Report of the Meeting for Promotion of the Use of Big Data No,03

June 2022

Validation of SDG Indicator 11.3.1 (Ratio of land consumption rate to population growth rate)

FUJIMURA Hidenori *
HAMAMOTO Ko **
MIZUNO Takayuki ***
OCHIAI Osamu **
SATO Aki-Hiro ****
TAKEUCHI Wataru *****

(in alphabetical order)

* Geospatial Information Authority of Japan
** Japan Aerospace Exploration Agency
*** National Institute of Informatics
**** School of Data Science, Yokohama City University
***** Institute of Industrial Science, the University of Tokyo

Contents

1. Introduction

1.1. Background and Objectives of Estimation and Verification of SDG11.3.1

The 2030 Agenda for Sustainable Development (hereinafter "2030 Agenda"), adopted by the United Nations Summit in September 2015, is based on the concept of "Leave No One Behind" and expresses the determination of the entire international community, including developed and developing countries, to work together to achieve sustainable development and resolve issues. The Sustainable Development Goals (SDGs) have been set as the core of this agenda. The SDGs consist of 17 goals and 169 targets, with 248 indicators (231 excluding duplicates) to measure progress, and require high-quality, accessible, timely, and disaggregated data.

Article 76 of the 2030 Agenda states that the use of a wide range of data, including Earth observation and geospatial information, should be exploited. Special mention should be made of the fact that Japan insisted on the inclusion of Earth observation in the negotiation of this article, which was adopted. Earth observation and geospatial information include satellite, aircraft, ship, and ground observation data and model output data, which have potential for monitoring at local, national, regional, and global levels and across sectors, raising expectations for the integration of Earth observation data and geospatial information into statistics by the UN and national statistical offices in various countries. Among the above, Earth observation satellite data has the advantage of being able to monitor a wide area repeatedly with uniform quality, but it also has issues such as huge data volume and complicated analysis. In addition, in order to use Earth observation satellite data for the calculation of SDG global indicators, its accuracy must be verified and evaluated for its suitability for the purpose.

The UN Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs), for which the UN Statistics Division serves as secretariat, is responsible for developing the indicator framework. One of its working groups, the Working Group on Geospatial Information (WGGI), is considering the use of satellite data and geospatial information for indicator calculation and provides advice and guidance to the IAEG-SDGs. The Japan Aerospace Exploration Agency (JAXA) co-chairs the EO4SDG, an SDG initiative of the Group on Earth Observation (GEO), with the National Aeronautics and Space Administration (NASA) and the National Institute of Statistics and Geographic (INEGI) of Mexico. And JAXA has been invited by the United Nations through the GEO to participate in the WGGI as a satellite data expert, together with NASA and the European Space Agency (ESA), and is participating in the study on the application of Earth observation satellite data to the assessment of SDG global indicators.

In Japan, the “Working Group (WG) on Verlidation of Using Observation Data” (Observation Data WG) has been set up under the “Industry-Government-Academia Partnership Meeting for Promotion of Big Data” (MIC Big Data Meeting) held by Ministry of Internal Affairs and Communications (MIC). With the cooperation of the Transdisciplinary Federation of Science (an association of 34 academic societies, including the Japan Statistical Society and the Remote Sensing Society of Japan) and Technology and related ministries and agencies, verification of indicators based on Earth observation data and geospatial information is underway to examine whether they can be positioned as data for use in calculating the government’s SDG global indicators.

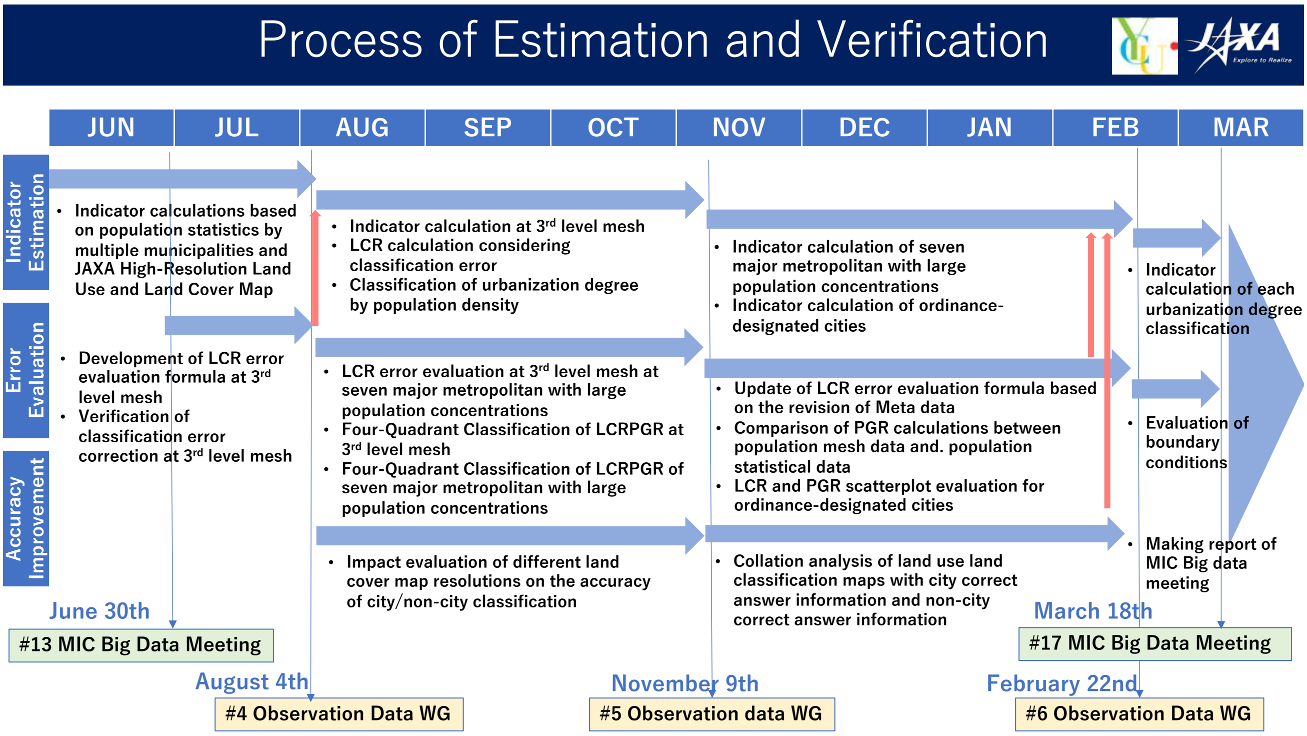
SDG11.3.1 was developed and published by the United Nations Human Settlements Programme (UN-Habitat) as the Custodian agency. According to the metadata published on the website of the UN Statistics Division (revised March 1, 2021), SDG 11.3.1 is defined as the ratio of Land Consumption Rate to Population Growth Rate (LCRPGR) [1-1], and the use of satellite data is also presented in calculating the indicator. In addition, estimates for representative regions in each country for SDG11.3.1 have been published by UN-Habitat [1-2], but in order to confirm the validity of the estimates and to use them in policies and measures for commercial and industrial activities, it is necessary to expand the calculation range of the estimates and to evaluate the reliability of the calculated values in each country.

For this purpose, the Working Group (WG) on Verlidation of Using Observation Data conducted trial calculation and validation of SDG 11.3.1 in FY2021 using data specific to Japan, including JAXA satellite data. This report describes the content conducted in this work, as well as the method used to calculate the key indicators included in SDG 11.3.1: Land Consumption Rate (LCR), Population Growth Rate (PGR), and ratio of Land Consumption Rate to Population Growth Rate (LCRPGR), error evaluation method, error evaluation results, estimated SDG 11.3.1 related indicator values, error estimates, and Japan-specific data used are presented.

1.2. Flow of Estimation and Verification

As shown in Figure/Table 1-1 (F/T 1-1), the process of estimation and verification of SDG11.3.1 is divided into three parts: estimation of indicators (June to July 2021), evaluation of errors (August to November 2021), and improvement of accuracy (November 2021 to January 2022), and carried out in parallel.

Figure/Table 1-1 (F/T 1-1) Schedule of Estimation and Verification of SDG11.3.1 Indicator



2. Overview of SDG11.3.1

2.1. Goal 11 "Sustainable cities and communities", Target 11.3 and SDG11.3.1

Under Goal 11 "Sustainable cities and communities", aiming at participatory, integrated and sustainable human settlement planning and management for Target 11.3, Indicator 11.3.1 "the ratio of Land Consumption Rate to Population Growth Rate (LCRPGR)" is set as follows:

Goal 11 "Sustainable cities and communities"

Make cities and human settlements inclusive, safe, resilient and sustainable

Target 11.3
By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries

SDG11.3.1
Ratio of land consumption rate to population growth rate

2.2. Overview of SDG11.3.1 Meta Data

SDG11.3.1 of the Custodian agency is the United Nations Human Settlements Programme (UN-Habitat), and according to the metadata published by the UN Statistics Division (revised March 1, 2021) [1-1], the ratio of Land Consumption Rate to Population Growth Rate (LCRPGR) is defined as the ratio of Land Consumption Rate (LCR) to Population Growth Rate (PGR). As shown in Equation (Eq.) (2.1), PGR_t is the change of population in a defined region (country, city, etc.) per year over a given period, and expressed as the natural logarithm of the ratio of population at the end of the period to the population at the beginning of the period divided by the number of years in the period. While, as shown in Eq. (2.2), LCR_t is the change of land occupied by a city/urban area per year over a given period, and expressed as the ratio of the change of the land occupied by a city/urban over the period to the land occupied by a city/urban at the beginning of the period divided by the number of years in the period.

$$PGR_t = \frac{\ln(Pop_{t+n}) - \ln(Pop_t)}{y} \quad (2.1)$$

$$LCR_t = \frac{Urb_{t+n} - Urb_t}{Urb_t} \times \frac{1}{y} \quad (2.2)$$

$$LCRPGR_t = \frac{LCR_t}{PGR_t} \quad (2.3)$$

In Eq. (2.1) and Eq. (2.2), PoP_t is the total population of the target region in the first or the past year, PoP_{t+n} is the total population of the target region in the last or the present year, Urb_t is the total area of city/urban area in the first or the past year, Urb_{t+n} is the total area of city/urban area in the last or the present year and y is the number of years in the measurement period for population and the area of the region. Where $\ln(x)$ means the natural logarithm.

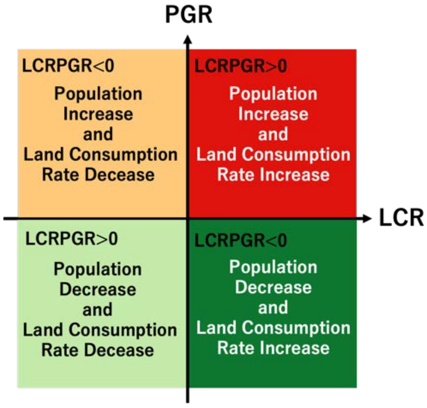
Calculation of $LCRPGR_t$ in Eq. (2.3) requires population data and urban and city area data, and the metadata suggests the use of gridded population datasets and medium-to-high resolution satellite data such as land cover maps.

SDG indicator metadata and indicator formulas are reviewed and updated periodically. For SDG 11.3.1, prior to the March 1, 2021 revision, the formula for LCR_t in Eq. (2.3) was defined as Eq. (2.4) [2-2], thus this paper also compares the old and revised versions in Japan.

$$LCR_t = \frac{\ln(Urb_{t+n}) - \ln(Urb_t)}{y} \quad (2.4)$$

As shown in Eq. (2.3), since LCRPGR is the ratio of LCR to PGR, LCRPGR is positive both when PGR_t and LCR_t are positive values and when PGR_t and LCR_t are negative values as shown in F/T 2-1. Therefore, the assessment of each value of PGR_t and LCR_t is also necessary to compare and evaluate $LCRPGR_t$ among multiple cities and over multiple periods.

F/T 2-1 Four-Quadrant Classification of LCRPGR



2.3. Calculation values by UN-Habitat

UN-Habitat releases LCR, PGR, and LCRPGR estimations for representative cities in each country, including Tokyo, Osaka, Fukuoka, Okayama, and Yamaguchi for Japan [1-2]. As shown in F/T 2-2, these estimates are based on a limited number of cities and a long calculation interval of 15 years. The time resolution of the indicator and the number of target cities are considered insufficient for use in comparing major Japanese cities, including government ordinance-designated cities, and for policy decision making. Therefore, it is necessary to set the target cities and make calculations based on the situation in one's own country for the domestic use of Indicator 11.3.1.

F/T 2-2 LCRPGR Calculation values by UN-Habitat (Excerpts from Japanese Cities)

Cities	**LCR_1990_to_2000**	**LCR_2000_to_2015**	**PGR_1990_to_2000**	**PGR_2000_to_2015**	**LCRPGR_1990_to_2000**	**LCRPGR_2000_to_2015**
Tokyo	0.014851	0.0173	0.008484	0.00658	1.75038	2.62831
Osaka	0.015277	0.005407	0.002587	0.00092	5.90565	5.88961
Fukuoka	0.030163	0.008188	0.003192	0.00032	9.44867	25.27458
Okayama	0.006747	0.005681	0.000163	-	41.38004	-
Yamaguchi	0.017941	0.003232	-	-	-	-

3. Datasets used

3.1. Population data

Considering that the PGR is estimated by 3rd level mesh and by administrative district unit, the following population 3rd level mesh statistical data and population administrative boundary statistical data were used for PGR estimation.

Population 3rd level mesh statistical data:
The following 3rd level mesh (1km grid) population statistical data was retrieved from Portal Site of Official Statistics of Japan, e-Stat of MIC/Statistics Map of Japan (Statistics GIS) [3-1] via API and used.

- Ministry of Internal Affairs and Communications 2010 Population Census – World Geodetic System (1km mesh) Total Population by Sex and Total Households [3-2] (2010 Population Census Population 3rd Level Mesh Statistical Data)

- Ministry of Internal Affairs and Communications 2015 Population Census – World Geodetic System (1km mesh) No.1 Basic Population Data [3-3] (2015 Population Census Population 3rd Level Mesh Statistical Data)

Population administrative boundary statistical data:
The following population statistical data by administrative district was retrieved from Portal Site of Official Statistics of Japan, and the total population in 2010, 2015, and 2020 for government ordinance-designated cities was used.

- Ministry of Internal Affairs and Communications, Population Census / 2010 Population Census / Basic Complete Tabulation on Population and Households Japan [3-4] (2010 Population Census Population Administrative Boundary Statistical Data)
- Ministry of Internal Affairs and Communications, Population Census / 2015 Population Census / Basic Complete Tabulation on Population and Households Japan [3-5] (2015 Population Census Population Administrative Boundary Statistical Data)
- Ministry of Internal Affairs and Communications, Population Census / 2020 Population Census / Basic Complete Tabulation on Population and Households Japan [3-6] (2020 Population Census Population Administrative Boundary Statistical Data)

3.2. Land cover data

Data for the period (version) shown in F/T 3-1 of JAXA HRLULC Map: High-Resolution Land Use and Land Cover Map [3-7] was used as the data for the city/urban area (ratio of city/urban area to the target region) required for the LCR calculation. In the LCR estimation, the built-up and solar panel are regarded as urban areas and cities in the classification categories of JAXA HRLULC Map.

