as part of a distinct regional area, with clear boundaries designated to ecological and social functions. Compact city strategies also include a large block or open space close to urban neighborhoods, and the intensification of abandoned or unused land within the urban core. The large blocks or superblocks present two patterns such as high and low buildings and wide roads and narrow streets. Major roads divide the city into a series of 'superblocks' and within these blocks is a network of narrow streets made up essentially of streets without sidewalks. In this way, the road grid can be called a superblock grid [22].

One of the first compact city models was developed by Swiss architect and urban designer, LeCorbusier [23]. He thought that each city should be concentrated with high-density urban living associated with high-rise residential buildings. Later, in 1994, Haughton and Hunter described a concentrated city model, explaining the importance of improving urbanization, industrialization and housing policies among other factors [24].

Several metrics have been developed in order to evaluate compactness [25]; in this study we will use Burton's metrics for compactness evaluation. The term "compactness" has been defined by many scientists, for instance as high-density development [26], Bertaud and Malpezzi defined a dispersion index such as the ratio between the average distance per person to the CBD (Central Business District) and the average distance to the center of gravity of a hypothesized cylindrical city with equal distribution of development [27]. We propose a compact city model analysis through Kriging models applied to population density and land use transformation taking into account different periods of time.

1.3. Characteristics of a Japanese Compact City

In northern Japan, cities must deal with snow-related problems every year and invest a part of their budget in this

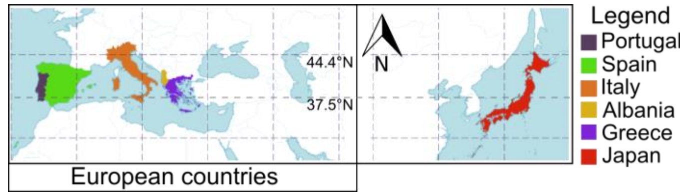

Fig. 1 Comparison between European countries and Japan

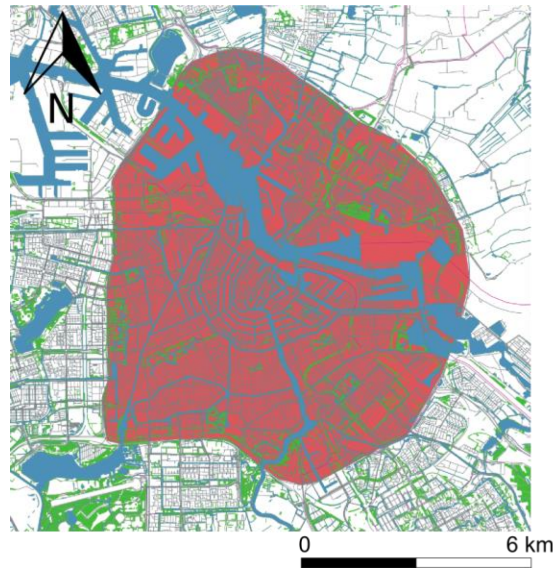

Fig. 2 Amsterdam an example of European compact city.

issue. Another constraint is that the habitable area of Japan is less than 21% of its land mass and 66% is forest [28]. Regarding physical features, such as lack of space, location in the northern hemisphere (See Fig. 1) and problems related to depopulation and snowfall, Japan is comparable to some European countries. In order to analyze the compact city model we choose 3 different areas in Japan. The smallest MtA and benchmark corresponds to Aomori, which applies a compact city model, and Sendai and Sapporo MtAs are middle and large scale areas.

The main goal of the compact city is to reduce the distances between the activities of different citizens [29]. The concept of compact cities around the world depends on the physical attributes of each area. Thus, it is possible to compare Japanese compact cities with European compact cities, since both regions have limited space, and housing, businesses, hospitals, etc., are located in specific areas according to a master city plan.

In Japan, some cities have officially incorporated a compact city model, such as Sapporo, Wakkanai, Aomori, Sendai, Kobe and Kitakyushu [30]. The aim of Japanese compact cities can be divided into five main goals, namely 1) addressing the issue of aging, 2) progress of suburbanization, 3) preservation of city history and culture with special attention to the city core, 4) conservation of nature and environment, and 5) study of the current status and future of regional collaboration. Currently Japan is faced with important problems related to depopulation and aging, and as a result, it is necessary to gather new residents who live in the suburbs. Another important problem is related to architecture, because the core of some Japanese cities is still comprised of wooden houses preserving the traditional style or lack of maintenance and new buildings, and it is important to improve the foundations of the city and to study disaster prevention.

European cities such as Oslo in Norway, Groningen, Delft and Amsterdam (Fig. 2) in the Netherlands, as well as Oxford in U.K., are examples of cities pursuing the compact city model. Multi-functionality is sought through the integration of land use, transformation to urban mobility, harmonizing of spatial-functional structures and the public transit system [31]. There are some differences between Japanese planners and their counterparts in Europe. For example, Japanese planners do not have the authority to enforce their ideas or projects within the cities. This happens when they come to the direction and type of growth on the urban fringe, and constitutes a barrier to the planned development of a sustainable urban form [32].

