Analysis of Land Use Zoning Regulations and Green Coverage Ratio

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Abstract
The purpose of this study is to make clear the relation between Land Use Zoning Regulations and Green Coverage Ratio in Japanese urbanized city. It is probable that Land Use Zoning Regulations has an influence on Green Coverage Ratio for its restrictions to building form and use. However, this relation is not clear. For creating and protecting green area in urbanized city, it is important to consider the influence brought by land use zones. The study area was selected in Sakai City, Osaka, Japan. Green Coverage Ratios of past 3 terms in the study area were estimated by satellite remote sensing data (LANDSAT5-TM data), and its changes were analyzed statistically using GIS. The results of this study show that there are some tendencies of Estimated Green Coverage Ratio’s change in each land use zones. And this means the possibility to take control of Green Coverage Ratio in urbanized city and give supports to the establishment of the green area-related laws by Land Use Zoning Regulations.

Keywords: land use zoning regulations; green coverage ratio; remote sensing; GIS; normalized difference vegetation index

Introduction
The purpose of this study is to make clear the relation between Land Use Zoning Regulations and Green Coverage Ratio in Japanese urbanized city. The Building Standard Law restricts building use and form according to land use zones designated in the city planning (Table 1). Although Land Use Zoning Regulations does not contain regulations for the green area, it is probable that Land Use Zoning Regulations has big influence on Green Coverage Ratio (GCR) in urbanized city for its restrictions to building form and use. There are many studies about Land Use Zoning Regulations. However, the relation between Land Use Zoning Regulations and GCR is not clear. Laws and regulations with ties to the green area of the city, for example Scenic Zone, are not closely connected with Land Use Zoning Regulations. Therefore, some of the green area-related laws and regulations conflict with Land Use Zoning Regulations [1]. To make clear the relation between land use zones and the green area is useful for creating and protecting the green area in urbanized city, and replacement of land use districts with environmental considerations.

Remote sensing data is well suited to gain information of the green area on the surface. Above all, Normalized Difference Vegetation Index (NDVI) calculated from multispectral remote sensing data is the most widely used vegetation index [2]. NDVI correlates with GCR well [3]. Various methods using NDVI have been proposed to estimate GCR. In this study, the method introduced by Hirano, Y., (2001) [4] was used. This method is superior to other methods at convenience and simplicity. The study area is in Sakai city, Osaka, Japan (Fig.1). City’s center area is located in north-west side of the
city, and middle zone has still a lot of agricultural land. In southern side, there are some big new residential areas beside mountains. Some old tombs are existent with dense green nearby the center area, and these make an important role in Sakai city.

Methods
The following approach was employed.
1. We chose land use districts for the study area in Sakai city, Osaka. These districts have no change about Maximum Building Coverage Ratio (BCR), Maximum Floor Area Ratio (FAR) and big categories of land use zones (Residential Area and Commercial Area) for about 30 years (from 1984 to 1999). This process was come off by sampling details of land use zones from Sakai Urban Planning Maps published in 1973, 1980, 1995, 1996 and 2000. Table 2 shows details of land use zones in the study area.
2. Green coverage ratios of past 3 terms were estimated by satellite remote sensing data (LANDSAT5-TM data, Path: 110 Row: 36, 06/Sep/1984, 06/Aug/1990, 31/Aug/1999 observed).
3. Estimated Green Coverage Ratios (EGCR) in 3 terms was compared on conditions of each district patch (BCR, FAR and Building Use) using GIS, and the change of EGCR was analyzed statistically. Designated conditions of each district patch are shown in Table 2.