F/T 3-1 JAXA High-Resolution Land Use and Land Cover Map List

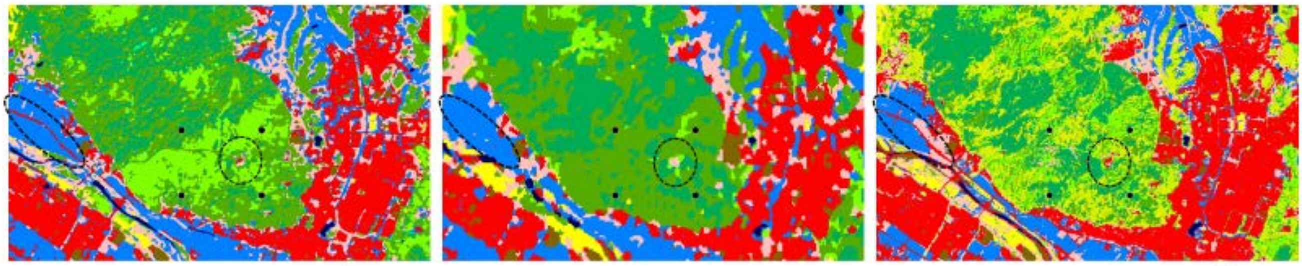
Period (Version)	Resolution	Classification	Overall classification accuracy of all classifications	Producer Accuracy of Artificial Structure Classification*
2006-2011 （ver.16.09）	10 m	10 categories (Water bodies, Built-up, Paddy field, Cropland, Grassland, DBF (deciduous broad-leaf forest), DNF (deciduous needle-leaf forest), EBF (evergreen broad-leaf forest), ENF (evergreen needle-leaf forest), Bare	78.0 %	96.5 %
2014-2016 （ver.18.03）	30 m	10 categories (same as ver16.09)	81.62 %	81.8 %
2018-2020 （ver.21.11）	10 m	12 categories (ver16.09 + Bamboo forest, Solar panel)	88.85 %	95.3 %

*The percentage indicates the ratio of built-up verification data points actually classified as built-up (recall ratio). It is calculated based on the confusion matrix of each version.

The accuracy of JAXA HRLULC Map was verified by comparing the land cover classification of the visually verified data points with the land cover classification automatically classified from the satellite images, and the results are organized and released in a confusion matrix shown in Appendix F/T A-1, F/T A-2, and F/T A-3. [3-8][3-9][3-10]

Because JAXA HRLULC Map uses different satellite data for classification in each target period, the resolution and classification accuracy for built-up differ for each target period, as shown in F/T 3-1. In fact, when the land cover maps were compared period by period, a case was identified where built-up finely distributed in mountainous areas and agricultural land (paddy field) that were captured in the land cover maps of 2006-2011 (Ver. 16.09) and 2018-2020 (Ver. 21.11) were not captured in the 2014-2016 (Ver. 18.03). As a result, there is a possibility that errors in detection/non-detection of built-up may occur in mountainous and suburban areas due to differences in resolution, therefore, an error evaluation that takes into account the accuracy of land cover map classification is necessary in estimating the LCR.

F/T 3-2 Comparison of JAXA HRLULC Maps



Ver16.09, 2006-2011 10 m Resolution | Ver18.03, 2014-2016, 30 m Resolution | Ver21.09, 2018-2020, 10 m Resolution

Four points (black) in the image indicate the four corners of the 3rd level mesh code “2052364018.” No classification of built-up (red) only for 2014-2016 (Ver. 18.03) in the area enclosed by the dashed line (black).

3.3. Administrative district boundary data

In the estimation of PGR and LCR for each administrative district, “Ministry of Land, Infrastructure, Transport and Tourism, Digital National Land Information, Administrative Districts Boundary Data (2021)” [3-12] (2021 Administrative Districts Data) was retrieved from GIS website of Ministry of Land, Infrastructure, Transport and Tourism (MLIT) [3-11] for extracting population 3rd level mesh statistical data and land cover map for each administrative district.

4. Development of error evaluation method

4.1. 95% confidence interval of city population proportion

When the 3rd level mesh statistic of the city ratio in year t within the parcel indicated by the region w_i is $p_{t,i}$, and the area classified as city in year t from the definition of Eq. (2.4) is $m_t(w_i)$, LCR between year t and year $t+n$ in the region w_i is

$$LCR(w) = \frac{\ln m_{t+n}(w_i) - \ln m_t(w_i)}{y} \tag{4.1}$$

When the area of region w_i is $A(w_i)$, the area $m_t(w_i)$ classified as city within the region in year t can be expressed by the city ratio $p_{t,i}$ within w_i as follows,

$$m_t(w_i) = A(w_i)p_{t,i} \tag{4.2}$$

Substituting Eq. (4.2) into Eq. (4.1), the LCR, originally defined as the logarithmic rate of increase in city area, becomes

$$LCR(w) = \frac{\ln\left(A(w_i)p_{t+n,i}\right) - \ln\left(A(w_i)p_{t,i}\right)}{y} = \frac{\ln p_{t+n,i} - \ln p_{t,i}}{y} \tag{4.3}$$

Thus, it is evident that it is possible to calculate the LCR for region w_i using the logarithm of the ratio of the city ratios.

Furthermore, consider estimating the city population proportion $p_{t,i}$ by the sample city proportion $\tilde{p}_{t,i} = n_{t,i}/N_{t,i}$, which is calculated by the total pixels $N_{t,i}$ in region w_i identified by the land cover map in year t and the number of city identified pixels $n_{t,I}$. Since the binomial distribution $\mathrm{B}(p_{t,i},N_{t,i})$ can be approximated by the normal distribution $\mathrm{N}(N_{t,i}p_{t,i},N_{t,i}p_{t,i}(1\text{-}p_{t,i}))$ for sufficiently large $N_{t,i}$, the 95% confidence interval for the city population proportion $p_{t,i}$ is given by

$$\tilde{p}_{t,i} - 1.96\sqrt{\frac{\tilde{p}_{t,i}(1-\tilde{p}_{t,i})}{N_{t,i}}} \le p_{t,i} \le \tilde{p}_{t,i} + 1.96\sqrt{\frac{\tilde{p}_{t,i}(1-\tilde{p}_{t,i})}{N_{t,i}}}$$

4.2. 95% confidence interval of LCR

Consider here how an error ε_x sufficiently small compared to x_0 can cause error propagation for any twice or more differentiable continuous function $f(x)$. Let $z_0 = f(x_0)$ when there is a relation of transformation $z=f(x)$ and $x = x_0 \pm \varepsilon_x$. In this case, the error propagation of z is $z = z_0 \pm \left|\frac{df}{dx}\right|_{x=x_0} \varepsilon_x$. If $f(x) = \ln(x)$, then $\frac{d}{dx}\ln(x) = \frac{1}{x}$, thus,

$$\ln(x_0 \pm \varepsilon_x) = \ln(x_0) \pm \frac{\varepsilon_x}{x_0}$$

Therefore, by setting $p_{t+n,i}$ and $p_{t,i}$ as the city population proportion with year $t+n$ and year t, respectively, and $\delta\alpha_{t+n,i}$ and $\delta\alpha_{t,i}$ as half of the 95% confidence interval width, respectively, the sample LCR is expressed as

$$\widetilde{LCR}(w_i) = \frac{\ln\left(p_{t+n,i} \pm \delta\alpha_{t+n,i}\right) - \ln\left(p_{t,i} \pm \delta\alpha_{t,i}\right)}{y} = \frac{\ln\left(p_{t+n,i}\right) - \ln\left(p_{t,i}\right)}{y} \pm \frac{1}{y}\left(\frac{\delta\alpha_{t+n,i}}{p_{t+n,i}} + \frac{\delta\alpha_{t,i}}{p_{t,i}}\right)$$

Where by expressing the population LCR as

$$LCR(w_i) = \frac{\ln(p_{t+n,i}) - \ln(p_{t,i})}{y} \tag{4.4}$$

the 95% confidence interval of the population LCR is calculated as

$$\widetilde{LCR}(w_i) - \frac{1}{y}\left(\frac{\delta\alpha_{t+n,i}}{p_{t+n,i}} + \frac{\delta\alpha_{t,i}}{p_{t,i}}\right) \le LCR(w_i) \le \widetilde{LCR}(w_i) + \frac{1}{y}\left(\frac{\delta\alpha_{t+n,i}}{p_{t+n,i}} + \frac{\delta\alpha_{t,i}}{p_{t,i}}\right) \quad (4.5)$$

Where $\delta\alpha_{t+n,i} = 1.96\sqrt{\frac{p_{t+n,i}(1-p_{t+n,i})}{N_{t+n,i}}}$, $\delta\alpha_{t,i} = 1.96\sqrt{\frac{p_{t,i}(1-p_{t,i})}{N_{t,i}}}$ then

$$\widetilde{LCR}(w_i) - \frac{1.96}{y}\left(\sqrt{\frac{1-\widetilde{p_{t+n,\iota}}}{n_{t+n,i}}} + \sqrt{\frac{1-\widetilde{p_{t,\iota}}}{n_{t,i}}}\right) \le LRC(w_i) \le \widetilde{LCR}(w_i) + \frac{1.96}{y}\left(\sqrt{\frac{1-\widetilde{p_{t+n,\iota}}}{n_{t+n,i}}} + \sqrt{\frac{1-\widetilde{p_{t,\iota}}}{n_{t,i}}}\right)$$

Where the sample LCR is expressed by the total pixels $N_{t,i}$ in the region w_i identified by the land cover map and the number of pixels $n_{t,i}$ identified as city

$$\widetilde{LCR}(w_i) = \frac{\ln(n_{t+n,i}/N_{t+n,i}) - \ln(n_{t,i}/N_{t,i})}{y} \quad (4.6)$$

4.3. 95% confidence interval of LCR considering classification error

Correction method by confusion matrix of classification error that had been used for SDG15.4.2 [4-1] is used. Correct classification error of city coverage ratios in the city/non-city binary classification problem by calculating the conditional probability $R(a|b)$ from a 2 × 2 confusion matrix for city (1)/non-city (0) binary classification. Calculate 95% confidence interval of LCR which is corrected the city/non-city classification error for each 3rd level mesh.

F/T 4-1 Confusion matrix for city/non-city binary classification

Confusion matrix		**validated** *b*	
	a / b	city (x=1)	non-city (x=0)
classified a	city (x=1)	*TP*	*FP*
	non-city (x=0)	*FN*	*TN*

Consider the confusion matrix for the binary classification, as shown in F/T 4-1. Let $p_{t,i}$ be the true city population proportion of region w_i in year t, and define $R_t(a|b)$ as the conditional probability that actual land cover (validated) is b={1(city), 0(non-city), but land cover classification data (classified) is a={1(city), 0(non-city). From the conditional probability definition,

$$R_t(a|b) = \frac{p_{AB,t}(a,b)}{p_{B,t}(b)} \quad (4.7)$$

the point estimate by sample proportions of the conditional probability $R_t(a|b)$ is calculated as

$$R_t(0|0) = \frac{TN_t}{FP_t + TN_t},\ R_t(1|0) = \frac{FP_t}{FP_t + TN_t}$$
$$R_t(0|1) = \frac{FN_t}{TP_t + FN_t},\ R_t(1|1) = \frac{TP_t}{TP_t + FN_t}$$

From Eq. (4.7),

$$p_A(a) = \sum_b p_{AB}(a,b) = \sum_b R_t(a|b)p_B(b)$$

is established, thus especially

$$p_A(1) = \sum_{b=0,1} R_t(a|b)p_B(b) = R_t(1|1)p_B(1) + R_t(1|0)p_B(0) \tag{4.8}$$

Let $p_{t,i}$ be the true sample city proportion of region w_i in year t. Then $p_B(1) = \hat{p}_{t,i},\ p_B(0) = 1 - \hat{p}_{t,i}$. Thus, the sample city proportion $\tilde{p}_{t,i} = n_{t,i}/N_{t,i}$ calculated in the situation where a classification error is included in the observation is

$$\tilde{p}_{t,i} = R_t(1|1)\hat{p}_{t,i} + R_t(1|0)(1 - \hat{p}_{t,i})$$

Therefore, from

$$\hat{p}_{t,i} = \frac{\tilde{p}_{t,i} - R_t(1|0)}{R_t(1|1) - R_t(1|0)} \tag{4.9}$$

it may be better to correct the true sample city proportion from the sample proportion estimated with classification error. Here only the region that is $\tilde{p}_{t,i} \geq R_t(1|0)$ is subject to estimation.
In addition, estimation from the confusion matrix of $R_t(a|b)$ is the sample proportion, so there are interval estimates. 95% confidence interval is

$$\frac{TN_t}{FP_t+TN_t} - 1.96\sqrt{\frac{TN_t}{FP_t+TN_t}\left(1-\frac{TN_t}{FP_t+TN_t}\right)/(FP_t+TN_t)} \leq R_t(0|0) \leq \frac{TN_t}{FP_t+TN_t} + 1.96\sqrt{\frac{TN_t}{FP_t+TN_t}\left(1-\frac{TN_t}{FP_t+TN_t}\right)/(FP_t+TN_t)} \tag{4.10}$$

$$\frac{FP_t}{FP_t+TN_t} - 1.96\sqrt{\frac{FP_t}{FP_t+TN_t}\left(1-\frac{FP_t}{FP_t+TN_t}\right)/(FP_t+TN_t)} \leq R_t(1|0) \leq \frac{FP_t}{FP_t+TN_t} + 1.96\sqrt{\frac{FP_t}{FP_t+TN_t}\left(1-\frac{FP_t}{FP_t+TN_t}\right)/(FP_t+TN_t)} \tag{4.11}$$

$$\frac{FN_t}{TP_t+FN_t} - 1.96\sqrt{\frac{FN_t}{TP_t+FN_t}\left(1-\frac{FN_t}{TP_t+FN_t}\right)/(TP_t+FN_t)} \leq R_t(0|1) \leq \frac{FN_t}{TP_t+FN_t} + 1.96\sqrt{\frac{FN_t}{TP_t+FN_t}\left(1-\frac{FN_t}{TP_t+FN_t}\right)/(TP_t+FN_t)} \tag{4.12}$$

$$\frac{TP_t}{TP_t+FN_t} - 1.96\sqrt{\frac{TP_t}{TP_t+FN_t}\left(1-\frac{TP_t}{TP_t+FN_t}\right)/(TP_t+FN_t)} \leq R_t(1|1) \leq \frac{TP_t}{TP_t+FN_t} + 1.96\sqrt{\frac{TP_t}{TP_t+FN_t}\left(1-\frac{TP_t}{TP_t+FN_t}\right)/(TP_t+FN_t)} \tag{4.13}$$

By applying Eq.s (4.4), (4.11) and (4.13) to Eq. (4.9), the conditional probabilities calculated from the sample proportion and confusion matrix of the region w_i in year t, respectively, from the error propagation Eq. for the four arithmetic operations can be expressed as

$$a_{t,i} = \tilde{p}_{t,i},\ b_t = R_t(1|0),\ c_t = R_t(1|1)$$

and $\delta a_{t,i}, \delta b_t, \delta c_t$ are half of the 95% confidence interval width of $\tilde{p}_{t,i},\ R_t(1|0),\ R_t(1|1)$, respectively, the confidence interval for the city population proportion $p_{t,i}$ of the region w_i in period t is given by

$$\frac{a_{t,i}-b_t}{c_t-b_t}\left(1-\left(\frac{\delta a_{t,i}+\delta b_t}{a_{t,i,}-b_t}+\frac{\delta c_t+\delta b_t}{c_t-b_t}\right)\right) \leq p_{t,i} \leq \frac{a_{t,i}-b_t}{c_t-b_t}\left(1+\left(\frac{\delta a_{t,i}+\delta b_t}{a_{t,i}-b_t}+\frac{\delta c_t+\delta b_t}{c_t-b_t}\right)\right) \tag{4.14}$$

Eq.s (4.9) and (4.14) are applied to Eq.s (4.4) and (4.5), respectively. Here

$$\hat{p}_{t+n,i} = \frac{a_{t+n,i} - b_{t+n}}{c_{t+n} - b_{t+n}}$$
$$\hat{p}_{t,i} = \frac{a_{t,i} - b_t}{c_t - b_t}$$
$$\delta\alpha_{t+n,i} = \frac{a_{t+n,i} - b_{t+n}}{c_{t+n} - b_{t+n}}\left(\frac{\delta a_{t+n,i} + \delta b_{t+n}}{a_{t+n,i} - b_{t+n}} + \frac{\delta c_{t+n} + \delta b_{t+n}}{c_{t+n} - b_{t+n}}\right)$$
$$\delta\alpha_{t,i} = \frac{a_t - b_t}{c_t - b_t}\left(\frac{\delta a_t + \delta b_t}{a_t - b_t} + \frac{\delta c_t + \delta b_t}{c_t - b_t}\right)$$