II. Framework

In Section 3, methods to develop a relationship between land use and the population are proposed. An explanation of a residual Kriging model, variograms and compactness is given.

Section 4 explains the study of selection for each MtA. A master plan for Japanese cities is introduced, explaining the different types of areas in city planning. There is clarification of how the land is divided into different types of land use and the kind of data used for this study, as well as population distribution.

Section 5 explains how this study was developed and the procedures used to collect the information required in the Kriging model. The reasons used to construct the variograms in order to interpolate the population data are explained. For this section, GIS was used to construct a system with various types of data.

Section 6 shows results from the models. The Kriging models for population density and index of compactness for each MtA in the different periods of time are presented. Section 7 provides a discussion on this study, presenting the differences between MtAs based on analysis results. Finally, a conclusion and an introduction to future work are provided in Section 8.

III. 3. Methodology

3.1. Kriging Model

The Kriging interpolation is a method which predicts unknown values from observed data. Z(s) is defined as a random field, where Z is a random value and s is the non-random spatial index. This model is based on the sample data $Z(s_i)$ and unknown quantities $Z(s_0)$, where s_0 is the non-observed location.

In order to construct the best linear unbiased predictor the following model was evaluated:

$$\widehat{Z}(s_0) = x(s_0)\widehat{\beta} + v'V^{-1}\left(Z(s) - X\widehat{\beta}\right) \tag{1}$$

Where X is the matrix of observations and $v'V^{-1}$ are the weights of the model, also known as simple Kriging weights. Equation (1) is the best linear unbiased predictor of $Z(s_0)$. Prediction error variance is defined as follows:

$$\sigma^2(s_0) = \sigma_0^2 - v'^{V^{-1}}\, v + \delta\left(X'V^{-1}X\right)^{-1}\delta' \tag{2}$$

Where σ_0^2 is the variance of $Z(s_0)$, and $\delta = x(s_0) - v'V^{-1}X$.

Equation no. 2 can be written as a function of the lag vector h; in this way the expected value of the difference between $Z(s)$ and $Z(s + h)$ is 0.

$$\begin{aligned} Var\{[Z(s+h) - Z(s)]\} &= E\{[Z(s+h) - Z(s)]^2\} \\ &= 2\gamma_R(h) \end{aligned} \tag{3}$$

Where $\gamma_R(h)$ is the semi-variogram or residuals [33].

Let $C_R(0)$ be the variance of $R(s)$, where $R(s)$ is a stochastic zero-mean residual component. The covariance between $R(s)$ and $R(s+h)$ is obtained as:

$$C_R(h) = E\{R(s+h)\cdot R(s)\} = C_R(0) - \gamma_R(h) \tag{4}$$

Population density in different periods of time is analyzed using the residual Kriging model. The advantage of this model is that the extent of data distribution can be understood. In order to identify the best model applied to population density in different Metropolitan areas, variograms are calculated.

3.2. Variograms

A variogram is a function to describe the dissimilarity between observations. It models spatial correlation and plots semi-variance as a function of distance. It is defined as:

$$\gamma(h) = \frac{1}{2}E\left(Z(s) - Z(s+h)\right)^2 \tag{5}$$

Where h is the separation distance between pairs of points.

According to this, variograms only depend on the separation distance. However, in order to evaluate a sample, a sampling of variograms is required, and these can be estimated through N_h sample data pairs $z(s_i)$, $z(s_i + h)$ for the number of distances $\tilde{h}$

$$\hat{\gamma}\left(\tilde{h}_j\right) = \frac{1}{2N_h}\sum_{i=1}^{N_h}\left(Z(s) - Z(s+h)\right)^2, \quad \forall h \in \tilde{h}_j \tag{6}$$

Sample variograms can be estimated using Equation (6).

In order to interpolate the population density usage area to point by residual kriging, it was necessary to check if the land use zone was referred to by its centroid u. Population density is defined as:

