Research on the making factor of the heat island in the early-morning of Kumagaya

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Abstract: Heat island phenomenon is considered one of serious problems that have been developed due to the concentrations of human activities in urban areas, which caused unbalance in the heat budget.
In this study, spatial-correlation analysis was identified between temperature and many parameters that seem to affect the heat island phenomenon of Kumagaya city. The parameters used in the analysis are NDVI, thermal characteristic value and form of the buildings, and the latter consist of three parameters: two-dimensional building density, three-dimensional building density and roughness-parameter. The results showed that there was a low correlation in temperature with all parameters, but on the other hand, a clear relationship was found between land use and temperature. Moreover, the results indicated that the form of buildings in urban area blocks the cool-down effect of the river to penetrate to the urban area.
Keywords: heat island, land cover, land use, geographic information system (GIS), roughness-parameter

1. Introduction

Heat island phenomenon is considered one of serious problems that have been developed due to the concentrations of human activities in urban areas, which caused unbalance in the heat budget. In this study, the relationship between the temperature and land cover was evaluated. Furthermore, the roughness-parameter that shows the roughness of the ground surface was calculated, taking into consideration the impact of air temperature. Consequently, a relationship between the influence factors of heat island phenomenon was discovered.

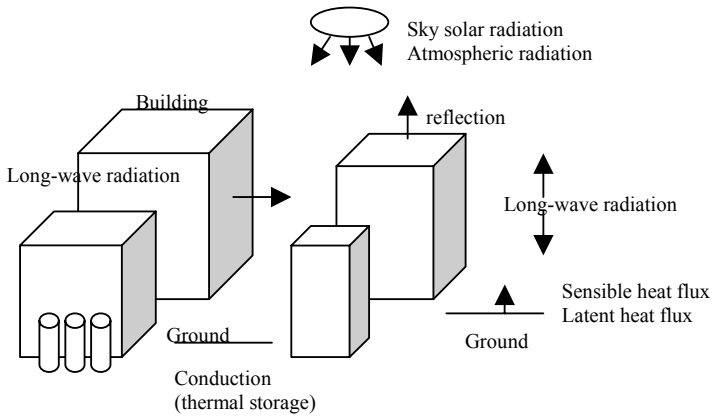

Fig 1. Element related to heat island phenomenon

2. Observation method and observation technique
2.1. Study area

Kumagaya city is located in the northwest of Saitama prefecture. The area of the city is 85.18km^2, and its population about 156,216 inhabitants. The topography of the study area is even topography. However, a Konan plateau and a Hiki

hill are present in the southern part in the study area. In addition, Arakawa River is also present in the southern part of the urban areas and flows from the west to east. For the climate of the study area, it is relatively cold in winter and very hot in summer. But during the period of Akagi monsoon, which is coming usually from the northwest, a cold weather is dominated.

2.2. Observation method

In August 24th 2001, an observation data of air temperature at 4 o'clock morning was used by Kumagai[1)] in Kumagaya city. The goal of the observation was to know the temperature distribution at early morning, and the observation movement was done by car for about one hour. Moreover, all the observation points are on the paving of asphalt.

2.3. Temperature distribution situation

Figure 2 shows the air temperature distribution map obtained according to the air temperature measurements. The high air temperatures are seen in a wide part in suburbs besides the part around Kumagaya station. This was due to the variations in the land use and the influences of land cover.
In addition, the formula which can be used to show the air temperature difference of the city and suburb and consequently shows the strength of appearance of the heat island is:

$$\Delta T_a - T_r = T_a - T_r \quad \ldots (1)$$

Here T_a is the value of maximum air temperature, and T_r is the value of minimum air temperature.
In this study, the difference in temperature was designated as heat island strength, and using this definition, the differences in air temperature T_a are highest in the city limits, which are lectured by Oke[2)] and T_r is lowest temperature found in suburb areas. As a result, heat island strength at the object time was 2.0 degrees. The velocity of the wind in this time zone was 0.3m/s and taking the direction north-northeast direction.