Thus, the 95% confidence interval for the sample LCR and population LCR is

$$\widetilde{LCR}(w_i) = \frac{\ln\left(\frac{a_{t+n,i} - b_{t+n}}{c_{t+n} - b_{t+n}}\right) - \ln\left(\frac{a_{t,i} - b_t}{c_t - b_t}\right)}{y} \tag{4.15}$$

$$\widetilde{LCR}(w_i) - \frac{1}{y}\left(\frac{\delta a_{t+n,i} + \delta b_{t+n}}{a_{t+n,i} - b_{t+n}} + \frac{\delta c_{t+n} + \delta b_{t+n}}{c_{t+n} - b_{t+n}} + \frac{\delta a_{t,i} + \delta b_t}{a_{t,i} - b_t} + \frac{\delta c_t + \delta b_t}{c_t - b_t}\right) \le LCR(w_i) \le \widetilde{LCR}(w_i) + \frac{1}{y}\left(\frac{\delta a_{t+n,i} + \delta b_{t+n}}{a_{t+n,i} - b_{t+n}} + \frac{\delta c_{t+n} + \delta b_{t+n}}{c_{t+n} - b_{t+n}} + \frac{\delta a_{t,i} + \delta b_t}{a_{t,i} - b_t} + \frac{\delta c_t + \delta b_t}{c_t - b_t}\right) \tag{4.16}$$

4.4. LCR definition by revised meta data

According to Eq. (2.2), which is the revised metadata [2-2], the LCR for region w_i is defined in place of Eq. (4.1) as

$$LCR(w_i) = \frac{m_{t+n}(w_i) - m_t(w_i)}{m_t(w_i)} \times \frac{1}{y} \tag{4.17}$$

where $m_{t+n}(w_i)$ and $m_t(w_i)$ are the region classified as city in year $t+n$ and the area classified as urban in year t in area w_i. where y is the number of years between year $t+n$ and year t. By substituting Eq. (4.2) into Eq. (4.17),

$$LCR(w_i) = \frac{A(w_i)p_{t+n,i} - A(w_i)p_{t,i}}{A(w_i)p_{t,i}} \times \frac{1}{y} = \frac{p_{t+n,i} - p_{t,i}}{p_{t,i}} \times \frac{1}{y} = \left(\frac{p_{t+n,i}}{p_{t,i}} - 1\right) \times \frac{1}{y} \tag{4.18}$$

By applying Eq. (4.14) to Eq. (4.18), and also using the following error propagation Eq. for the ratio

$$\frac{\alpha \pm \delta\alpha}{\beta \pm \delta\beta} = \frac{\alpha}{\beta}\left(1 \pm \left(\frac{\delta\alpha}{\alpha} + \frac{\delta\beta}{\beta}\right)\right)$$

expressed as

$$\widetilde{LCR}(w_i) \pm \delta = \left(\frac{p_{t+n,i} \pm \delta a_{t+n,i}}{p_{t,i} \pm \delta a_{t,i}} - 1\right) \times \frac{1}{y} = \left(\frac{p_{t+n,i}}{p_{t,i}}\left(1 \pm \left(\frac{\delta p_{t+n,i}}{p_{t+n,i}} + \frac{\delta p_{t,i}}{p_{t,i}}\right)\right) - 1\right) \times \frac{1}{y} = \left(\frac{(a_{t+n,i} - b_{t+n})}{(c_{t+n} - b_{t+n})}\frac{(c_t - b_t)}{(a_t - b_t)}\left(1 \pm \left(\frac{\delta a_{t+n,i} + \delta b_{t+n}}{a_{t+n,i} - b_{t+n}} + \frac{\delta c_{t+n} + \delta b_{t+n}}{c_{t+n} - b_{t+n}} + \frac{\delta a_{t,i} + \delta b_t}{a_{t,i} - b_t} + \frac{\delta c_t + \delta b_t}{c_t - b_t}\right)\right) - 1\right) \times \frac{1}{y} \tag{4.19}$$

Therefore, the 95% confidence interval for the LCR is given by

$$\left(\frac{(a_{t+n,i} - b_{t+n})}{(c_{t+n} - b_{t+n})}\frac{(c_t - b_t)}{(a_t - b_t)}\left(1 - \left(\frac{\delta a_{t+n,i} + \delta b_{t+n}}{a_{t+n,i} - b_{t+n}} + \frac{\delta c_{t+n} + \delta b_{t+n}}{c_{t+n} - b_{t+n}} + \frac{\delta a_{t,i} + \delta b_t}{a_{t,i} - b_t} + \frac{\delta c_t + \delta b_t}{c_t - b_t}\right)\right) - 1\right) \times \frac{1}{y} \le LCR(w_i) \le \left(\frac{(a_{t+n,i} - b_{t+n})}{(c_{t+n} - b_{t+n})}\frac{(c_t - b_t)}{(a_{t,i} - b_t)}\left(1 + \left(\frac{\delta a_{t+n,i} + \delta b_{t+n}}{a_{t+n,i} - b_{t+n}} + \frac{\delta c_{t+n} + \delta b_{t+n}}{c_{t+n} - b_{t+n}} + \frac{\delta a_{t,i} + \delta b_t}{a_{t,i} - b_t} + \frac{\delta c_t + \delta b_t}{c_t - b_t}\right)\right) - 1\right) \times \frac{1}{y} \tag{4.20}$$

4.5. Assessment/Verification

Calculate the sample LCR and 95% confidence intervals for Eq.s (4.15) and (4.16) derived in section 4.3 using actual data. For this calculation, a binary classification confusion matrix for city and non-city was derived based on the published confusion matrix values [3-8][3-9] for Ver 16.09 (2006-2011) and Ver 18.03 (2014-2016) of the JAXA HRLULC Map [3-7], and from it, point estimates and 95% confidence interval widths for the conditional probabilities $R_t(1|0)$ and $R_t(1|1)$ were calculated. F/T 4-2 shows the conditional probabilities for each period. F/T 4.3 also shows the calculation results of the sample LCR and 95% confidence interval widths for the N35E136 tile.

F/T 4-2 Point estimates and 95% confidence interval widths of conditional probabilities $R_t(1|0)$ and $R_t(1|1)$ for (left) Ver 16.09 (2006-2011) and (right) Ver 18.03 (2014-2016)

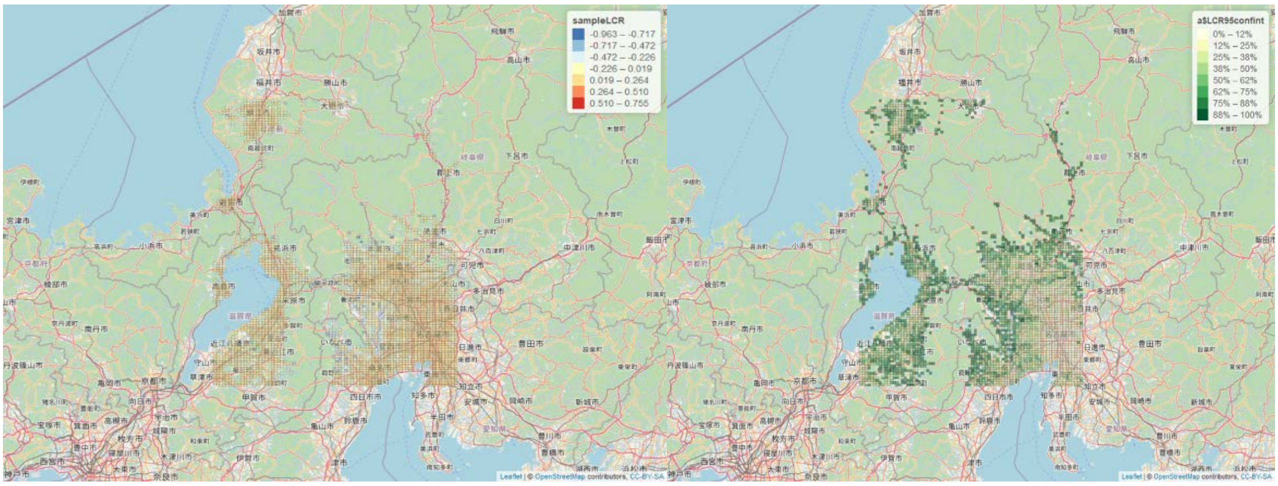
Ver 16.09 (2006-2011)

	Point estimate	95% confidence interval width
$R_t(1\|0)$	0.005937235	0.004385289
$R_t(1\|1)$	0.9652174	0.02368022

Ver 18.03 (2014-2016)

	Point estimate	95% confidence interval width
$R_{t+n}(1\|0)$	0.01832061	0.005135234
$R_{t+n}(1\|1)$	0.8178808	0.04352868

F/T 4-3 3rd level mesh map of (left) sample LCR (corrected values) and (right) 95% confidence interval width in eighth quartile display for N35E136 tile

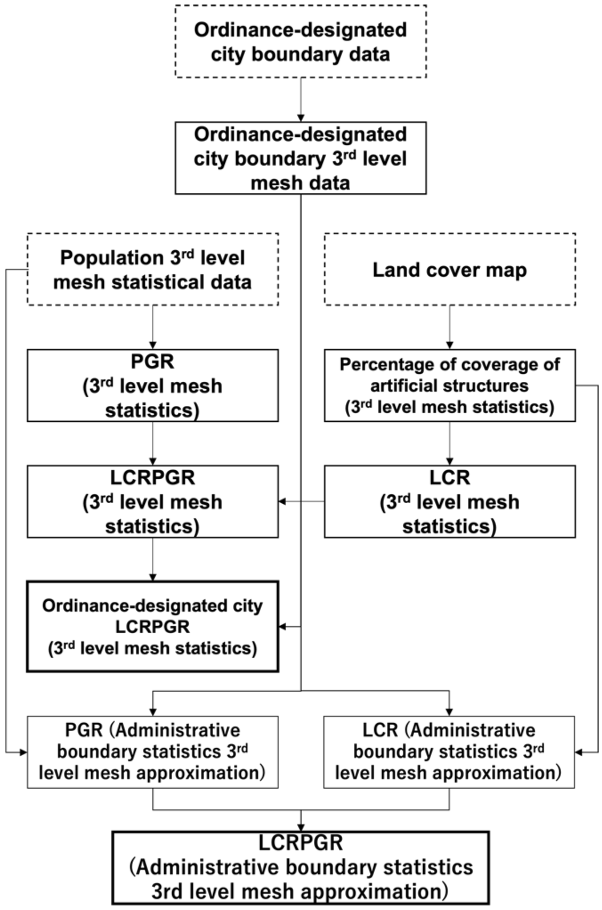


5. Estimation and verification by 3rd level mesh map

5.1. 3rd level mesh visualization application of SDG 11.3.1

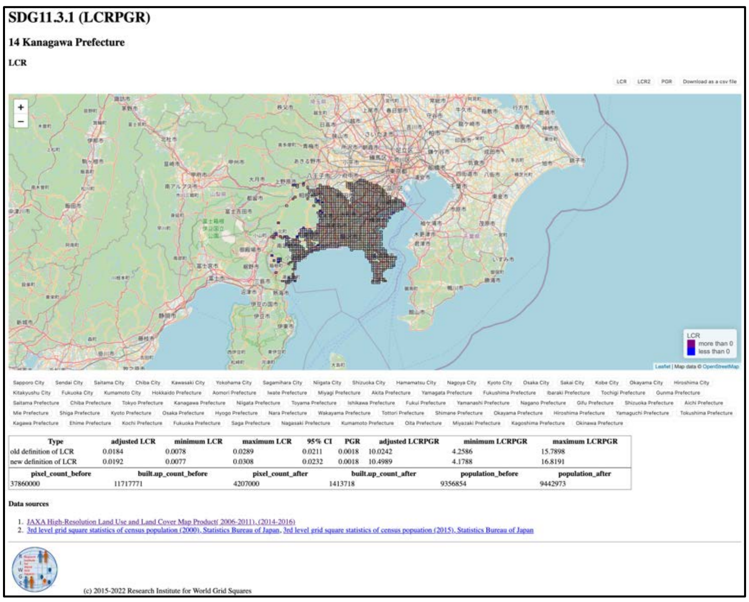
Following the calculation process shown in F/T 5-1, an algorithm was constructed to calculate LCR (3rd level mesh statistics) from the JAXA HRLULC Map [3-7] and PGR (3rd level mesh statistics) from the MIC Population Census Population 3rd level Mesh Statistical Data [3-2][3-3]. An application incorporating this algorithm was developed on MESHSTATS, which is currently under prototype production in the JST MIRAI PROJECT, “Architecture Design and Actual Proof for Self-distributed World Grid Square Statistics Platform”.

F/T 5-1　Overview of LCRPGR (3rd level mesh statistics) calculation process



This application is available as open data and open source, along with calculated indicator values from the Research Institute for World Grid Squares [5-1]. By using this application, LCRPGR indicators can be calculated and visualized at the 3rd level mesh statistical level, as shown in F/T 5-2, and can also be aggregated by administrative division.

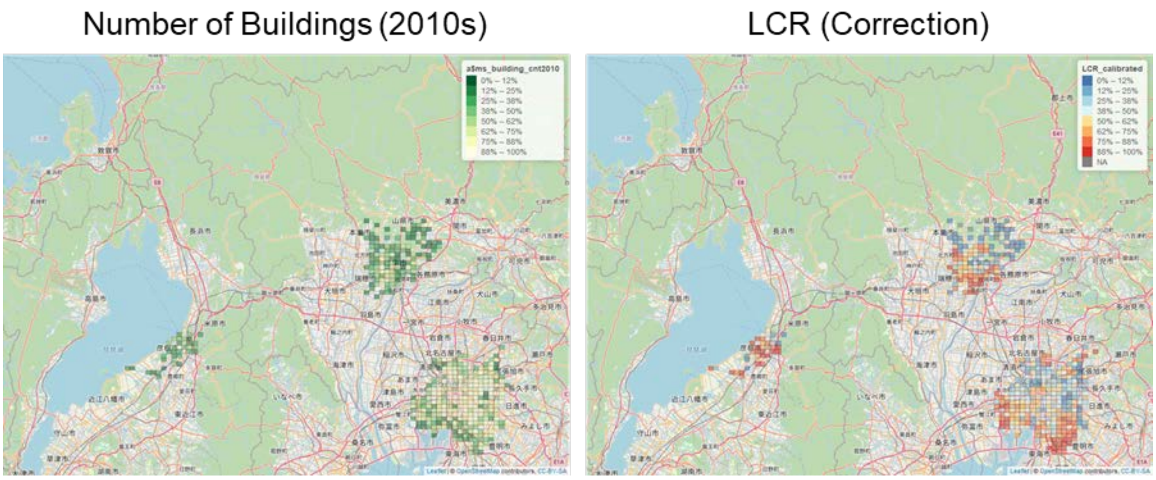
F/T 5-2　　LCRPGR indicator visualization application



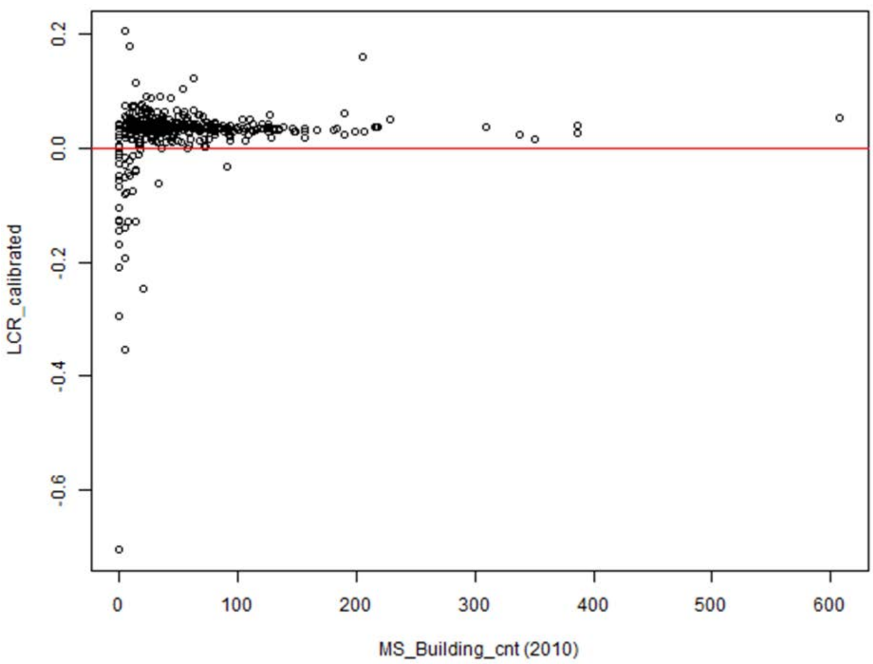
5.2. Collation analysis

In order to verify the validity of the LCR calculated at the 3rd level mesh level, a collation analysis was conducted with data on the age of land and buildings generated using different data collection methods. The data used was statistical data on building age and area data by zip code derived from fire insurance operations data provided by Mitsui Sumitomo Insurance[5-2]. F/T 5-3 shows a mesh map of the number of buildings that started construction in the 2010s and the 3rd level mesh-level LCR (corrected value), obtained by approximate transformation of building age data by zip code derived from Mitsui Sumitomo Insurance operations data to a 3rd level mesh.