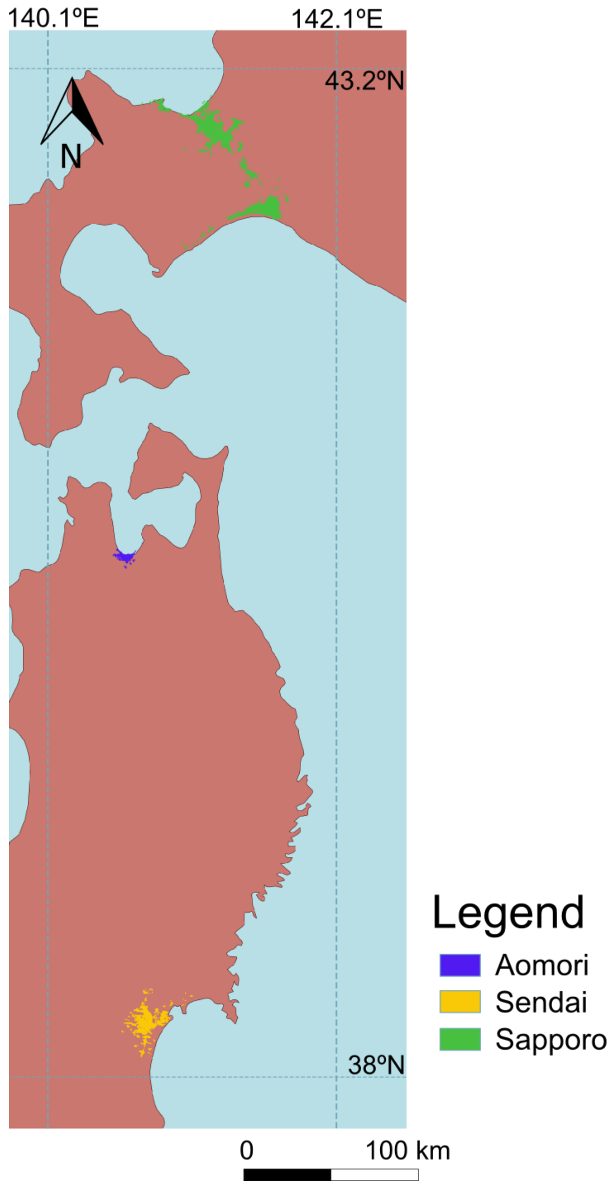

Fig. 3 Urbanization Promotion Area for Aomori, Sendai and Sapporo MtAs.

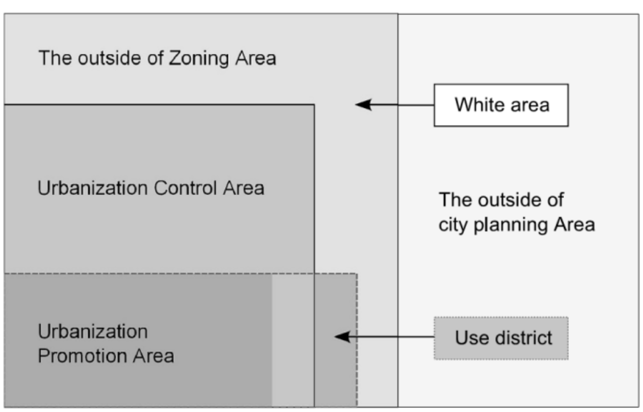

Fig. 4 City planning area [34]

$$d(u) = \hat{d}(u) + r(u) \tag{7}$$

Where *d(u)* is the unknown population density of a land use zone, $\hat{d}(u) = m(u)$ is the value estimated by the regression model, and *r(u)* is the residual population density. Let v_u be the census unit containing *u* which has a residual density $r(v_u)$ that can be defined as:

$$\begin{aligned} r(v_u) &= \frac{P_{v_u} - \sum_j \hat{d}(u_j) A_{u_j}}{A_{v_u}} = \\ &= \frac{\sum_j d(u_j) A_{u_j} - \sum_j \hat{d}(u_j) A_{u_j}}{A_{v_u}} \\ &= \sum_j \frac{\{d(u_j) \hat{d}(u_j)\} A_{v_u}}{A_{v_u}} = \sum_j \frac{A_{u_j}}{A_{v_u}} r(u_j) \end{aligned} \tag{8}$$

Where A_{u_j} is the area of the land-use zone u_j and P_{v_u} and A_{v_u} are the population and area of the host census unit, respectively. The value $\hat{d}(u_j)$ is calculated from the regression model.

3.3. Compactness

In order to calculate compactness for each MtA in the different periods of time, we will calculate the index using Burton's metrics. For this analysis we calculate some relationships before the compactness index.

$$densblt = \frac{RP_i}{BU} \tag{9}$$

Where RP_i is defined as residential population in zone and *BU* is the built-up acreage.

$$densres = \frac{RP_i}{RA} \tag{10}$$

Where *RA* is the residential area acreage.

$$supfacs = \frac{RA}{BU - RA} \tag{11}$$

supfacs is residential / nonresidential urban land.

Finally the index of compactness will be given by:

$$Compactness = \frac{OD}{MixU} \tag{12}$$

Table 1 Percentage of areas with special land use controls for the entire MtA (%).

City planning area	Aomori	Sendai	Sapporo
UPA	1.4	9.6	6.1
UCA	11.2	27.9	18.8
Use District	0.9	3.0	1.4
Outside of zoning area	12.9	12.1	3.3
Inside city planning area	25.5	49.6	28.2
White area	13.3	18.7	8.1
Outside city planning area	74.5	50.4	71.8

Table 2 Land use categories

Code	Description	Color
1	Rice fields	
2	Other agricultural land	
3	Forest	
4	Waste Land	
5	Buildings, residential areas	
6	Roads	
7	Other sites	
8	River and lake areas	
9	Beach	
10	Ocean	
11	Golf course	

Table 3 Land use changes in the Urbanization Promotion Areas (ha)