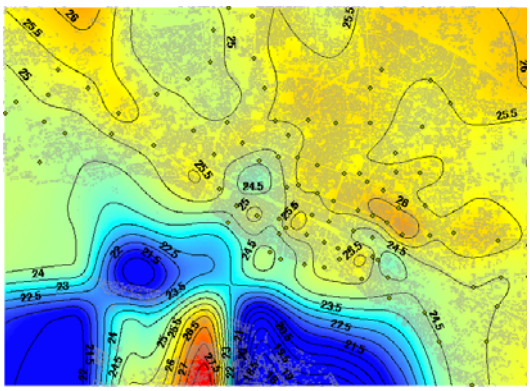

Fig 2. Air temperature distribution map in Kumagaya (AM 4:00, August 24th, 2001)

3. Calculation of the influence factor that causes the heat island

In this study, to understand the formation factor of the heat island of 4:00am in Kumagaya city, NDVI, thermal characteristic value, two-dimensional building density, and three-dimensional building density were evaluated as an influence factors.

3.1. The impact statement of NDVI and air temperature

NDVI is an index to understand the distribution situation of vegetation from the satellite image data. The definitional equation of NDVI:

$$y = \frac{X_{IR} - X_R}{X_{IR} + X_R} \quad \ldots (2)$$

Where, X_{IR} is the near-infrared band; X_R is the infrared band. A buffer of 125 meters was made in which its radius was centered on the observation points, and the averaged NDVI was assumed to be a value of typical NDVI of the observation points.

3.2. The impact statement of thermal characteristic value and air temperature

The thermal characteristic value is the one that a thermal character of the land use constituent was estimated. Brunt[3)] can be obtained by the next formula of the ground surface temperature.

$$T = T_0 - \frac{2}{\sqrt{\pi}} \frac{R}{\rho\ c\ \sqrt{\kappa}} \sqrt{t} \qquad \cdots (3)$$

Here, T_0: Ground surface temperature at time of sunset, R: Nocturnal radiation quantity, t: The time which designates the time of the sunset as standard, ρ: Density of component of ground surface, c: Specific heat of component, κ: heat diffusivity. Moreover, this boundary condition doesn't have the temperature transmission in air that touches the ground surface and the ground surface. And, it is assumed that radiant quantities at night time are always constant.
However, naturally there is temperature transmission in the air that is touching the ground surface and that ground surface. Moreover, it is thought that radiant quantities at night time are different according to the material. Then, Kawamura[4)] estimated thermal properties of the component of every land use using, the formula:

$$1 / c\rho\sqrt{\kappa} \qquad \cdots (4)$$

The resultant value is constant value which does not change vis-à-vis all conditions. As a result, a regional difference of the thermal characteristic value of the material was estimated.

3.3. The impact statement of two-dimensional building density, three-dimensional building density and air temperature

Radiant quantities R from the ground surface when there is an obstacle are shown by the next formula.

$$R = \sigma T^4 - \gamma\sigma T_1^4 - (1-\gamma)\Gamma\sigma T_a^4 \qquad \cdots (5)$$

Here, σ: Stefan constant, T: Ground surface temperature, T_1: Ground surface temperature of obstacle, T_a: Air temperature, Γ: The emission absorption quantity by the atmosphere and the emission absorption quantity by the planckian radiator ratio, γ: The spatial ratio which the obstacle occupies.

In addition, $0 < \gamma < 1$ and $0 < \Gamma < 1$ is. At the early morning of the city, it is thought T 1 > Ta and T > Ta. If the value of R decreases, cooling rate of the ground level becomes small. As a result, ground surface temperature of the city becomes high in comparison with suburb. In addition, when altitude of the building is high, in order to reflect multiplex with the wall surface, the structure of the city is likely to be heated.
In this study, the rank data in the residential map was used; two- dimensional building density and three- dimensional building density inside the buffer were calculated.