F/T 5-3 (Left) Mesh map of 3rd level mesh data of number of buildings construction started in 2010s and (Right) 3rd level mesh data of LCR (corrected value)



F/T 5-4 Scatter plot of 3rd level mesh data of number of new buildings in 2010s and 3rd level mesh data of LCR (corrected values)



F/T 5-4 shows a scatter plot of 3rd level mesh data for the number of buildings construction started in the 2010s and 3rd level mesh level LCR (corrected value), obtained from the building area age statistics data provided by Mitsui Sumitomo Insurance. The scatter plot shows that 98.28% of the 3rd level mesh with LCR (corrected value) greater than 0 have buildings newly constructed in the 2010s.

To calculate the correction and 95% confidence interval of the sample LRC accounting for classification errors, the conditional probabilities calculated from the confusion matrix (Appendix F/T A-4, F/T A-5, and F/T A-6), which is calculated from the collation analysis of the residential location coordinates from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), National Spatial Planning and Regional Policy Bureau, National Land Information Division, Land Market Value Publication Data (2010, 2015, 2020) [5-3] and the JAXA HRLULC Map (2006-2011, 2014-2016, and 2018-2020), is used.

Using the calculated values of $R_t(1|0)$ and $R_t(1|1)$ and their respective 95% confidence interval widths shown in F/T 5-5, calculations were performed using Eq.s (4.15), (4.16) and (4.18) and (4.20).

F/T 5-5 $R_t(1|0)$ and $R_t(1|1)$ calculated by the collation analysis s from the MLIT Land Market Value Publication Data (2010, 2015, 2020) and the JAXA HRLULC Map (2006-2011, 2014-2016, and 2018-2020).

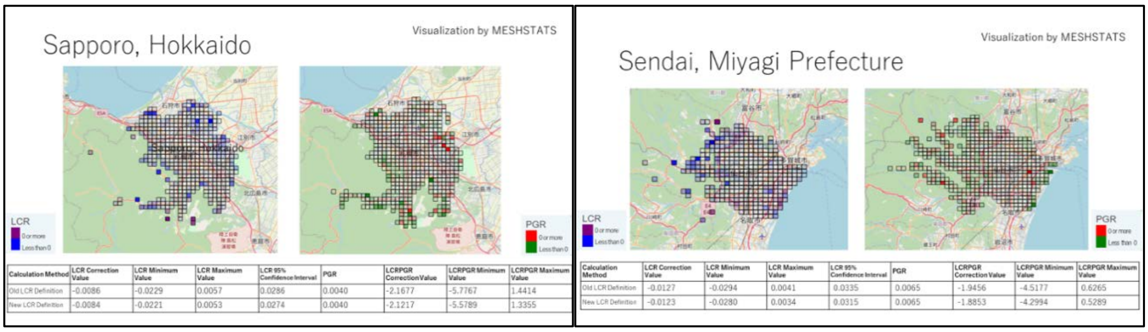
		Point estimate	95% confidence interval width
2006-2011	$R_t(1|0)$	0.00594	0.00439
	$R_t(1|1)$	0.89135	0.00364
2014-2016	$R_t(1|0)$	0.01832	0.00514
	$R_t(1|1)$	0.86368	0.00437
2018-2020	$R_t(1|0)$	0.00801	0.00369
	$R_t(1|1)$	0.94365	0.00279

In the subsequent estimation calculations, $R_t(1|0)$ and $R_t(1|1)$, shown in F/T 5-5, were used as the conditional probabilities calculated from the confusion matrix used to correct for classification error.

5.3. Nationwide estimation by 3rd level mesh level

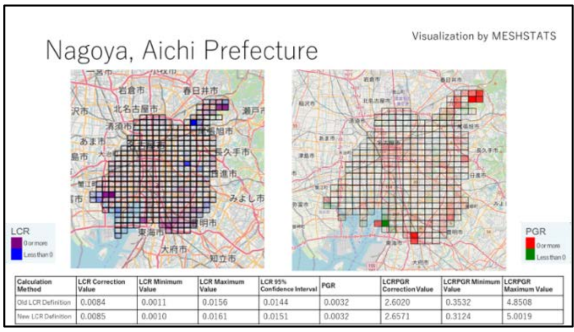
Next, error evaluation of PGR and LCR at the 3rd level mesh is verified in 7 populated cities. F/T 5-6 shows the visualization results of LCR and PGR for 3rd level meshes in Sapporo, Hokkaido; Sendai, Miyagi Prefecture; Nagoya, Aichi Prefecture; Osaka, Osaka Prefecture; Hiroshima, Hiroshima Prefecture; and Fukuoka, Fukuoka Prefecture, and the total values in these regions.

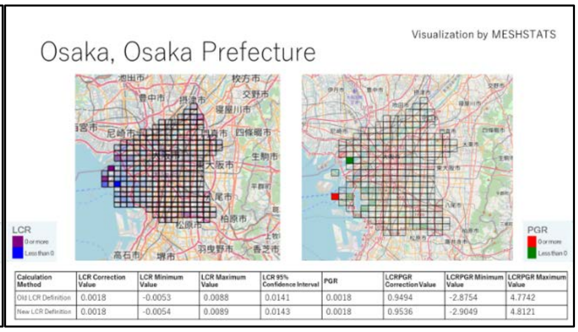
F/T 5-6 PGR and LCR at the 3rd level mesh and total values in seven major metropolitan areas (Sapporo, Hokkaido; Sendai, Miyagi Prefecture; Nagoya, Aichi Prefecture; Osaka, Osaka Prefecture; Hiroshima, Hiroshima Prefecture; and Fukuoka, Fukuoka Prefecture)

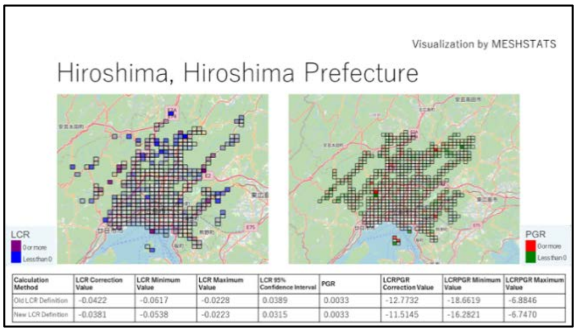


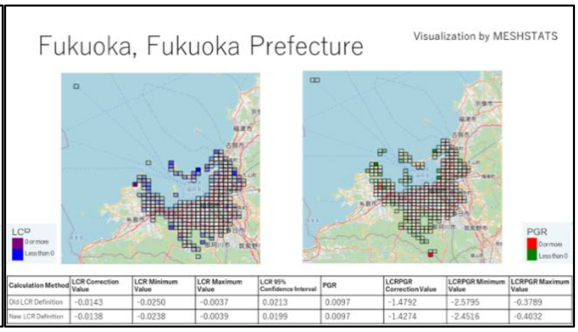
Calculation Method	LCR Correction Value	LCR Minimum Value	LCR Maximum Value	LCR 95% Confidence Interval	PGR	LCRPGR Correction Value	LCRPGR Minimum Value	LCRPGR Maximum Value
Old LCR Definition	-0.0086	-0.0229	0.0057	0.0286	0.0040	-2.1677	-5.7767	1.4414
New LCR Definition	-0.0084	-0.0221	0.0053	0.0274	0.0040	-2.1217	-5.5789	1.3355

Calculation Method	LCR Correction Value	LCR Minimum Value	LCR Maximum Value	LCR 95% Confidence Interval	PGR	LCRPGR Correction Value	LCRPGR Minimum Value	LCRPGR Maximum Value
Old LCR Definition	-0.0127	-0.0294	0.0041	0.0335	0.0065	-1.9456	-4.5177	0.6265
New LCR Definition	-0.0123	-0.0280	0.0034	0.0315	0.0065	-1.8853	-4.2994	0.5289







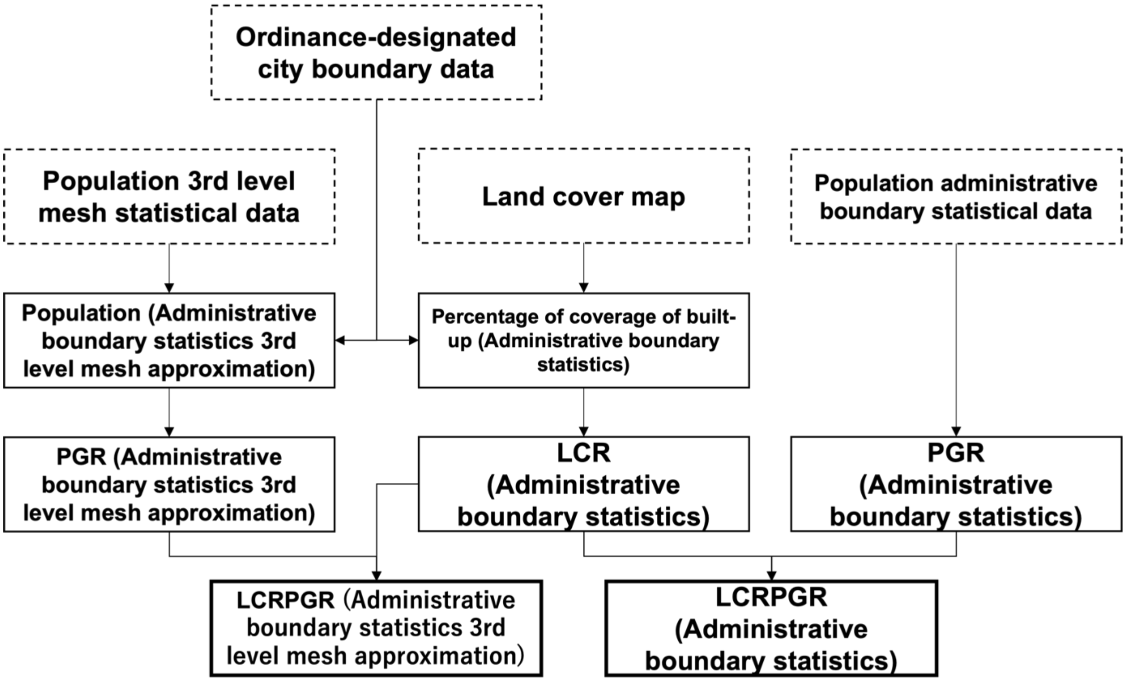


6. Estimation and verification for government ordinance-designated cities

6.1. Calculation process

In order to compare the LCRPGRs of major cities in Japan, the LCR, PGR, and LCRPGR of each city were calculated according to the following procedure (F/T 6-1) using the data described in Chapter 3 for the 20 government ordinance-designated cities shown in Appendix F/T A-7 as major cities representing each region in Japan. The sample LCR and 95% confidence interval widths were calculated using Eq. (4.16) and (4.20) and the values in F/T 5-5.

F/T 6-1 Conceptual Diagram of LCRPGR Calculation Process for Government-Designated Cities



Process (6-1) Create boundary data for each ordinance-designated city from the MLIT, Digital National Land Information, Administrative Districts Boundary Data (2021) [3-12]

Process (6-2) Calculate the total population within the boundaries of each ordinance-designated city using MIC 2010 Population Census Population 3rd level Mesh Statistical Data [3-2], 2015 Population Census Population 3rd level Mesh Statistical Data[3-3] and the results of Process (6-1)

Process (6-3) Calculate PGR (administrative boundary statistics 3rd level mesh approximation) (One period: 2010-2015) using the results of Process (6-2)

Process (6-4) Calculate PGR (administrative boundary statistics) using the total population of ordinance-designated cities acquired from MIC 2010 Population Census Population administrative boundary statistical data [3-4], 2015 Population Census Population administrative boundary statistical data [3-5] and 2020 Population Census Population administrative boundary statistical data [3-6] (Two periods: 2010-2015, 2015-2020)

Process (6-5) Calculate the ratio of pixels of built-up (including the classification of solar panels in 2020) to the total number of pixels within the ordinance-designated city boundaries using JAXA HRLULC Map [3-7] and the results of Process (6-1)

Process (6-6) Calculate LCR (administrative boundary statistics) using the results of Process (6-5) (Two periods: 2010-2015*, 2015-2020)
*For the period 2010-2015, both the old and new LCR formulas were used.

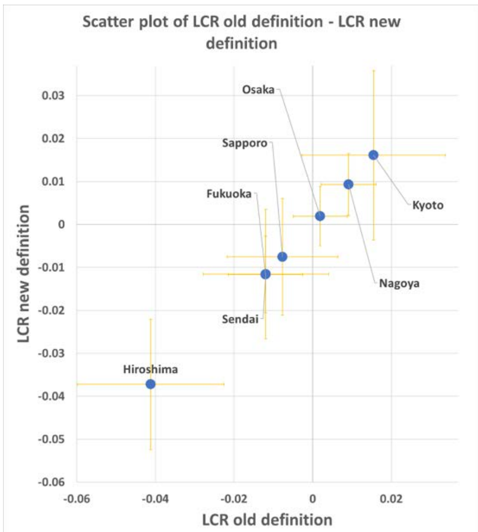
Process (6-7) Calculate LCRPGR (administrative boundary statistics 3rd level mesh approximation) using the results of Process (6-3) and Process (6-6)

Process (6-8) Calculate LCRPGR (administrative boundary statistics) using the results of Process (6-4) and Process (6-6).

6.2. Comparison of new/old definition of LCR

The results of the LCR (administrative boundary statistics) obtained in the calculation process (6-6) in Section 6.1 are plotted on a scatter plot using the two axes of LCR old definition - LCR new definition for the LCR corrected values for representative cities, and are shown in F/T 6-3. The point estimates are confirmed to be almost the same values for the LCR old and new definitions. Furthermore, for the 95% confidence interval widths by the LCR old and new definitions, the value for the LCR new definition is slightly larger than that for the LCR old definition.

F/T 6-3 Scatter plot of LCR old definition - LCR new definition for representative cities (2010-2015)



Error bars indicate 95% confidence interval widths for the old and new LCR definitions.

6.3. Comparison and assessment of boundary condition

Two different boundary conditions, A and B shown in F/T 6-4, are considered when calculating LCR (administrative boundary statistics 3rd level mesh approximation) and PGR (administrative boundary statistics 3rd level mesh approximation) for administrative units such as ordinance-designated city. A is a method that uses pixels or grids within an administrative block region to approximate polygon aggregation. B is a method that approximates the polygon aggregate using pixels or grids that overlap with the administrative block region. The actual aggregate value is always between these values.

F/T 6-4 Comparison of boundary conditions for PGR

A：Land cover maps and 3rd level mesh population data **with the center of the pixel/grid located within the administrative district boundaries** are subject to calculation.