Met. Area	Period	Rice field	Other agricultural land	Forest	Waste Land	Building site	Arterial traffic	Other	Rivers and lakes	Beach	Ocean	Golf course
Aomori	97-91	-118	-19	-65	-52	259	-2	11	0	0	-14	0
Aomori	06-97	-310	-35	-103	-6	521	60	216	15	1	-359	0
Sapporo	97-91	-185	-1,861	-1,521	-2,926	7,286	474	-1,223	-35	-1	-14	6
Sapporo	06-97	-139	-2,328	-2,638	-938	6,660	-168	206	-192	74	-351	-186
Sendai	97-91	-1,210	-631	-1,772	-171	4,106	43	-209	14	263	28	-215
Sendai	06-97	-1,010	-584	-1,930	-59	3,715	-74	-446	148	-242	-4	240

Note: The column period refers to years 1991 (91), 1997 (97) and 2006 (06)

Where *OD* is the overall density and *MixU* is mix-of-use measures. To avoid extreme values we will standardize the values. The *OD* of the regions of interest (ROI) corresponds to the land area of the whole UPA.

IV. Description of the Study Area

4.1. Study Area Description

The reason for considering Aomori, Sendai and Sapporo MtAs is that all these areas share common features as such as geographical location, problems related to snowfall (i.e. problems on roads) which affects the city budget and problems related to depopulation and aging as life expectancy in Japan reaches almost 83, 10 years longer than in other countries.

Aomori and Sendai MtAs are located in the Tohoku area, while Sapporo is on the island of Hokkaido. Figure 3 shows the UPAs for Aomori, Sendai and Sapporo Metropolitan areas. The difference in the size of the areas is evident - Aomori is equivalent to 6.031 ha (60.31 km^2), while Sendai and Sapporo are 31.718ha (317.18 km^2) and 74.023 ha (740.23 km^2) respectively.

Aomori, which has been working as a compact city since 2000, is a small scale city. Sendai and Sapporo are mid-size and large cities and their related MtAs represent an important section of the Tohoku and Hokkaido regions respectively. Another important aspect is that Sendai and Sapporo MtAs have high population densities and have been studying how to reduce urban sprawl in their areas as a way to improve quality of life. We sought to understand the Aomori compact city model and then apply this approach to the other MtAs.

4.2. Master Plan Study of Metropolitan Areas

In Japan, each city has its own master plan consisting of a transportation system, community facilities, parks and open spaces, neighborhoods and housing, economic development and land use. According to the Ministry of Internal Affairs and Communications of Japan[1], city planning areas are classified into different areas, such as undivided city planning areas like Urbanization Promotion Areas (UPA) or Urbanization Control Areas (UCA), and divided city planning areas such as District or Zoning areas. An UPA is designated as an industrial, commercial and residential area, and is defined as an area which already forms an urban area or that will be urbanized within 10 years.

In 2000, a reform of zoning responsibilities was carried out. Today, prefectures may freely decide whether to designate a zone or not. Figure 4 represents city planning distribution for a city planning area and explains how city planning is defined by the local government. A UCA is designated for agricultural

[1] Dwelling Environment and Type of City Planning-related terms. Ministry of Internal Affairs and Communications.

Table 4 Population group divisions

Population group	Range	Code
Children	0 – 19 years old	CH
Middle age	20 – 39 years old	MA
Mature people	40 – 59 years old	MP
Elderly people	60 years old onwards	EP