3.4. Calculation method of roughness-parameter

Roughness-parameter is the value that shows the unevenness of the ground surface. In this study, the calculation type of the following Lettau[5)] was used. And, Takahashi's et al.[6)] techniques were used and calculated.

$$Z_0 = 0.5h \times s / S \qquad \cdots (6)$$

Here, $\boldsymbol{Z_0}$: roughness-parameter (cm) , $\boldsymbol{h}$: average altitude (cm) , $\boldsymbol{s}$: silhouette area (㎡) , $\boldsymbol{S}$: lot area (㎡).
In this study, one of the following three methods were examined.

1) Method of using and calculating rank data of residential map.
2) Method of using DSM calculated from Ortho BASE Pro.
3) Method of using and calculating Stereo Analyst.

The best one among these was assumed to be height of the buildings. Next, it explains the method of calculating h, s, and S in formula (6). As for the result of the accuracy verification, the accident error of DSM was the fewest.
Because of that, the DSM was overlaid on the residential map, and the maximum value of DSM in the buildings polygon was assumed to be height of the buildings.
The calculation method of h is the same as the calculation method of Lettau[5)], calculated mean value every lot area which shows in the next formula.

$$h = \frac{1}{n}\sum_{i=1}^{n} h_i \quad \cdots (7)$$

Here, n: Building total number, h: Height of the building (cm).
In addition, S is the area of one-lot area. In this study, it was thought that the lot area on the leeward side did not influence the temperature of the observation point, and only the area of the windward side was calculated by using the following expression.

$$S = \frac{1}{2} r^2 \pi \quad \cdots (8)$$

Here, γ : The radius from the observation point (m). Moreover, s is cross sectional area of the building when viewed from the windward side.
As a calculation method

1) The image is converted into the lusterware of 1m mesh.
2) The maximum value is calculated toward from the windward to leeward in every one row.
3) It was calculated using the following expression every one-lot area.

$$s = \sum_{i=1}^{n} h_i \quad \cdots (9)$$

Here, h: When viewed from the upwind height of the highest building (m), n: Diameter of the lot area (m).
When the residential map and DSM were overlaid on each other, the maximum value of DSM in the building polygon was assumed to be height of the building.

Fig 3. Three-dimensional image calculated from experience type by using rank data of house map