B：Land cover map compiled for each 3rd level mesh and 3rd level mesh population data **with intersections within and with administrative district boundaries** are subject to calculation.

In the estimation and verification of this paper, the LCR (administrative boundary statistics 3rd level mesh approximation) and PGR (administrative boundary statistics 3rd level mesh approximation) obtained in Section 5.1 were calculated using boundary condition B, while the LCR (administrative boundary statistics 3rd level mesh approximation) and PGR (administrative boundary statistics 3rd level mesh approximation) obtained in Section 6.1 were calculated using boundary condition A. The results of these calculations are compared for Kanagawa and Fukuoka prefectures as representative cities, as shown in F/T 6-5.

F/T 6-5 Comparison results of boundary conditions (Left: Kanagawa Prefecture, Right: Fukuoka Prefecture)

Kanagawa

Population Census 2010 https://www.e-stat.go.jp/stat-search/file-download?statInfId=000012660889&fileKind=0

Population Census 2015 https://www.e-stat.go.jp/stat-search/file-download?statInfId=000031495550&fileKind=0

Boundary conditions	LCR correction value	LCR minimum value	LCR maximum value	PGR	LCRPGR correction value	LCRPGR minimum value	LCRPGR maximum value
A	0.01996499	0.008768204	0.03116177	0.001705654	11.70518	5.140671	18.26969
B	0.0192	0.0077	0.0308	0.0018	10.4989	4.1788	16.8191

Population in Kanagaw：9048000 (2010), 9126000 (2015), PGR =0.001716749

Boundary conditions	pixel_count_before	built.up_count_before	pixel_count_after	build.up_count_after	population_before	population_after
A	34527477	11380055	3836380	1374150	8950887	9027549
B	37860000	11717771	4207000	1413718	9356854	9442973

B is aggregated by mesh included in prefectural boundaries using values aggregated by 3rd level mesh.

Fukuoka

Population Census 2010 https://www.e-stat.go.jp/stat-search/file-download?statInfId=000012660889&fileKind=0

Population Census 2015 https://www.e-stat.go.jp/stat-search/file-download?statInfId=000031495550&fileKind=0

Boundary conditions	LCR correction value	LCR minimum value	LCR maximum value	PGR	LCRPGR correction value	LCRPGR minimum value	LCRPGR maximum value
A	-0.01215291	-0.03382473	-0.003805619	0.001194026	-15.75776	-28.3283	-3.187215
B	-0.0202	-0.0361	-0.0043	0.0011	-18.9223	-33.7963	-4.0483

Population in Fukuoka：5072000 (2010), 5102000 (2015), PGR =0.001179481

Boundary conditions	pixel_count_before	built.up_count_before	pixel_count_after	build.up_count_after	population_before	population_after
A	69694845	12370110	7743857	1290936	5007024	5037006
B	76395000	12501814	8488850	1304583	5099268	5126575

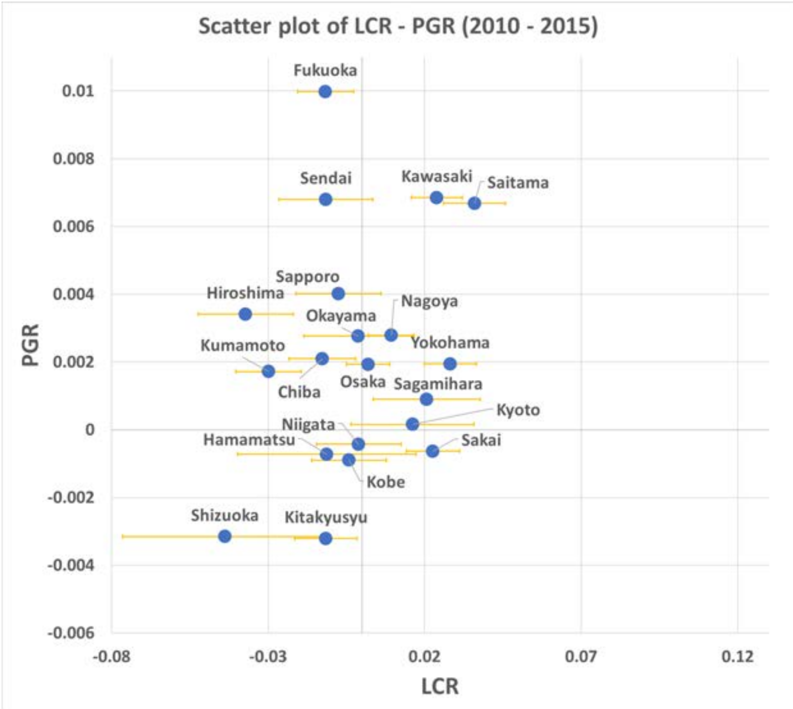
B is aggregated by mesh included in prefectural boundaries using values aggregated by 3rd level mesh.

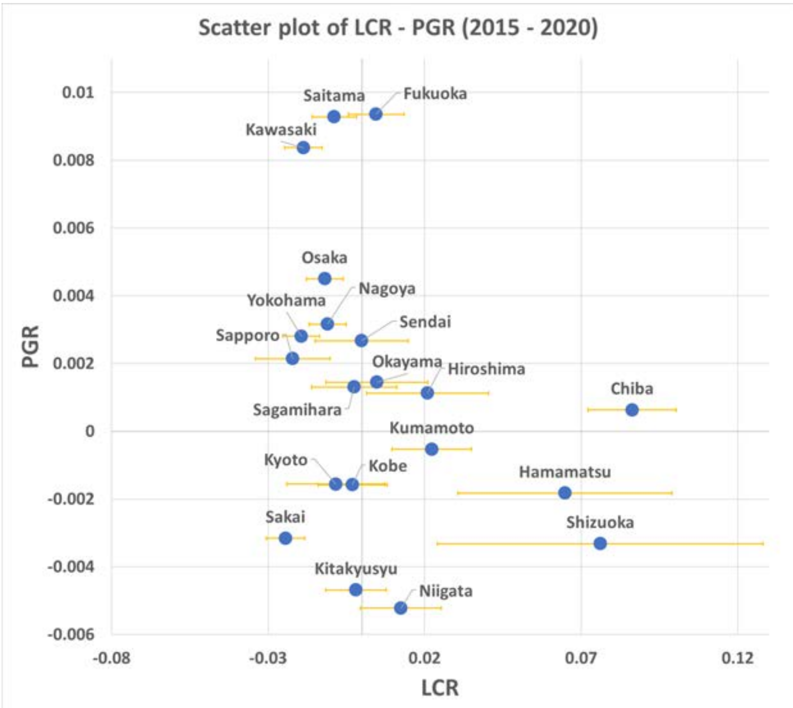
As shown in F/T 6-5, the LCRPGR correction values, minimum LCRPGR values, and maximum LCRPGR values are slightly different due to different methods of calculating the boundary conditions, but they are of roughly the same order of values. Since two different programs were implemented and output the calculation results for the A and B boundary conditions, it was determined that there were no errors in the calculation logic for either method.

6.4. Comparison of LCRPGR for two periods

The results for the two periods (2010-2015 and 2015-2020) of the PGR (administrative boundaries statistics) and LCR (administrative boundaries statistics) corrected values obtained in the calculation process (6-4) and (6-6) in section 6.1 are indicated in F/T 6-6, a scatter plot using two axes of LCR-PGR. (List of Calculation results is indicated in Appendix F/TA-8, F/TA-9.)

F/T 6-6 Scatter plot of LCR-PGR of Government-Designated Cities
(Top: 2010-2015, Bottom: 2015-2020)



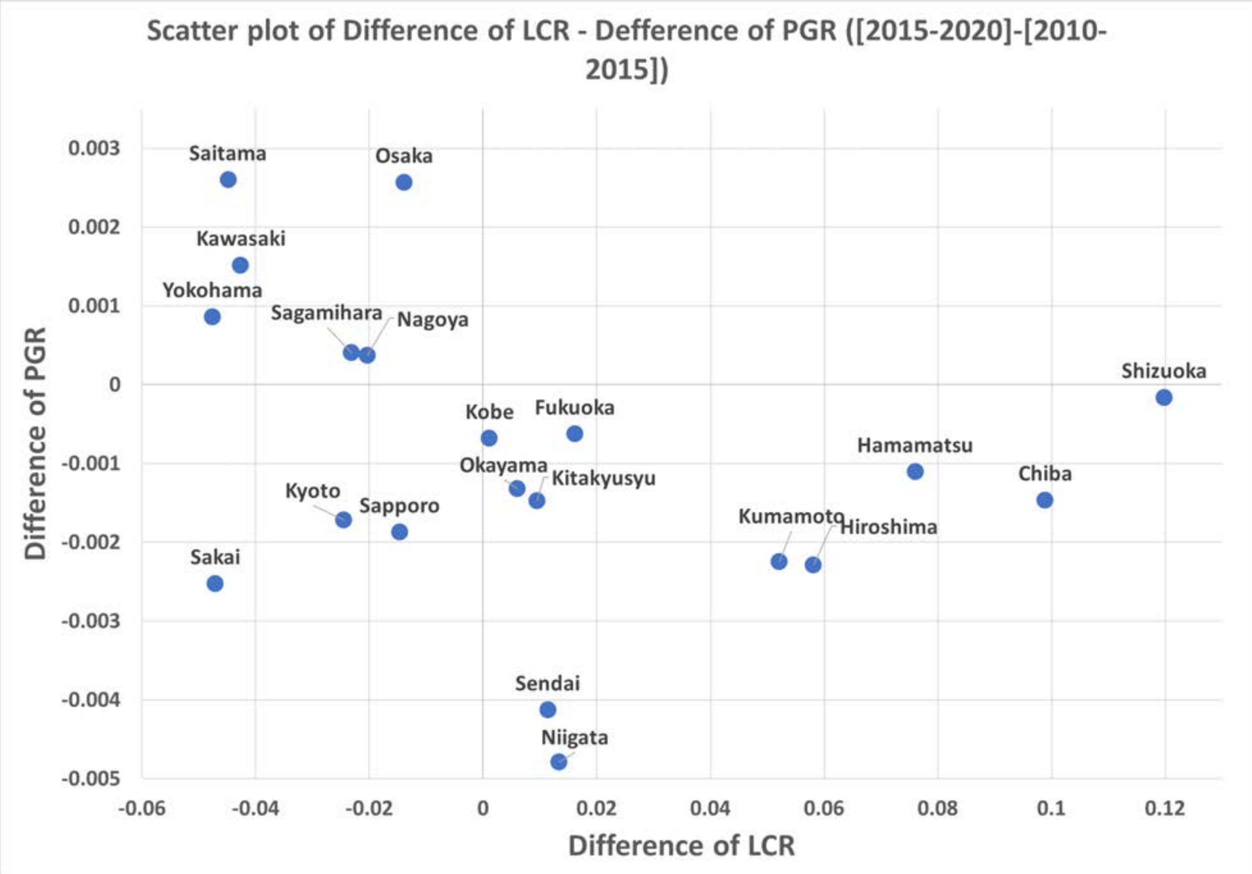


Error bars indicate 95% confidence interval widths for LCR correction values.

As shown in F/T 6.6, the trend of change in cities indicating positive LCR and negative PGR was confirmed: only Sakai City was applicable in 2010-2015, while four cities (Niigata, Hamamatsu, Shizuoka, and Kumamoto) were applicable in 2015-2020.

In order to understand the change during two periods, the difference between LCR (administrative boundary statistics) correction values and the difference between PGR (administrative boundary statistics) correction values for the two periods are indicated in F/T 6-7, a scatter plot of the two axes of LCR-PGR.

F/T 6-7 Scatter plot of Difference of LCR – Difference of PGR of Government-Designated Cities ("2015-2020" - "2010-2015")



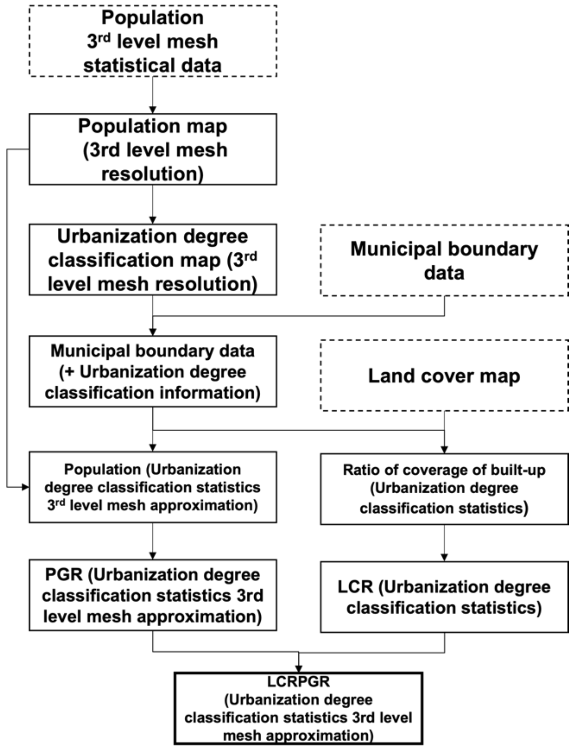
As shown in F/T 6-7, it was confirmed that it is possible to compare the trend of changes in LCR and PGR for each ordinance-designated city, and that no ordinance-designated city shows a trend of increasing both LCR and PGR correction values.

7. Estimation and verification of Urbanization degree classification

7.1. Calculation process

In SDG 11.3.1 metadata [1-1], it is proposed to use a method of setting up city region using population density at the 3rd level mesh, rather than only a single administrative district boundary for the LCRPGR calculation scope [7-1]. In this paper, the following procedure (F/T 7-1) was used to calculate the LCRPGR after performing an urbanization degree classification for all of Japan. For LCR calculation, the sample LCR and 95% confidence interval widths were calculated using Eq. (4.20) and the values in F/T 5-5.

F/T 7-1 Diagram of LCRPGR Calculation Process for Government-Designated Cities



Process (7-1) Create a national population map of 3rd level mesh resolution using MIC 2010 Population Census Population 3rd level Mesh Statistical Data [3-2] and 2015 Population Census Population 3rd level Mesh Statistical Data [3-3]

Process (7-2) Classify the national population map (2015) obtained Process (7-1) into three categories:

1. **Urban centre**:
   Contiguous population grid cells (using 4 adjacent) with a density of at least 1,500 inhabitants/km^2 and a total population of at least 50,000 in the target region
2. **Urban cluster**:
   Contiguous population grid cells with a density of at least 300 inhabitants/km^2 and a total population of at least 5,000 in the target region (including the urban centre region)
3. **Rural grid cells**:
   Remaining population grid cells not belonging to the Urban cluster

Process (7-3) Classify municipalities across the country into three categories based on the following conditions, using the urbanization degree classification map obtained in Process (7-2) and municipal administrative district boundaries MLIT, Digital National Land Information, Administrative Districts Boundary Data (2021) [3-12]"

1. **Cities (or densely populated areas)**:
   Total population of the Urban centre grid is more than 50% of the total population within its boundaries
2. **Towns and semi-dense areas (or intermediate density areas)**:
   Total population of urban centers is less than 50% of the total population within the boundaries, and total population of Rural grid cells is less than 50% of the total population within the boundaries.
3. **Rural areas (or thinly populated areas)**:
   Total population of Rural grid cells is more than 50% of the total population within the boundaries

Process (7-4) Calculate total population of municipalities classified by Cities and Towns and semi-dense areas using the results of Process (7-1) and (7-3).

Process (7-5) Calculate PGR (Urbanization degree classification statistics 3rd level mesh approximation) using the result of Process (7-4).

Process (7-6) Calculate the ratio of coverage of built-up in municipalities classified as Cities and Towns and semi-dense areas using JAXA HRLULC Map [3-7] and the results of Process (7-3).