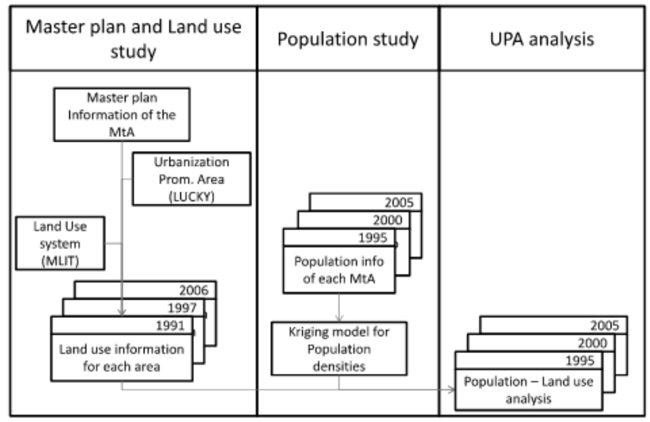

Fig. 5 Study development

Table 5 Population statistics in the MtAs

City	year	TOTAL				Men				Women				Total
		CH	MA	MP	EP	CH	MA	MP	EP	CH	MA	MP	EP	records
Aomori	1995	184,531	192,088	360,703	49,284	93,651	91,638	165,394	16,946	90,880	100,450	195,309	32,338	1,671
	2000	169,054	195,107	382,264	62,474	85,782	95,012	176,908	21,277	83,272	100,095	205,356	41,197	1,763
	2005	149,237	182,589	381,960	83,005	75,579	89,134	176,768	29,056	73,658	93,455	205,192	53,949	1,810
Sendai	1995	425,325	503,228	705,684	78,578	219,204	254,200	342,149	29,082	206,121	249,028	363,535	49,496	2,510
	2000	414,316	551,461	789,683	111,019	213,036	278,711	385,134	40,553	201,280	272,750	404,549	70,466	2,841
	2005	386,308	548,044	829,577	156,339	198,532	275,203	403,883	58,672	187,776	272,841	425,694	97,667	3,243
Sapporo	1995	590,568	750,429	1,134,651	127,934	302,283	366,307	535,251	47,843	288,285	384,122	599,400	80,091	6,584
	2000	622,462	854,783	1,384,540	197,288	318,704	416,924	653,997	72,693	303,758	437,859	730,543	124,595	8,508
	2005	567,262	849,059	1,433,571	267,132	290,609	417,543	673,856	100,804	276,653	431,516	759,715	166,328	8,474

activity and land use is regulated by plans. For a UPA, use of districts is specified for the entire area. However, for the UCA and outside zoning areas, land use districts are only specified for some areas and their management conforms to that of the UPA. Outside zoning areas, which are excluded from the use district, are called White areas. In table 1, the UPA in Aomori MtA is clearly the smallest among the three MtAs, but also has the largest area outside of city planning. This is because Aomori's government wants to keep the UPA just for urban development projects. It is clear that Sendai MtA has the largest area inside the city planning area and the areas of Aomori and Sapporo MtA are similar.

The central government in Japan has defined land use into 11 different categories (table 2), excluding mixed type land use. For the next analysis, respective codes and colors for each type of land use are used. In table 3, land use changes for each UPA are shown for years 1991, 1997 and 2006. The largest change related to rice fields was in Aomori, with a reduction greater than 55%, but residential areas and roads also grew more than 25% and 23%, respectively. However, there was a reduction in agricultural fields and Sendai experienced the largest change at more than 67% as well as a large growth in residential areas at more than 70%. It is evident that areas such as paddy fields and those for other agricultural related activities are decreasing while activities in residential areas are increasing.

4.3. Population distribution

Information related to populations in 2000 and 2005 was obtained from the National Census. Information for 1995 was not available for download, but was obtained from the Statistics Bureau of Japan. Detailed population data can be obtained from the National Census, which is carried out every five years.

Over time and depending on the economic conditions of each region, municipalities are merged or dissolved. It was important to construct the extent of this in order to determine which cities were merging or becoming independent. Detailed information for each district was obtained, such as: key code, city name, district name, population by age, latitude, longitude, area, perimeter and density. The information was divided into 4 different groups, as shown in table 4.

Population data in the different periods of time presents problems associated with depopulation and aging in each MtA (table 5). The numbers in the children and middle age groups in all MtAs have decreased, while the mature and elderly groups have increased for each year. According to records from the National census, the total population in Aomori MtA has increased, but only by 8.3%, while Sapporo and Sendai have increased growth by 28.7% and 29.2%, respectively, meaning that there was a merging of municipalities.

Table 6 Variogram characteristics

MtA	Model	1995		2000		2005	
		psill	range	psill	range	psill	range
Aomori	Nug	0	0	0.004	0	0.044	0
	Exp	3.898	5.688	3.850	5.844	3.722	6.672
Sendai	Nug	0.579	0	0.723	0	0.694	0
	Exp	3.024	9.729	2.768	9.424	2.637	10.009
Sapporo	Nug	0.998	0	0.992	0	0.988	0
	Exp	11.344	3209.804	16.743	3851.751	20.849	4622.098

Table 7 Compactness calculation for each UPA MtA

city	year	densblt	densres	supfacs	dens	mixuse	compact	code
Aomori	1991	1.27	1.57	0.13	1.42	0.13	0.78	a91
Aomori	1997	1.35	1.36	0.58	1.36	0.58	0.97	a97
Aomori	2006	1.31	0.79	1.80	1.05	1.80	1.42	a06
Sapporo	1991	-0.97	-0.57	-1.29	-0.77	-1.29	-1.03	sp91
Sapporo	1997	-0.82	-0.80	-0.76	-0.81	-0.76	-0.79	sp97
Sapporo	2006	-0.81	-1.09	-0.11	-0.95	-0.11	-0.53	sp06
Sendai	1991	-0.53	0.06	-1.07	-0.24	-1.07	-0.65	sd91
Sendai	1997	-0.42	-0.48	-0.26	-0.45	-0.26	-0.36	sd97
Sendai	2006	-0.37	-0.83	0.97	-0.60	0.97	0.19	sd06

V. Collection and Processing of Data

Procedures in this study are shown in Figure 5. In the first phase, as shown in the left column, the master plan of each MtA, as obtained from the Minister of Land, Infrastructure, Transportation and Tourism of Japan (MLIT) via the Land Use Control Back-up System (LUCKY), is considered. It was necessary to first analyze image files (raster files) with an automated process [35] in a Geographical Information System (GIS) in order to reduce calculation errors.