The method for EGCR in this study was introduced by Hirano, Y. (2001) [4]. It is based on NDVI. The formula of NDVI:

$$NDVI = \frac{NIR - R}{NIR + R}$$  \hspace{1cm} (1)

where NIR and R correspond to near-infrared and visible red reflectance simulated by TM4 and TM3 of the LANDSAT5-TM. TM3 reflects the absorption of red wavelength by chlorophyll in the vegetation. When TM3 value is low, it means that the content of chlorophyll is high. TM4 observes the reflection of near-infrared wavelength. The green plant has an aspect to reflect near-infrared wavelength of light. When TM4 value is high,

| Zones and their purposes | Ratio to the site area | Maximum floor area ratios, % (FAR) | Maximum building coverage area ratios, % (BCR) |
|-------------------------|-----------------------|-------------------------------------|----------------------------------------------|
| Category I Exclusively Low-story Residential District (LR-I) | FAR: 50, 60, 80, 100, 150, 200 | BCR: 30, 40, 50, 60 |
| Category II Exclusively Low-story Residential District (LR-II) | FAR: 50, 60, 80, 100, 150, 200 | BCR: 30, 40, 50, 60 |
| Category I Exclusively Medium-high Residential District (MR-I) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 30, 40, 50, 60 |
| Category II Exclusively Medium-high Residential District (MR-II) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 30, 40, 50, 60 |
| Category I Residential District (R-I) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 50, 60, 80 |
| Category II Residential District (R-II) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 50, 60, 80 |
| Quasi-residential District (QR) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 50, 60, 80 |
| Neighborhood Commercial District (NC) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 60, 80 |
| Commercial District (C) | FAR: 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300 | BCR: 80 |
| Quasi-industrial District (QC) | FAR: 100, 150, 200, 300, 400, 500 | BCR: 50, 60, 80 |
| Industrial District | FAR: 100, 150, 200, 300, 400 | BCR: 50, 60 |
| Exclusively Industrial District | FAR: 100, 150, 200, 300, 400 | BCR: 30, 40, 50, 60 |
| Areas other than the Land-Use Zones | FAR: 50, 60, 100, 200, 300, 400 | BCR: 30, 40, 50, 60, 70 |
it means that the vegetation is vigorous. NDVI uses these aspects of the vegetation. NDVI takes values between -1 and 1. Higher values mean higher density of vegetation, and low values mean non-vegetation. NDVI has good relation to GCR [3]. However, it does not indicate GCR directly. If we assume that the surface of study area is composed by vegetation and soil (non-vegetation), it is described:

\[ R = X R_v + (1-X) R_s \]
\[ \text{NIR} = X \text{NIR}_v + (1-X) \text{NIR}_s \quad (2) \]

where \( v \) and \( s \) means vegetation and soil (non-vegetation), so \( R_v \) means TM3 value in pure vegetation area. \( X \) means GCR. To rearrange \( X \) by substituting (2) into (1):

\[ X = \left( a \text{NDVI} + b \right) / \left( c \text{NDVI} + d \right) \quad (3) \]

where

- \( a = R_s + \text{NIR}_s \)
- \( b = R_s - \text{NIR}_s \)
- \( c = R_s - R_v + \text{NIR}_s - \text{NIR}_v \)
- \( d = R_s - R_v - \text{NIR}_s + \text{NIR}_v \)

\( a, b, c \) and \( d \) are constants which are calculated by sampled value from observed image. In fact, the soil (non-vegetation) value is mean of various surface’s values in the city’s center area which has no green area. The sampled value of vegetation and soil (non-vegetation), and constants of each 3-term satellite data are shown in Table 3.

In order to verify the performance of these formulae for EGCR, the relation between 1999’s EGCR data and the Real Green Coverage Ratio (RGCR) data was compared. RGCR data was observed from aerial photographs in 1996. The result of this comparison is shown in Fig. 2. The coefficient of correlation \((r^2)\) is 0.81. This method can estimate GCR from satellite remote sensing data and general map. In-depth ground truth data do not necessarily need, and additionally the process of this method is simple. These are advantages of this method. However, as this method uses NDVI, there are some high-dispersed patches from RGCR. NDVI is apt to be affected by non-vegetation cover such as water and asphalt. The rate of area of high-dispersed patches was very small in this study area, so we determined that the adverse affect of high-dispersed patches to this analysis was a little.

The General Tendency of Estimated Green Coverage Ratio

Fig.3 shows the cumulative frequency distribution of EGCR in 3 terms. On the whole, low-EGCR patch had been increasing. The decrease rate in 1984-1990 (6 years) is bigger than one in 1990-1999 (9 years). EGCR in each terms are shown in Fig.4. The process of the change of EGCR in each patch is clear. Fig.5 shows results of the calculation: 1999’s EGCR - 1984’s EGCR.