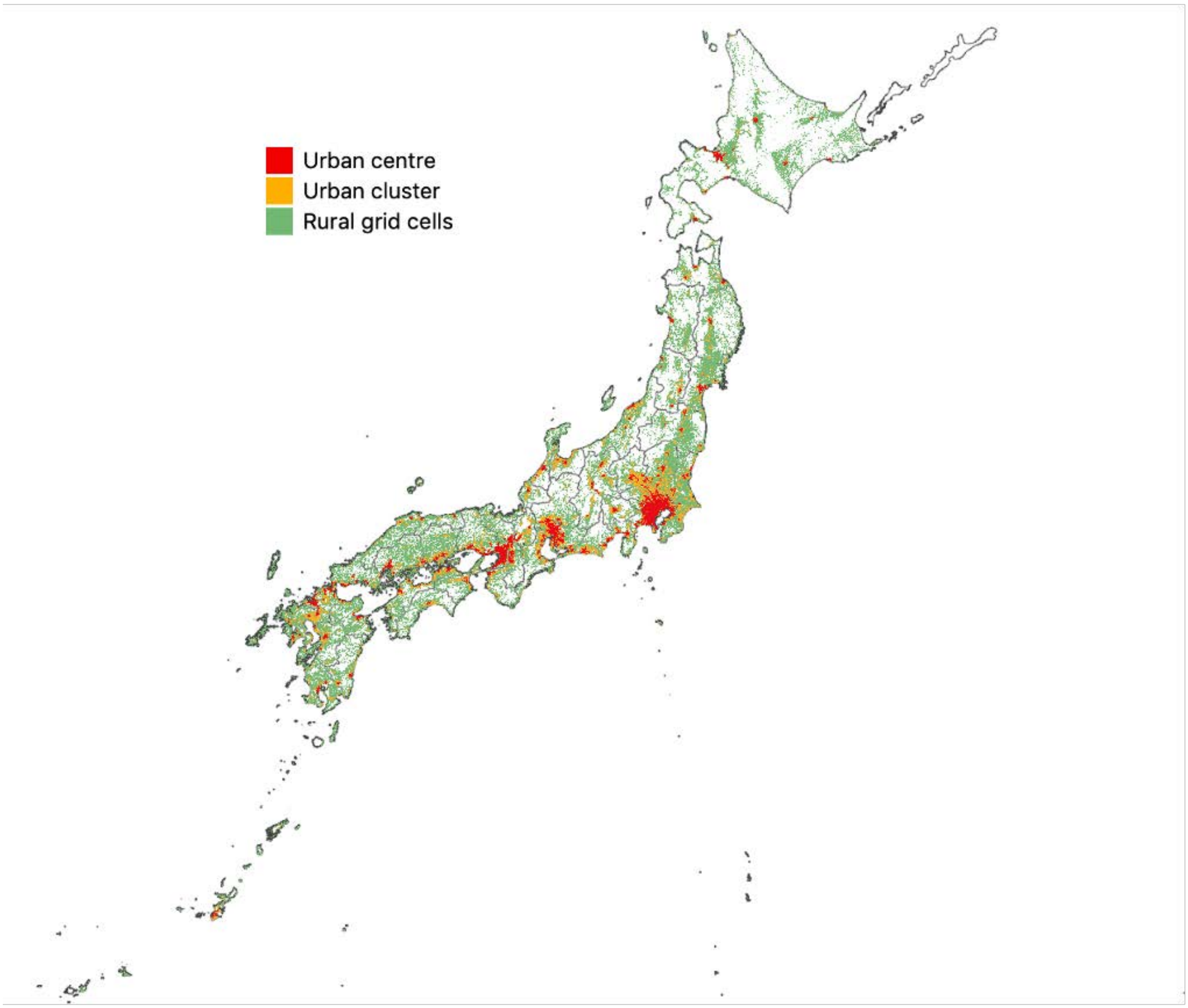
Process (7-7) Calculate LCR (urbanization degree classification statistics) using the results of Process (7-6).

Process (7-8) Calculate LCRPGR (Urbanization degree classification statistics 3rd level mesh approximation) using the results of Process (7-5) and Process (7-7).

7.2. Urbanization degree classification results and LCRPGR of each urbanization degree classification

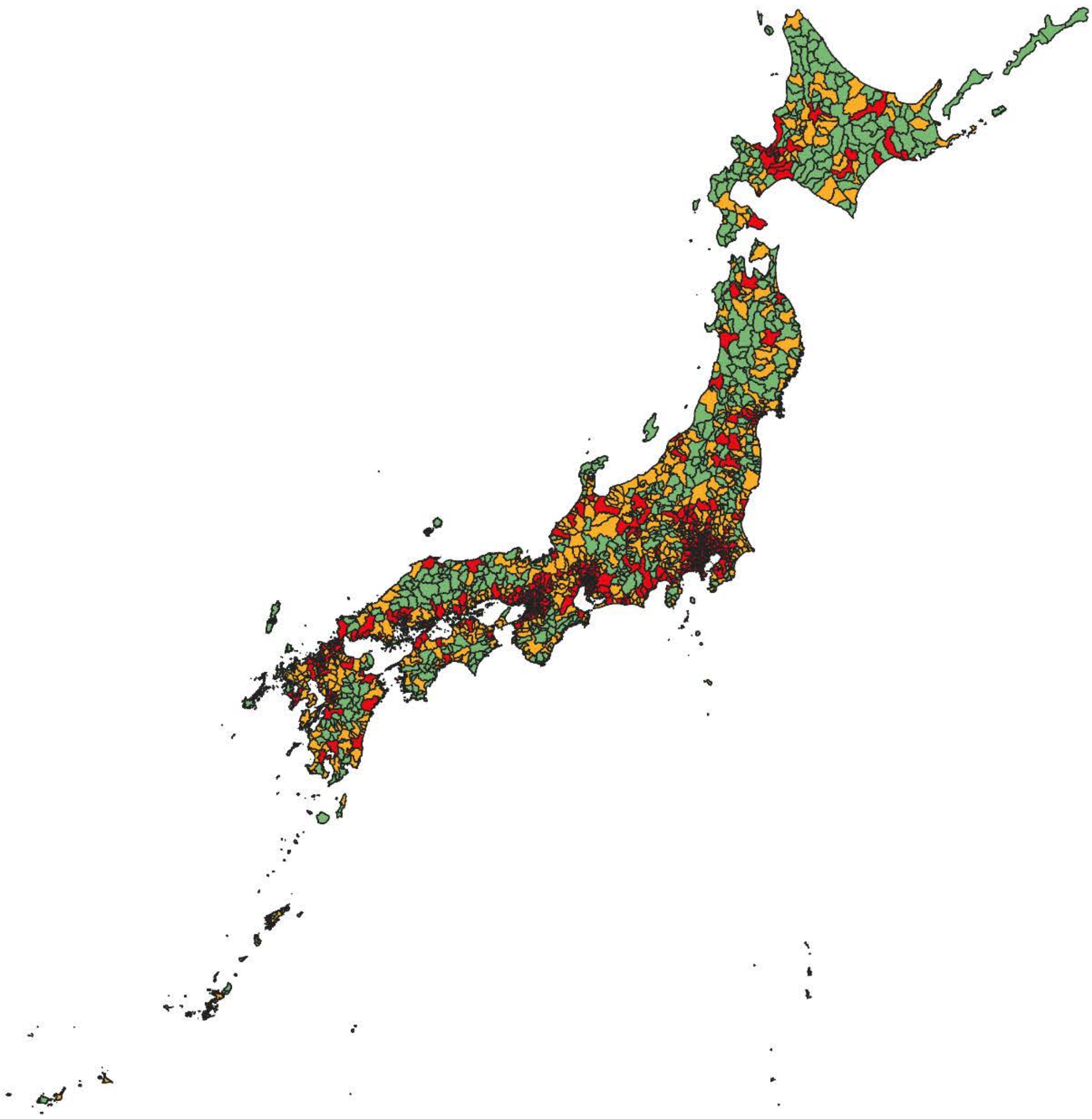
F/T 7-2 shows the urbanization degree classification map (3rd level mesh resolution), and F/T 7-3 shows the urbanization degree classification results for municipalities.

F/T 7-2 Urbanization degree classification Map (3rd level Mesh Resolution)



Red indicates Urban center, orange indicates Urban cluster, green indicates Rural grid cells, and white indicates 3rd level mesh with population of 0.

F/T 7-3 Urbanization degree classification Results for Municipalities

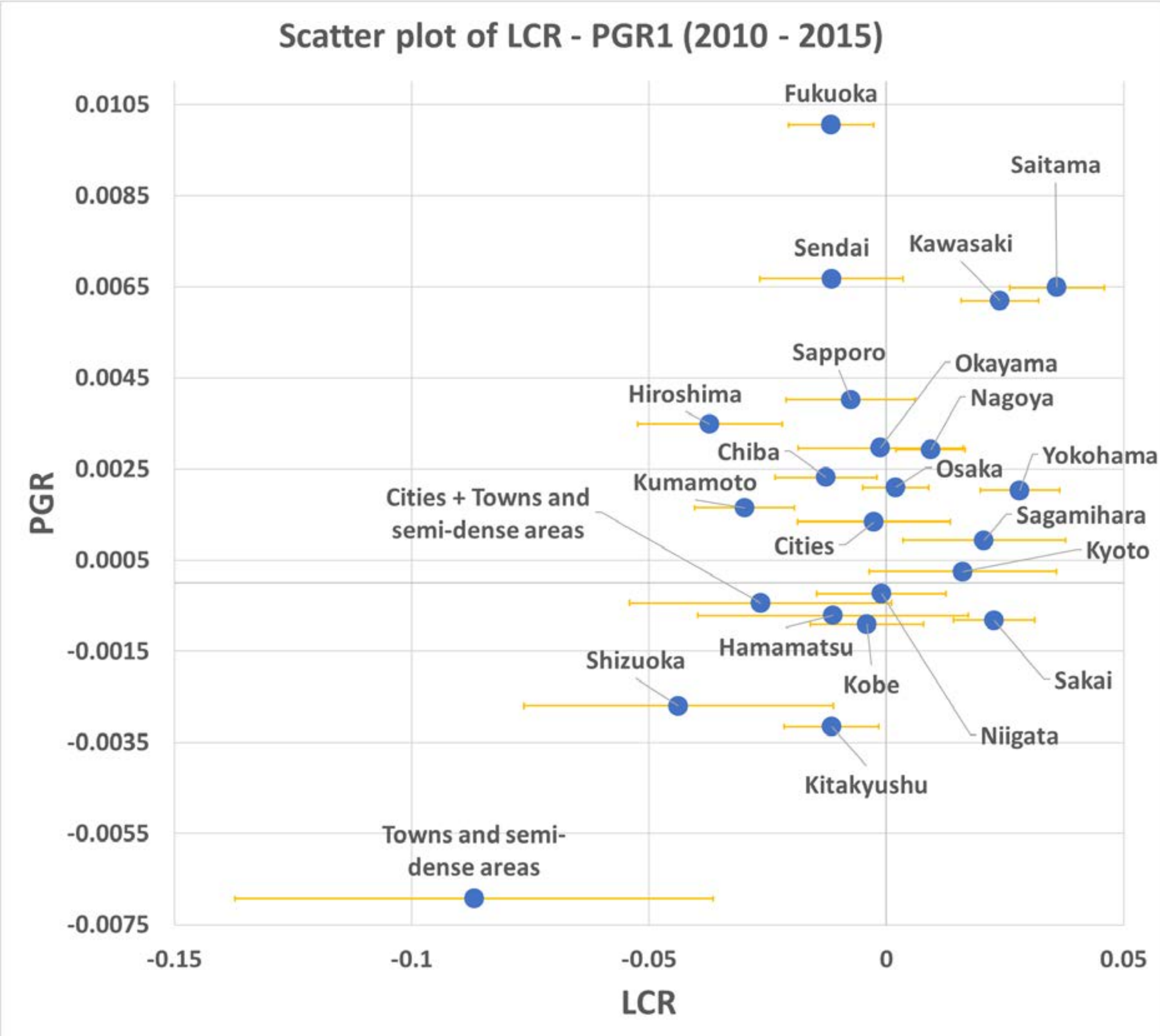


Red indicates Cities (or densely populated areas), green indicates Towns and semi-dense areas (or intermediate density areas), green indicates Rural areas (or thinly populated areas).

As F/T 7-2 shows, 3rd level meshes of Urban centers and Urban clusters are often distributed around large cities such as government-designated cities. On the other hand, as shown in F/T 7-3, in the classification by municipality, the most urbanized category, Cities (or densely populated areas), is distributed mostly around ordinance-designated cities, but is also found in rural areas. In addition, Towns and semi-dense areas (or intermediate density areas) were found to be widely distributed around Cities (or densely populated areas) as well as in rural areas.

Next, the values of the LCR (urbanization degree classification statistics) and PGR (urbanization degree classification statistics 3rd level mesh approximation) are plotted together with the LCR (administrative boundary statistics) and PGR (administrative boundary statistics 3rd level mesh approximation) for government-designated cities for the period 2010-2015 obtained in Section 6.1 on a scatter plot with two axes of LCR-PGR, and the results are shown in F/T 7 -4. List of Calculation results is indicated in Appendix F/TA-10.

F/T 7-4 Scatter plot of LCR-PGR of LCRPGR of Each Urbanization degree classification and LCRPGR of Each Government-Designated City (2010-2015)



Error bars indicate 95% confidence interval widths for LCR correction values.

As F/T 7-4 shows, while the urbanization degree classification, Cities shows average values for ordinance-designated cities, the urbanization degree classification, Towns and semi-dense areas shows large negative values for both LCR and PGR. These trends are consistent with those observed in F/T 7-3, that Cities are distributed mostly in the surrounding areas of government-designated cities, while Towns and semi-dense areas are distributed mostly in relatively rural areas.

8. Summary

In the estimation and verification of this paper, it was confirmed that the ratio of Land Consumption Rate (LCR) to Population Growth Rate (LCRPGR) can be estimated for each 3rd level mesh, government-designated city, and urbanization degree classification using JAXA High-Resolution Land Use and Land Cover Map of Japan, MIC, 3rd level mesh population data, and population statistics information based on metadata before and after the March 2021 revision [2-2].

For the indicator estimation, the error evaluation formulas to calculate 95% confidence intervals for statistical errors in the city population proportion and land cover map classification errors were developed, and it was confirmed that the corrected values for LCR, PGR, and LCRPGR, as well as the minimum and maximum 95% confidence interval values can be calculated.

In order to narrow the 95% confidence interval of the conditional probability of city/non-city and to narrow the 95% confidence interval of the LCR, the number of samples were increased by collation of city correct answer data and land cover map. As a result, it was possible to narrow the 95% confidence interval of the conditional probability of city/non-city.

Comparing the calculation results of the indicators before and after the revision of the metadata, it was confirmed that the point estimates were almost the same values in the LCR new and old definitions. Furthermore, it was confirmed that the 95% confidence interval widths for the new and old LCR definitions were slightly larger than those for the old LCR definition.

Although the calculation results of LCR and PGR change depending on the handling of boundary conditions, it was confirmed that they output values of the same order. In addition, the calculation results of PGR change depending on used population data (Population administrative boundary statistical data and Population 3rd level mesh statistical data), it was confirmed that they output values of the same order. Furthermore, from the viewpoint of computing resources, it was to confirm the usefulness of calculating approximate indicators using 3rd level mesh data, for example, when expanding the scope of indicator estimation verification and calculations.

The LCRPGR values released by UN-Habitat for Japan are limited to the target regions and cities, and there is no information on the spatial distribution of LCR and PGR that covers the entire area of the target region. Therefore, it was not sufficient to understand the situation of population and land use in Japan from the perspective of either bird's eye comparison among cities or local analysis within cities. This estimation and verification allowed us to calculate the values of LCR, PGR, and LCRPGR at the 3rd level mesh for almost all inhabitable land with point estimates and 95% confidence interval estimates, using data from Japan's own Earth observation satellites, geospatial information, and 3rd level mesh population data. This enables us to understand the demographic and land use status of any given administrative and commercial area, and shows the possibility of using the reliability of the LCR, PGR, and LCRPGR values in decision making for policy and commercial activities.