In the second phase, as shown in the middle column, population data and the development of the spatial regression model (residual Kriging) are developed. Depending on the size of the map and size of the grid, computational time may increase. In the same way as in the first phase, it is necessary to efficiently handle the database in order to reduce time complexity O(N4) [36] or improve the Kriging model. We developed a residual Kriging model for population density, where the population was rescaled in order to reduce calculation errors and the density was rescaled and recentered to have a mean of 0 and a variance of 1[37][38]. Later, the extent of the range was increased in order to obtain the boundaries of the UPA as shown by the Kriging model.

These models were constructed using R software v.2.15 and the package *gstat*. We also used GIS to compare the Kriging models and manipulate the geographical databases. Socioeconomic factors such as land prices, taxes, and population income, etc., were not considered as the focus was on the analysis of the relationship between population and change in land use. To further improve the Kriging model, we developed variograms and later integrated ranges and sills from the variogram model, as shown in table 6.

VI. Results

6.1. Residual Kriging model

The residual Kriging model was useful in calculating the population density in 100m mesh. In Aomori UPA MtA it was clear that the population is concentrated in the urban core. However, there are some areas that are detached from the main part of the UPA. In the southern part there is an area with high population density. For Sendai MtA, the UPA can be divided in two: a western area where most of the residents are concentrated and the commuter belt in the eastern part. The commuter belt is located close to Shiogama and Shichigahama, where the Senseki line is operating and the Sen-en highway helps the transportation process to the commuter belt. For Sapporo UPA MtA, the Kriging model allowed identification of the main area, where most of the population is concentrated. In addition, commuter belts were identified in the areas of Tomakomai and Chitose in the southern part, and in the northern part, close to Otaru and Ishikari. By calculating the Kriging model we identified population hot spots in every period of time.

6.2. Compactness

The compactness index (compact) was calculated and is shown in table 7. As expected, the most compact area corresponds to Aomori UPA MtA in the year 2006, with a

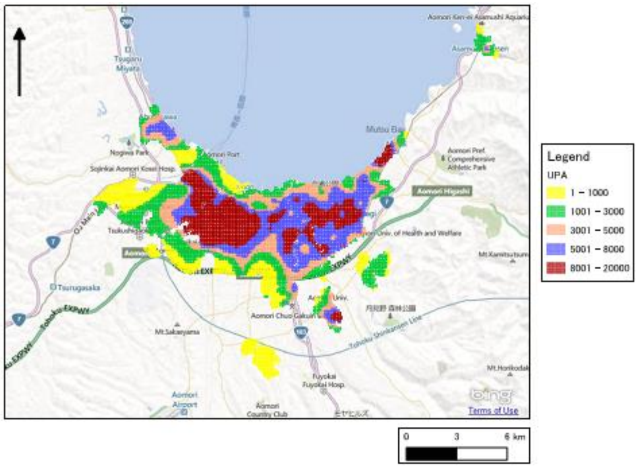

Fig. 6 Population density (people/km^2) for Aomori UPA in 1995.

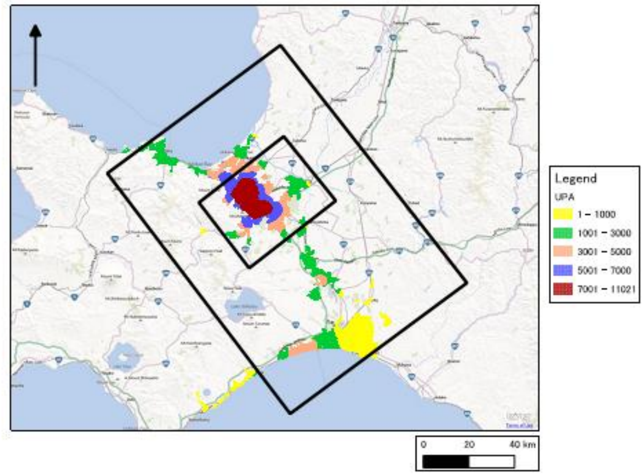

Fig. 7 Population density (people/km^2) for Sapporo UPA in 1995.