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Table 2. Details of Land Use Zones in the Study Area

| Land Use Zones              | BCR (%) | FAR (%) | Count of patches | Area ratio to the study area (%) |
|-----------------------------|---------|---------|------------------|----------------------------------|
| Residential Area            |         |         |                  |                                  |
| Category I Exclusively Low-story Residential District | 40 | 80 | 20 | 12.1 |
| Category II Exclusively Low-story Residential District | 50 | 100 | 24 | 4.9 |
| Category I Exclusively Medium-high Residential District | 50 | 100 | 4 | 0.3 |
| Category II Exclusively Medium-high Residential District | 60 | 200 | 44 | 38.6 |
| Category I Residential District | 60 | 200 | 35 | 16.9 |
| Category II Residential District | 60 | 200 | 57 | 20.5 |
| Quasi-residential District | 60 | 200 | 11 | 2.2 |
| Commercial Area             |         |         |                  |                                  |
| Neighborhood Commercial District | 80 | 200 | 15 | 0.4 |
| Commercial District        | 80 | 400 | 14 | 2.5 |

Table 3. Detail of Sampled Value and Constants of Formulae (3)

| Band | Vegetation (TM3) | soil (TM4) | a | b | c | d |
|------|------------------|------------|---|---|---|---|
| 1984 | R (TM3) 29.1     | 57.0       | 103.5 | 10.5 | -4.4 | 60.3 |
| 1990 | R (TM3) 35.7     | 59.2       | 110.4 | 7.9 | -12.1 | 59.0 |
| 1999 | R (TM3) 19.7     | 51.2       | 91.6 | 10.7 | -6.9 | 69.9 |

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Fig.2. Relation between Estimated Green Coverage Ratio and Real Green Coverage Ratio in 1996

Fig.3. Shows the cumulative frequency distribution of EGCR in 3 terms.
color shows that the decreasing width of EGCR is large from 1984 to 1999. There are many high decreasing areas in middle of the study area.

Relation between Building Coverage Ratio and Estimated Green Coverage Ratio

Relation between BCR and EGCR is shown in Fig. 6. On the whole, higher-BCR areas have low-EGCR. These differences of EGCR were assayed by t-test. T-test is a one of the statistical method to judge whether there is a ‘difference’ between two means of two sets. Table 4 and 5 shows results of this t-test. ○ means that t-test accepted the difference, ✗ means that t-test did not accept. We see from Table 4 that t-test in almost pairs accepted its differences of EGCR, except for BCR 50-60% pair. Table 5 shows that there is no change of EGCR in BCR 80% area through 1984-1999. All BCR 80% zones are located in Commercial Area (see Table 2).

Relation between Floor Area Ratio and Estimated Green Coverage Ratio

Fig. 7 shows the relation between FAR and EGCR, and Table 6 and 7 show results of t-test. From Table 6, we see tendencies that t-test accepted the difference of the pair including low-FAR. Table 7 shows that t-test in almost pairs accepted its differences of EGCR by 3 terms, except for FAR 400% and 600%.

Relation between Land use Zones and Estimated Green Coverage Ratio

Fig. 8 shows the relation between 2 big categories of land use zones (Residential Area and Commercial Area). The result of t-test by pairs of terms in 2 big categories is shown in Table 8. We see from Table 8 that Residential Area has statistical difference in every term, and Commercial Area has no statistical change. Fig. 9 shows the relation between land use zones and EGCR in Residential Area, and Fig. 10 shows the relation between...
Table 4. Result of t-test by Pairs of BCR. Left side mark in a square is result in 1984, middle is in 1990 and right is in 1999

| BCR (%) | 40 | 50 | 60 | 80 |
|---------|----|----|----|----|
| 40      | O  | O  | O  | O  |
| 50      |   | O  | O  | O  |
| 60      |   |   | O  | O  |
| 80      |   |   |   | O  |

Table 5. Result of t-test by Pairs of Terms in Each BCRs

|        | 84-90 | 90-99 | 84-99 |
|--------|-------|-------|-------|
| 40%    | O     | O     | O     |
| 50%    | O     | X     | O     |
| 60%    | O     | O     | O     |
| 80%    | X     | X     | X     |