Future issues include the continuous creation of high-resolution land use land cover maps and the collection and updating of land cover map validation data (city/non-city correct data) in order to continuously calculate indicators and improve their accuracy.

Appendix

F/T A-1 Confusion Matrix of JAXA High-Resolution Land Use and Land Cover Map 2006-2011 (ver.16.09)

		Validation											User's accuracy (%)
		1	2	3	4	5	6	7	8	9	10	Total	
Classified	1	193	1	1	0	0	0	0	0	0	2	197	98.0
	2	2	222	2	1	0	0	0	0	0	2	229	96.9
	3	1	2	260	18	6	2	0	1	0	1	291	89.3
	4	1	2	28	76	41	4	1	9	1	5	168	45.2
	5	0	0	10	14	42	4	2	8	0	1	81	51.9
	6	0	1	2	8	5	74	13	15	13	0	131	56.5
	7	0	0	0	0	1	1	11	0	1	0	14	78.6
	8	0	0	0	0	1	5	1	32	16	0	55	58.2
	9	1	0	0	1	0	11	4	30	167	0	214	78.0
	10	0	2	1	1	3	0	0	0	0	22	29	75.9
	Total	198	230	304	119	99	101	32	95	198	33	1409	
Producer's accuracy (%)		97.5	96.5	85.5	63.9	42.4	73.3	34.4	33.7	84.3	66.7		78.0

City
Non-city

F/T A-2 Confusion Matrix of JAXA High-Resolution Land Use and Land Cover Map 2014-2016 (ver.18.03)

		Validation											User's accuracy (%)
		1	2	3	4	5	6	7	8	9	10	Total	
Classified	1	276	1	1	0	0	0	0	1	3	0	282	97.9
	2	3	247	2	7	1	0	0	0	0	35	295	83.7
	3	0	5	284	5	1	1	1	0	0	1	298	95.3
	4	1	3	31	218	26	4	3	1	1	6	294	74.1
	5	0	2	6	14	240	14	0	8	0	5	289	83.0
	6	0	0	0	0	9	236	29	13	11	0	298	79.2
	7	0	0	0	1	4	24	252	4	14	0	299	84.3
	8	0	1	0	1	2	15	7	207	49	0	282	73.4
	9	0	0	0	0	1	6	4	24	264	0	299	88.3
	10	15	43	6	14	23	8	3	6	7	161	286	56.3
	Total	295	302	330	260	307	308	299	264	349	208	2922	
Producer's accuracy (%)		93.6	81.8	86.1	83.8	78.2	76.6	84.3	78.4	75.6	77.4		81.6

City
Non-city

F/T A-3 Confusion Matrix of JAXA High-Resolution Land Use and Land Cover Map 2018-2020 (ver.21.11)

		Validation													User's accuracy (%)
		1	2	3	4	5	6	7	8	9	10	11	12	Total	
Classified	1	153	0	0	0	0	0	0	0	0	1	0	0	154	99.35
	2	0	243	1	2	0	0	1	0	0	8	1	5	261	93.10
	3	0	0	235	17	3	0	0	0	0	0	0	0	255	92.16
	4	0	0	11	188	16	2	1	0	0	5	1	0	224	83.93
	5	0	0	0	19	202	2	1	1	0	4	1	4	234	86.32
	6	0	0	0	2	5	193	39	6	3	0	8	0	256	75.39
	7	0	0	0	0	0	3	162	0	0	0	0	0	165	98.18
	8	0	0	0	1	1	0	0	126	10	0	4	0	142	88.73
	9	0	0	0	1	0	9	7	16	214	1	12	0	260	82.31
	10	3	11	0	6	0	0	0	0	0	199	0	3	222	89.64
	11	0	0	0	1	0	1	0	17	0	0	137	1	157	87.26
	12	0	1	0	0	0	0	0	0	0	0	0	171	172	99.42
	Total	156	255	247	237	227	210	211	166	227	218	164	184	2502	
Producer's accuracy (%)		98.08	95.29	95.14	79.32	88.99	91.90	76.78	75.90	94.27	91.28	83.54	92.93		88.85

City
Non-city

F/T A-4 Confusion Matrix from Collation Analysis of MLIT, National Spatial Planning and Regional Policy Bureau, National Land Information Division, Land Market Value Publication Data (2010) and the JAXA HRLULC Map (2006-2011)

		Validation											User's accuracy (%)
		1	2	3	4	5	6	7	8	9	10	Total	
Classified	1	193	108	1	0	0	0	0	0	0	2	304	63.5
	2	2	24988	2	1	0	0	0	0	0	2	24995	100.0
	3	1	1269	260	18	6	2	0	1	0	1	1558	16.7
	4	1	1224	28	76	41	4	1	9	1	5	1390	5.5
	5	0	20	10	14	42	4	2	8	0	1	101	41.6
	6	0	158	2	8	5	74	13	15	13	0	288	25.7
	7	0	30	0	0	1	1	11	0	1	0	44	25.0
	8	0	72	0	0	1	5	1	32	16	0	127	25.2
	9	1	53	0	1	0	11	4	30	167	0	267	62.5
	10	0	112	1	1	3	0	0	0	0	22	139	15.8
	Total	198	28034	304	119	99	101	32	95	198	33	29213	
Producer's accuracy (%)		97.5	89.1	85.5	63.9	42.4	73.3	34.4	33.7	84.3	66.7		88.5

City
Non-city

		Validation			User's accuracy (%)
		City	Non-city	Total	
Classified	City	24988	7	24995	99.97199
	Non-city	3046	1172	4218	27.78568
	Total	28034	1179	29213	
Producer's accuracy (%)		89.13462	99.40628		89.54917

	Point estimate	95% confidence interval width
R(1|0)	0.00594	0.00439
R(1|1)	0.89135	0.00364

F/T A-5 Confusion Matrix from Collation Analysis of MLIT, National Spatial Planning and Regional Policy Bureau, National Land Information Division, Land Market Value Publication Data (2015) and the JAXA HRLULC Map (2014-2016)

		Validation											User's accuracy (%)
		1	2	3	4	5	6	7	8	9	10	Total	
Classified	1	276	49	1	0	0	0	0	1	3	0	330	83.6
	2	3	20439	2	7	1	0	0	0	0	35	20487	99.8
	3	0	890	284	5	1	1	1	0	0	1	1183	24.0
	4	1	1602	31	218	26	4	3	1	1	6	1893	11.5
	5	0	63	6	14	240	14	0	8	0	5	350	68.6
	6	0	111	0	0	9	236	29	13	11	0	409	57.7
	7	0	60	0	1	4	24	252	4	14	0	359	70.2
	8	0	22	0	1	2	15	7	207	49	0	303	68.3
	9	0	12	0	0	1	6	4	24	264	0	311	84.9
	10	15	417	6	14	23	8	3	6	7	161	660	24.4
	Total	295	23665	330	260	307	308	299	264	349	208	26285	
Producer's accuracy (%)		93.6	86.4	86.1	83.8	78.2	76.6	84.3	78.4	75.6	77.4		85.9

City
Non-city

		Validation			User's accuracy (%)
		City	Non-city	Total	
Classified	City	20439	48	20487	99.76571
	Non-city	3226	2572	5798	44.36012
	Total	23665	2620	26285	
Producer's accuracy (%)		86.36805	98.16794		87.54423

	Point estimate	95% confidence interval width
R(1|0)	0.01832	0.00514
R(1|1)	0.86368	0.00437

F/T A-6 Confusion Matrix from Collation Analysis of MLIT, National Spatial Planning and Regional Policy Bureau, National Land Information Division, Land Market Value Publication Data (2020) and the JAXA HRLULC Map (2018-2020)

		Validation													User's accuracy (%)
		1	2	3	4	5	6	7	8	9	10	11	12	Total	
Classified	1	153	0	0	0	0	0	0	0	0	1	0	0	154	99.35
	2	0	24769	1	2	0	0	1	0	0	8	1	5	24787	99.93
	3	0	100	235	17	3	0	0	0	0	0	0	0	355	66.20
	4	0	1043	11	188	16	2	1	0	0	5	1	0	1267	14.84
	5	0	31	0	19	202	2	1	1	0	4	1	4	265	76.23
	6	0	83	0	2	5	193	39	6	3	0	8	0	339	56.93
	7	0	10	0	0	0	3	162	0	0	0	0	0	175	92.57
	8	0	9	0	1	1	0	0	126	10	0	4	0	151	83.44
	9	0	27	0	1	0	9	7	16	214	1	12	0	287	74.56
	10	3	102	0	6	0	0	0	0	0	199	0	3	313	63.58
	11	0	35	0	1	0	1	0	17	0	0	137	1	192	71.35
	12	0	39	0	0	0	0	0	0	0	0	0	171	210	81.43
	Total	156	26248	247	237	227	210	211	166	227	218	164	184	28495	
Producer's accuracy (%)		98.08	94.37	95.14	79.32	88.99	91.90	76.78	75.90	94.27	91.28	83.54	92.93		93.87

City
Non-city

		Validation			User's accuracy (%)
		City	Non-city	Total	
Classified	City	24769	18	24787	99.92738
	Non-city	1479	2229	3708	60.11327
	Total	26248	2247	28495	
Producer's accuracy (%)		94.36528	99.19893		94.74645

	Point estimate	95% confidence interval width
R(1|0)	0.00801	0.00369
R(1|1)	0.94365	0.00279

F/T A-7 List of Ordinance-designated Cities *

City	Transition Date	Cabinet Order for Designation
Osaka	1956/9/1	Article 254 of the Cabinet Order, 1956
Nagoya	1956/9/1	
Kyoto	1956/9/1	
Yokohama	1956/9/1	
Kobe	1956/9/1	
Kitakyushu	1963/4/1	Article 10 of the Cabinet Order, 1963
Sapporo	1972/4/1	Article 276 of the Cabinet Order, 1971
Kawasaki	1972/4/1	
Fukuoka	1972/4/1	
Hiroshima	1980/4/1	Article 237 of the Cabinet Order, 1979
Sendai	1989/4/1	Article 261 of the Cabinet Order, 1988
Chiba	1992/4/1	Article 324 of the Cabinet Order, 1991
Saitama	2003/4/1	Article 319 of the Cabinet Order, 2002
Shizuoka	2005/4/1	Article 322 of the Cabinet Order, 2004
Sakai	2006/4/1	Article 323 of the Cabinet Order, 2005
Niigata	2007/4/1	Article 338 of the Cabinet Order, 2006
Hamamatsu	2007/4/1	
Okayama	2009/4/1	Article 315 of the Cabinet Order, 2008
Sagamihara	2010/4/1	Article 251 of the Cabinet Order, 2009
Kumamoto	2012/4/1	Article 323 of the Cabinet Order, 2011

* Excerpt from the list of Ordinance-designated Cities by the Ministry of Internal Affairs and Communications [6-1]

F/T A-8 LCRPGR (administrative boundary statistics) Estimation value of Ordinance-designated Cities (2010-2015)

	built-up_ratio_before	built-up_ratio_after	LCR	LCR_calibrated	LCR_min	LCR_max	LCR_95%_interval	population_before	population_after	PGR	LCRPGR	LCRPGR_calibrated	LCRPGR_1	LCRPGR_2	LCRPGR_min	LCRPGR_max
Sapporo	0.22166501	0.216543723	-0.004620744	-0.007523352	-0.021071283	0.006024578	0.027095861	1913545	1952356	0.004015861	-1.15062347	-1.873409481	-5.247014731	1.50019577	-5.247014731	1.50019577
Sendai	0.191863194	0.185581224	-0.006548385	-0.011555003	-0.026607938	0.003497932	0.03010587	1045986	1082159	0.006799628	-0.963050487	-1.69935814	-3.91314624	0.51442996	-3.91314624	0.51442996
Saitama	0.512127305	0.588538623	0.029840751	0.035967973	0.02606424	0.045871706	0.019807466	1222434	1263979	0.006684146	4.464407636	5.381087455	3.899412294	6.862762616	3.899412294	6.862762616
Chiba	0.335648972	0.313186737	-0.013384361	-0.012665428	-0.023376486	-0.00195437	0.021422116	961749	971882	0.002096179	-6.385122352	-6.042149311	-11.15194986	-0.932348763	-11.15194986	-0.932348763
Kawasaki	0.716120131	0.777380188	0.017108877	0.023887894	0.015739719	0.032036068	0.016296348	1425512	1475213	0.006854268	2.496091184	3.485112368	2.296338546	4.67388619	2.296338546	4.67388619
Yokohama	0.654411308	0.724609962	0.021453986	0.028147221	0.019836395	0.036458047	0.016621652	3688773	3724844	0.001946218	11.02342441	14.46252294	10.19227859	18.73276729	10.19227859	18.73276729
Sagamihara	0.192972892	0.215299373	0.023139499	0.020610244	0.003525085	0.037695402	0.034170317	717544	720780	0.000899938	25.71233055	22.90185236	3.917031976	41.88667274	3.917031976	41.88667274
Niigata	0.23314282	0.234099305	0.000820514	-0.001061433	-0.014609872	0.012487005	0.027096877	811901	810157	-0.000430071	-1.907855853	2.468040995	33.97082817	-29.03474618	-29.03474618	33.97082817
Shizuoka	0.068697135	0.065113582	-0.010432905	-0.043812565	-0.076422457	-0.011202674	0.065219783	716197	704989	-0.003154614	3.307189253	13.88840842	24.22561399	3.551202849	3.551202849	24.22561399
Hamamatsu	0.087129557	0.091471165	0.009965868	-0.011268674	-0.039772026	0.017234678	0.057006704	800866	797980	-0.000722022	-13.80272894	15.6071164	55.08426508	-23.87003228	-23.87003228	55.08426508
Nagoya	0.771455495	0.783363755	0.003087219	0.009341438	0.002069073	0.016613803	0.01454473	2263894	2295638	0.002784892	1.108559532	3.354326405	0.742963244	5.965689567	0.742963244	5.965689567
Kyoto	0.149819743	0.166764157	0.022619734	0.016115725	-0.003588345	0.035819795	0.039408141	1474015	1475183	0.000158416	142.786967	101.7304381	-22.65141399	226.1122901	-22.65141399	226.1122901
Osaka	0.829237854	0.812036539	-0.004148705	0.001944189	-0.004972028	0.008860405	0.013832433	2665314	2691185	0.001931949	-2.147419874	1.006335693	-2.57358172	4.586253106	-2.57358172	4.586253106
Sakai	0.647325698	0.700091336	0.016302655	0.02266009	0.014105246	0.031214934	0.017109687	841966	839310	-0.000631902	-25.79935976	-35.86015957	-22.32190533	-49.39841382	-49.39841382	-22.32190533
Kobe	0.282205777	0.276630501	-0.003951213	-0.004143546	-0.016064387	0.007777295	0.023841682	1544200	1537272	-0.000899312	4.393595547	4.60746255	17.86297476	-8.648049661	-8.648049661	17.86297476
Okayama	0.165601394	0.169818073	0.005092565	-0.001239488	-0.018619866	0.01614089	0.034760756	709584	719474	0.002768301	1.839599143	-0.447743247	-6.726097961	5.830611468	-6.726097961	5.830611468
Hiroshima	0.169687299	0.145581539	-0.028411979	-0.037203172	-0.052396687	-0.022009656	0.030387031	1173843	1194034	0.003410902	-8.329755989	-10.90713673	-15.36153515	-6.45273831	-15.36153515	-6.45273831
Kitakyushu	0.36214055	0.33880103	-0.012889758	-0.011535023	-0.02152279	-0.001547256	0.019975533	976846	961286	-0.003211409	4.013739558	3.591888894	6.701977918	0.48179987	0.48179987	6.701977918
Fukuoka	0.450218278	0.417839883	-0.014383421	-0.011632388	-0.020557147	-0.002707629	0.017849518	1463743	1538681	0.009985741	-1.440396031	-1.164899914	-2.058650255	-0.271149573	-2.058650255	-0.271149573
Kumamoto	0.309185376	0.26459949	-0.028840876	-0.029879374	-0.040338031	-0.019420717	0.020917314	734474	740822	0.001721157	-16.75668172	-17.36005364	-23.43658145	-11.28352583	-23.43658145	-11.28352583