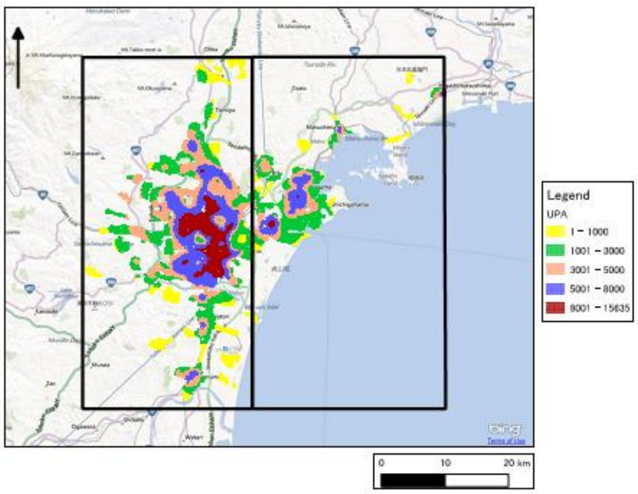

Fig. 8 Population density (people/km^2) for Sendai UPA in 1995

higher index (1.42) than other MtAs. Aomori MtA is the smallest MtA in this study and its compactness index values for all the different periods of time are positive. Sendai UPA MtA is a mid-sized MtA, and it presents a positive compactness index only in the latest period of time. This demonstrates that although residential areas in the UPA are being promoted, it is necessary to improve this in order to increment the index of compactness in this MtA. Sapporo UPA MtA also presents an increment which is not as fast as the other MtAs. This area is the largest MtA. However, if the trend continues this way, the index of compactness will only be positive until 2023. In the same way as in other MtAs it is necessary to improve residential areas. Although residential areas are increasing in the core of the UPA, they are also increasing in the commuter belt. If the situation continues in this direction, it will be difficult to reach an appropriate compact city model in this MtA.

VII. Discussion

7.1. Compact City Model

Geospatial analysis is important for proper urban planning. Without it, territorial chaos would emerge. As a result, countries like Japan seek ways to improve their cities due to high population density and geographical features. Japan invests part of its budget in gathering detailed information related to land use, and scientists and researchers take advantage of this data to create new systems, develop ideas and analyze various changes over time.

When using residual Kriging models to understand population behavior in specific grid areas, the use of variograms is needed in order to understand randomness in the data. During the experiments, it was necessary to enlarge the map range of each MtA. This method was implemented because the Kriging model has some problems nearing the range boundaries. It is important to analyze a compact city model with other detailed information such as socio-economic factors and in consideration of how some specific community services, such as banks, hospitals, ATMs, convenience stores, etc., influence housing.

7.2. Characteristics of Each Metropolitan Area

According to the city planning of Aomori, it is possible to define the boundaries of the UPA (Figure 6). A commuter belt cannot be identified in the area because the size of the UPA is not as wide and extended as other MtAs. On the other hand, Sendai UPA (Figure 7) shows that the area is divided into two parts, the eastern part consisting of Tagajo and Shiogama cities with high population density (also called the regional core). This situation occurred due to important transportation routes such as the Senseki line, Tohoku's main railway line from Tokyo to Aomori, and the Sanriku Expressway.

Sapporo UPA (Figure 8) concentrates high population density mainly in the capital. However, this area in Hokkaido intersects the Sea of Japan and the Pacific Ocean. Cities located in the eastern area such as Eniwa city, Chitose city with a national airport, Tomakomai city as an important harbor and industrial city, and Otaru city, another important harbor to the north, are all part of the commuter belt. Sapporo UPA includes the Hokkaido Expressway, the Kawazoi line and the Ebetsu Eniwa line. This transportation system helps cross the entire area. Figures 9, 10 and 11 show the standard errors of the Kriging models for population density in Aomori, Sendai and Sapporo UPA MtAs in 1995. Aomori presents less dispersion

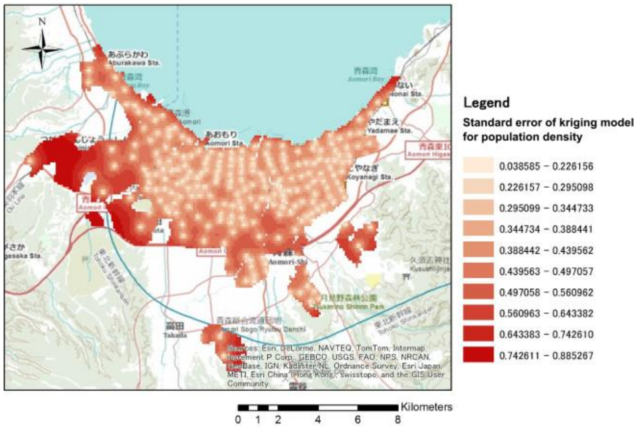

Fig. 9 Standard error of Kriging model in Aomori UPA for population density (1995)

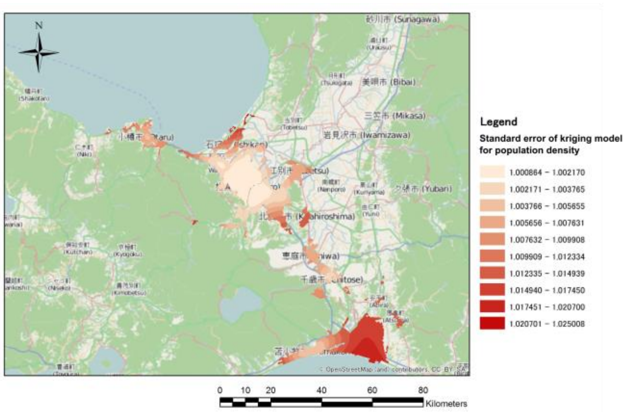

Fig. 11 Standard error of Kriging model in Sapporo UPA for population density (1995)

of the standard error in the urban core than the other MtAs. This is because Aomori is trying to preserve a more well-defined area than Sendai. The reader might see that standard errors are higher in the suburban areas, for example, Sapporo UPA MtA presents a higher standard error in the south-eastern area. This is due to the commuter belt and the geographical conditions in the area.