Table 6. Result of t-test by Pairs of FAR

| FAR (%) | 80 | 100 | 200 | 300 | 400 | 600 |
|---------|----|-----|-----|-----|-----|-----|
| 80      | O  | O   | O   | O   | O   | O   |
| 100     | O  | X   | O   | O   | O   | O   |
| 200     | O  | O   | O   | O   | O   | O   |
| 300     | X  | O   | O   | O   | O   | O   |
| 400     | X  | X   | O   | O   | O   | O   |
| 600     | X  | X   | X   | X   | X   | X   |

Table 7. Result of t-test by Pairs of Terms in Each FAR

|        | 84-90 | 90-99 | 84-99 |
|--------|-------|-------|-------|
| 80%    | O     | X     | O     |
| 100%   | O     | X     | O     |
| 200%   | O     | O     | O     |
| 300%   | X     | O     | O     |
| 400%   | X     | X     | X     |
| 600%   | X     | X     | X     |

Table 8. Result of t-test by Pairs of Terms in 2 Big Categories

|        | 84-90 | 90-99 | 84-99 |
|--------|-------|-------|-------|
| Residential Area | O     | O     | O     |
| Commercial Area  | X     | X     | X     |

Table 9. Result of t-test by Pairs of Land Use Zones

|        | LR-I | LR-II | MR-I | MR-II | R-I | R-II | QR | NC | O  |
|--------|------|-------|------|-------|-----|------|----|----|----|
| LR-I   | O    | O     | O    | O     | O   | O    | X  | X  | X  |
| LR-II  | O    | O     | O    | O     | O   | O    | X  | X  | X  |
| MR-I   | X    | X     | O    | X     | O   | O    | X  | X  | X  |
| MR-II  | O    | O     | O    | O     | O   | O    | X  | X  | X  |
| R-I    | O    | O     | O    | O     | O   | O    | X  | X  | X  |
| R-II   | X    | X     | X    | X     | X   | X    | X  | X  | X  |
| QR     | X    | X     | X    | X     | X   | X    | X  | X  | X  |
| NC     | X    | X     | X    | X     | X   | X    | X  | X  | X  |
| O      | O    | O     | O    | O     | O   | O    | X  | X  | X  |
land use zones and EGCR in Commercial Area. The result of t-test by pairs of all land use zones is shown in Table 9. From Fig. 9 and Table 9, we see that the decreasing tendency of EGCR disappeared in the Category I Exclusively Low-story Residential District and the Category I Medium-high Residential District from 1990. And districts in Residential Area fell into 2 groups in 1999. Table 10 shows details of Table 8. T-test did not accept differences of NC and C districts (both districts are included in Commercial Area) in every term.

Conclusions
The result of this study is followings,
1. On the whole, Estimated Green Coverage Ratio had been decreasing from 1984 to 1999.
2. T-test in almost pairs of Building Coverage Ratio accepted its statistical differences, except for BCR 50-60% pair.
3. Statistical differences of Estimated Green Coverage Ratio between the low-floor area ratio zones and other parts were clear.
4. In the Category I Exclusively Low-story Residential District and the Category I Medium-high Residential District, the decreasing tendency of Estimated Green Coverage Ratio disappeared from 1990. And the differences of Estimated Green Coverage Ratio between two groups (one is Category I Exclusively Low-story Residential District and the Category I Medium-high Residential District, another is all of rest districts in Residential Area) of the Residential Area become wide (not less than 10%).
5. Commercial Area had no change of Estimated Green Coverage Ratio and it’s percentage was low (about 15%).

The results of this study clearly show that there are some tendencies of Estimated Green Coverage Ratio’s change in each land use zones, and these tendencies can be defined by Building Coverage Ratio, Floor Area Ratio and land use zones. Information brought by this results shows the possibility to take control of Green Coverage Ratio in urbanized city by Land Use Zoning Regulations and will be useful for city planning with consideration of the green area. It is probable that the tendencies of relation between Land Use Zoning Regulations and the green area are difference by each city, because every city has its own natural environments and histories of development. Therefore, research and analysis are needed in each area. In this regard, method of this study will be informative too.

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