F/T A-9 LCRPGR (administrative boundary statistics) Estimation value of Ordinance-designated Cities (2015-2020)

	built-up_ratio_before	built-up_ratio_after	LCR	LCR_calibrated	LCR_min	LCR_max	LCR_95%_interval	population_before	population_after	PGR	LCRPGR	LCRPGR_calibrated	LCRPGR_min	LCRPGR_max
Sapporo	0.216543723	0.203070016	-0.01244433	-0.022182076	-0.034073566	-0.010290587	0.023782979	1952356	1973395	0.002143712	-5.805037411	-10.34750626	-15.89465439	-4.800358128
Sendai	0.185581224	0.193002507	0.007997882	-0.000141889	-0.014947327	0.014663549	0.029610876	1082159	1096704	0.00267024	2.995192499	-0.053137123	-5.59774727	5.491473024
Saitama	0.588538623	0.611196896	0.007699842	-0.008850392	-0.015936882	-0.001763902	0.01417298	1263979	1324025	0.009282332	0.829515975	-0.953466501	-1.716905076	-0.190027926
Chiba	0.313186737	0.475120353	0.103410264	0.086257332	0.072157302	0.100357361	0.028200058	971882	974951	0.000630563	163.9966973	136.794134	114.4331214	159.1551467
Kawasaki	0.777380188	0.76948482	-0.002031276	-0.018723193	-0.024669539	-0.012776847	0.011892692	1475213	1538262	0.008370164	-0.242680528	-2.236896689	-2.947318343	-1.526475034
Yokohama	0.724609962	0.713787618	-0.002987081	-0.019429102	-0.025328254	-0.01352995	0.011798305	3724844	3777491	0.002807012	-1.064149666	-6.92163077	-9.023207758	-4.820053782
Sagamihara	0.215299373	0.223241338	0.007377602	-0.002554306	-0.016141643	0.01103303	0.027174673	720780	725493	0.001303493	5.659871149	-1.959585816	-12.38337527	8.464203636
Niigata	0.234099305	0.261601674	0.023496327	0.012367527	-0.00061074	0.025345795	0.025956535	810157	789275	-0.005222651	-4.498927465	-2.368055593	-4.853051836	0.11694065
Shizuoka	0.065113582	0.079500655	0.044190698	0.076074247	0.0241175	0.128030994	0.103913493	704989	693389	-0.003318206	-13.3176469	-22.92631729	-38.5844001	-7.268234486
Hamamatsu	0.091471165	0.115201991	0.051887008	0.064791474	0.030625604	0.098957345	0.068331741	797980	790718	-0.001828428	-28.37792993	-35.43561262	-54.1215365	-16.74968875
Nagoya	0.783363755	0.808392098	0.006389967	-0.010951167	-0.016890991	-0.005011342	0.01187965	2295638	2332176	0.003158187	2.023302083	-3.467548049	-5.348318277	-1.58677782
Kyoto	0.166764157	0.165407783	-0.001626698	-0.008398718	-0.024089658	0.007292222	0.03138188	1475183	1463723	-0.001559772	1.042907688	5.38458054	-4.675184559	15.44434564
Osaka	0.812036539	0.834356994	0.005497402	-0.011869187	-0.017744474	-0.005993901	0.011750573	2691185	2752412	0.0044992	1.221862004	-2.63806598	-3.943917264	-1.332214696
Sakai	0.700091336	0.670375325	-0.008489181	-0.024441541	-0.030578414	-0.018304668	0.012273746	839310	826161	-0.003158091	2.688073481	7.739339721	5.796117566	9.682561876
Kobe	0.276630501	0.289626819	0.009396157	-0.002994007	-0.014010785	0.00802277	0.022033554	1537272	1525152	-0.001583068	-5.935409731	1.891268986	-5.067861844	8.850399815
Okayama	0.169818073	0.1797195	0.011661217	0.004809513	-0.011419676	0.021038702	0.032458378	719474	724691	0.001444994	8.0700824	3.328397435	-7.902925333	14.5597202
Hiroshima	0.145581539	0.163603288	0.024758289	0.02093097	0.001458761	0.040403178	0.038944417	1194034	1200754	0.001122441	22.05755143	18.64773167	1.299633217	35.99583012
Kitakyushu	0.33880103	0.359223453	0.012055703	-0.001969664	-0.011682269	0.007742942	0.019425212	961286	939029	-0.004685122	-2.573188861	0.42040818	-1.652666193	2.493482553
Fukuoka	0.417839883	0.460202483	0.020276954	0.004525682	-0.004370993	0.013422358	0.017793351	1538681	1612392	0.009358647	2.16665438	0.483582972	-0.46705397	1.434219914
Kumamoto	0.26459949	0.310914432	0.035007582	0.022249243	0.009571494	0.034926993	0.025355498	740822	738865	-0.000529031	-66.173011	-42.05658765	-66.0206776	-18.0924977

F/T A-10　LCRPGR (administrative boundary statistics 3rd level mesh approximation) Estimation value of Ordinance-designated Cities (2010-2015) and LCRPGR (urbanization degree classification statistics 3rd level mesh approximation) of Urbanization degree classification (2010-2015)

	built-up_ratio_before	built-up_ratio_after	LCR	LCR_calibrated	LCR_min	LCR_max	LCR_95%_interval	population_before	population_after	PGR	LCRPGR	LCRPGR_calibrated	LCRPGR_min	LCRPGR_max
Sapporo	0.22166501	0.216543723	-0.004620744	-0.007523352	-0.021071283	0.006024578	0.027095861	1905922	1944610	0.004019112	-1.149692695	-1.871894021	-5.242770256	1.498982215
Sendai	0.191863194	0.185581224	-0.006548385	-0.011555003	-0.026607938	0.003497932	0.03010587	1033824	1068891	0.006671423	-0.981557476	-1.732014788	-3.988345363	0.524315786
Saitama	0.512127305	0.588538623	0.029840751	0.035967973	0.02606424	0.045871706	0.019807466	1203953	1243604	0.006480661	4.604584379	5.550046782	4.021848898	7.078244665
Chiba	0.335648972	0.313186737	-0.013384361	-0.012665428	-0.023376486	-0.00195437	0.021422116	946956	957994	0.002317777	-5.774654126	-5.464472021	-10.0857352	-0.843208843
Kawasaki	0.716120131	0.777380188	0.017108877	0.023887894	0.015739719	0.032036068	0.016296348	1409849	1454173	0.00619095	2.763530434	3.858518533	2.542375655	5.174661411
Yokohama	0.654411308	0.724609962	0.021453986	0.028147221	0.019836395	0.036458047	0.016621652	3689004	3726553	0.002025435	10.59228571	13.89687718	9.793646953	18.00010741
Sagamihara	0.192972892	0.215299373	0.023139499	0.020610244	0.003525085	0.037695402	0.034170317	684846	688043	0.000931468	24.84196638	22.12662307	3.784440173	40.46880597
Niigata	0.23314282	0.234099305	0.000820514	-0.001061433	-0.014609872	0.012487005	0.027096877	805146	804181	-0.000239852	-3.420918788	4.42536987	-52.06132767	60.91206741
Shizuoka	0.068697135	0.065113582	-0.010432905	-0.043812565	-0.076422457	-0.011202674	0.065219783	698489	689126	-0.002699061	3.865383864	16.23252426	4.150582607	28.31446592
Hamamatsu	0.087129557	0.091471165	0.009965868	-0.011268674	-0.039772026	0.017234678	0.057006704	800716	797865	-0.000713383	-13.96986137	15.79609754	-24.15906619	55.75126126
Nagoya	0.771455495	0.783363755	0.003087219	0.009341438	0.002069073	0.016613803	0.01454473	2243914	2276979	0.00292558	1.055250051	3.19302032	0.70723491	5.67880573
Kyoto	0.149819743	0.166764157	0.022619734	0.016115725	-0.003588345	0.035819795	0.039408141	1469291	1471087	0.000244322	92.58151563	65.96090905	-14.68693035	146.6087484
Osaka	0.829237854	0.812036539	-0.004148705	0.001944189	-0.004972028	0.008860405	0.013832433	2651108	2678946	0.002089154	-1.985830456	0.930610773	-2.379924402	4.241145947
Sakai	0.647325698	0.700091336	0.016302655	0.02266009	0.014105246	0.031214934	0.017109687	830187	826797	-0.000818355	-19.92123975	-27.68978933	-38.14349094	-17.23608772
Kobe	0.282205777	0.276630501	-0.003951213	-0.004143546	-0.016064387	0.007777295	0.023841682	1534597	1527617	-0.00091176	4.33361003	4.544557119	-8.529978318	17.61909256
Okayama	0.165601394	0.169818073	0.005092565	-0.001239488	-0.018619866	0.01614089	0.034760756	703772	714282	0.00296468	1.717744924	-0.418084935	-6.28056426	5.444394389
Hiroshima	0.169687299	0.145581539	-0.028411979	-0.037203172	-0.052396687	-0.022009656	0.030387031	1171002	1191603	0.003487933	-8.145791871	-10.66625071	-15.02227296	-6.310228456
Kitakyushu	0.36214055	0.33880103	-0.012889758	-0.011535023	-0.02152279	-0.001547256	0.019975533	968611	953460	-0.003153123	4.087934207	3.658285562	0.490706021	6.825865103
Fukuoka	0.450218278	0.417839883	-0.014383421	-0.011632388	-0.020557147	-0.002707629	0.017849518	1416260	1489271	0.010053429	-1.430698051	-1.157056809	-2.044789657	-0.269323961
Kumamoto	0.309185376	0.26459949	-0.028840876	-0.029879374	-0.040338031	-0.019420717	0.020917314	724508	730511	0.001650297	-17.47617221	-18.10545143	-24.44289032	-11.76801254
1:Cities	0.167794176	0.170812905	0.003598133	-0.002644769	-0.018776391	0.013486852	0.032263243	93731182	94360751	0.001338859	2.687462549	-1.975390613	-14.02417529	10.07339407
2:Towns and semi-dense areas	0.038797722	0.036075007	-0.014035436	-0.086810454	-0.13718531	-0.036435598	0.100749712	26239578	25346613	-0.006924754	2.02684976	12.53625096	5.26164509	19.81085683
1+2	0.082540424	0.081765057	-0.001878755	-0.026503972	-0.054129763	0.001121819	0.055251582	119970760	119707364	-0.000439583	4.273947959	60.29343353	-2.552007299	123.1388744

Reference

[1-1] United Nations Statistics Division (UNSD), Department of Economic and Social Affairs (DESA), SDG Indicators Metadata repository, Indicator 1.3.1, https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf, Last access date April 27, 2022

[1-2] UN-Habitat, Urban Indicators Database, 11 3 1 Land Consumption Rates 1990 2000 and 2015, https://data.unhabitat.org/datasets/GUO-UN-Habitat::11-3-1-land-consumption-rates-1990-2000-and-2015/about, Last access date May 2, 2022

[2-1] Ministry of Foreign Affairs, Japan SDGs Action Platform, https://www.mofa.go.jp/mofaj/gaiko/oda/sdgs/statistics/index.html, Last access date April 27, 2022

[2-2] United Nations Human Settlements Programme (UN-Habitat), Metadata on SDGs Indicator 11.3.1 Indicator category: Tier II, https://data.unhabitat.org/documents/GUO-UN-Habitat::metadata-on-sdg-indicator-11-3-1/explore, Last access date April 27, 2022

[3-1] Portal Site of Official Statistics of Japan, e-Stat of MIC/Statistics Map of Japan (Statistics GIS), https://www.e-stat.go.jp/gis, Last access date April 27, 2022

[3-2] Ministry of Internal Affairs and Communications 2010 Population Census - World Geodetic System (1km mesh) Total Population by Sex and Total Households, https://www.e-stat.go.jp/gis/statmap-search?page=1&type=1&toukeiCode=00200521&toukeiYear=2010&aggregateUnit=S&serveyId=S002005112010&statsId=T000608, Last access date April 27, 2022

[3-3] Ministry of Internal Affairs and Communications 2015 Population Census - World Geodetic System (1km mesh) No.1 Basic Population Data, https://www.e-stat.go.jp/gis/statmap-search?page=1&type=1&toukeiCode=00200521&toukeiYear=2015&aggregateUnit=S&serveyId=S002005112015&statsId=T000846, Last access date April 27, 2022

[3-4] Ministry of Internal Affairs and Communications, Population Census / 2010 Population Census / Basic Complete Tabulation on Population and Households Japan, https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00200521&tstat=000001039448&cycle=0&tclass1=000001045009&tclass2=000001046265&stat_infid=000012460662&tclass3val=0, Last access date April 27, 2022

[3-5] Ministry of Internal Affairs and Communications, Population Census / 2015 Population Census / Basic Complete Tabulation on Population and Households Japan, https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00200521&tstat=000001080615&cycle=0&tclass1=000001089055&tclass2=000001089056&stat_infid=000031473210&tclass3val=0, Last access date April 27, 2022

[3-6] Ministry of Internal Affairs and Communications, Population Census / 2020 Population Census / Basic Complete Tabulation on Population and Households Japan, https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00200521&tstat=000001136464&cycle=0&tclass1=000001136466&stat_infid=000032142402&tclass2val=0, Last access date April 27, 2022

[3-7] JAXA HRLULC Map: High-Resolution Land Use and Land Cover Map, https://www.eorc.jaxa.jp/ALOS/en/dataset/lulc_e.htm, Last access date April 27, 2022

[3-8] High-Resolution Land Use and Land Cover Map of Japan [2006-2011](Released in September 2016 / Version 16.09), https://www.eorc.jaxa.jp/ALOS/en/dataset/lulc/lulc_jpn_e.htm

[3-9] High-Resolution Land Use and Land Cover Map of Japan [2014 ~ 2016] (Released in March 2018 / Version 18.03), https://www.eorc.jaxa.jp/ALOS/en/dataset/lulc/lulc_v1803_e.htm

[3-10] High-Resolution Land Use and Land Cover Map of Japan [2018 ~ 2020] (Released in November 2021 / Version 21.11), https://www.eorc.jaxa.jp/ALOS/en/dataset/lulc/lulc_v2111_e.htm

[3-11] Ministry of Land, Infrastructure, Transport and Tourism, GIS Website, https://nlftp.mlit.go.jp/index.html, Last access date April 27, 2022

[3-12] Ministry of Land, Infrastructure, Transport and Tourism, Digital National Land Information, Administrative Districts Boundary Data (2021), https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-N03-v3_0.html#prefecture00, Last access date April 27, 2022

[4-1] FUJIMURA Hidenori, HAMAMOTO Ko, ISHIDA Chu, KAWAKITA Shiro, MIZUNO Takayuki, SATO Aki-Hiro, TAKEUCHI Wataru, Verification of SDG15.4.2 (Mountain Green Cover Index), Big Data Collaboration Meeting Report No.01, (2021) https://www.soumu.go.jp/main_content/000763968.pdf

[5-1] SDG11.3.1 (LCRPGR), Research Institute for World Grid Squares, https://fttsus.org/SDG_11_3_1/index-e.html, Last access date May 15, 2022

[5-2] Mitsui Sumitomo Insurance, https://www.ms-ins.com/english/, Last access date April 18, 2022

[5-3] Ministry of Land, Infrastructure, Transport and Tourism (MLIT), National Land Policy Division, National Land Numeric Information Public Land Price Data, https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-L01-v2_3.html, Last access date January 20, 2022

[6-1] Ministry of Internal Affairs and Communications, List of Ordinance-designated Cities, https://www.soumu.go.jp/main_sosiki/jichi_gyousei/bunken/shitei_toshi-ichiran.html, Last access date May 11, 2022

[7-1] European Comission (EC), Eurostat, A recommendation on the method to delineate cities, urban and rural areas for international statistical comparisons, https://unstats.un.org/unsd/statcom/51st-session/documents/BG-Item3j-Recommendation-E.pdf, Last access date April 27, 2022