7.3. Comparison, similarities and differences

Compactness analysis through correspondence analysis allowed the evaluation that in the different periods of time for each MtA (Figure 12), the results show that while the overall density measure (dens) is decreasing, the mixuse is increasing; it is also clear that Aomori UPA MtA preserves the compact city model and is in the positive quadrant. Roychansyah et al. [39] studied characteristics for delivering city compactness in the Tohoku area in the periods of 1980, 1990 and 2000. They noticed that Sendai's MtA had the higher degree of compactness, while Hirosaki and Aomori had the higher degree of compactness as big cities.

In this study, Aomori UPA MtA shows the best behavior of compactness. However, all the MtA compactness indexes are increasing in the different periods of time. According to this evaluation method it can be seen that local governments are

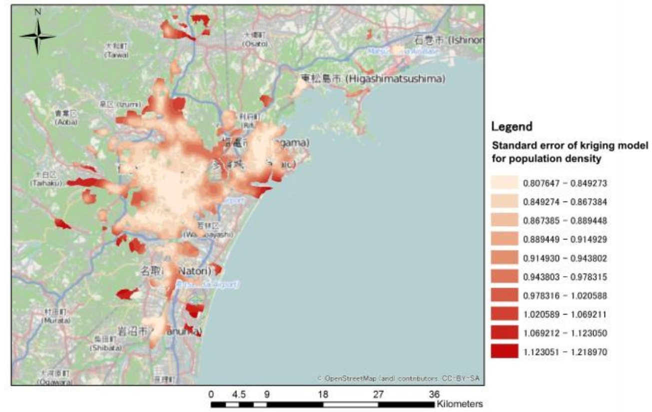

Fig. 10 Standard error of Kriging model in Sendai UPA for population density (1995)

pursuing the compact city model and are looking to grow this index. Aomori UPA MtA is the smallest area and it has been working as a compact city model since the middle of the 90s. For that reason, the land use policies applied in the UPA as UCA are more favorable than the other MtAs. In the UPA, the residential area is an important factor for improving and increasing the index of compactness.

Since the Aomori compact city model is a guide for housing location and proper land use, it should be further studied. Through residual Kriging models and later by analysis of the relationship between land use and population in the different periods of time, it was possible to validate the compact city model developed in Aomori.

VIII. Conclusions

The use of GIS in the development of this study was useful to understand changes in land use, population data and geographic information management. It was possible to graphically understand the situation of different MtAs and to use different tools for geostatistical analysis.

The major findings of this study are summarized as follows:

Using this analysis, it was possible to understand Aomori's compact city model. In future analysis of population behavior, we would like to consider socio-economic factors and other variables which may affect the decision-making process for housing.

The variogram model is useful in finding the best Kriging parameters. The size of the parameters for Sapporo MtA is clearly larger than those of other MtAs. This is because of a large total area and the geographic distribution of the population. In experiments, residual Kriging models showed a disadvantage in interpolating data near the boundaries of the map range. However this could be resolved by extending the analysis area.

The purpose of this study is to describe how the compactness indexes of three Japanese cities (Aomori, Sendai and Sapporo MtA) have changed over time to see if they follow the objectives of a compact city. Using variograms and later the residual Kriging model, we were able to estimate the population density by 100m mesh; and in this way understand

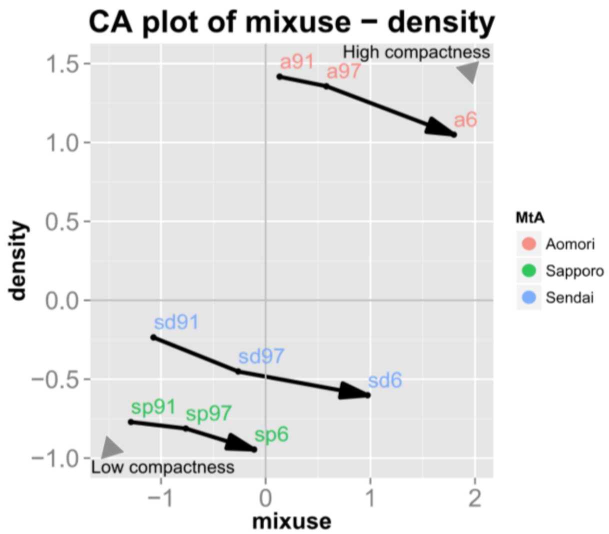

Fig. 12 Correspondence analysis between Mixuse and Density for all MtAs.

how the population is distributed in the compact city model. Through residual Kriging model calculations, it was possible to identify commuter belts in the Sendai and Sapporo MtAs.

Further improvements in the residual Kriging model are required to improve the model scope, because the model presents problems near the boundaries and for that reason it was necessary to increase the extent. In order to evaluate the compactness in a city there are several metrics and therefore it is necessary to choose appropriately which of these are useful to each study. In future experiments, relative entropy will be taken into account because it is not affected by the number of sub-areas. Improved residual Kriging models should be applied to MtAs in other countries.

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