Fig 4. Digital Surface Model of Kumagaya

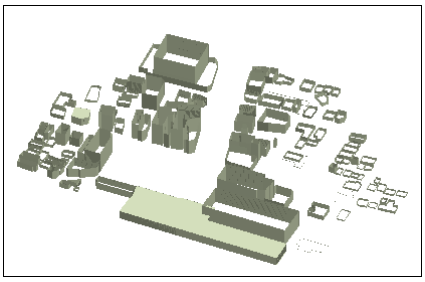

Fig 5. Stereo image of Kumagaya

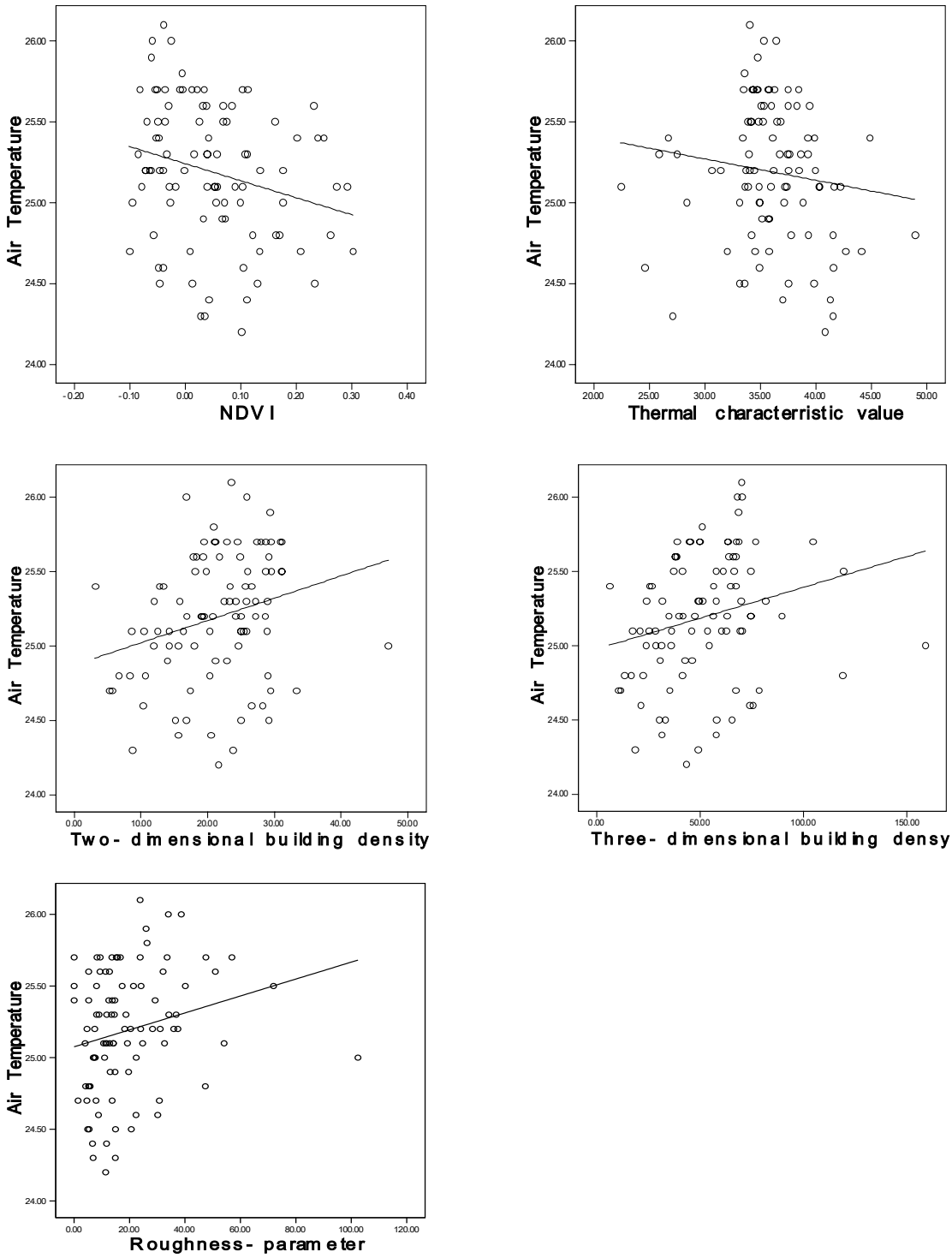

Fig 6 Scatter chart of influence factor parameter and temperature

4. Related appraisal of land use and heat island

A deep correlation was not seen in the relationship between the land cover parameter and the air temperature. A variety of land use districts exist in the city, and there are various differences of thermal characteristics between the rejection heat and the building structure, and the main constituents of differing are shown along with it. It is thought that not only the land cover but also the land use is greatly related from such a reason to the region on the heat island. In this study, the relation between the temperature influence factor and the temperature of the detailed land use in the object region is evaluated by using the current state of Kumagaya City land use map.
Figure 9 shows the existing land use map used for the analysis. In the first, the buffer of 125 meters in the radius was made from the land-use map. Next, multiple linear regression analysis was used in land use proportion (%) in the buffer, and the temperature and a stepwise method was used. The result is shown below.

$$Y=25.787+2.826X_1+2.009X_2-1.043X_3-1.918X_4 \quad \cdots (10)$$

Where Y: Constant X1: Right of way X2: Transportation facilities site X3: Rice field X4: Natural ground. Because the multiple correlation coefficient R=0.769, coefficients of determination R2=0.591 (contribution rate), and a significant probability is 0.05 or less, it can be said that the reliability of the result is high.

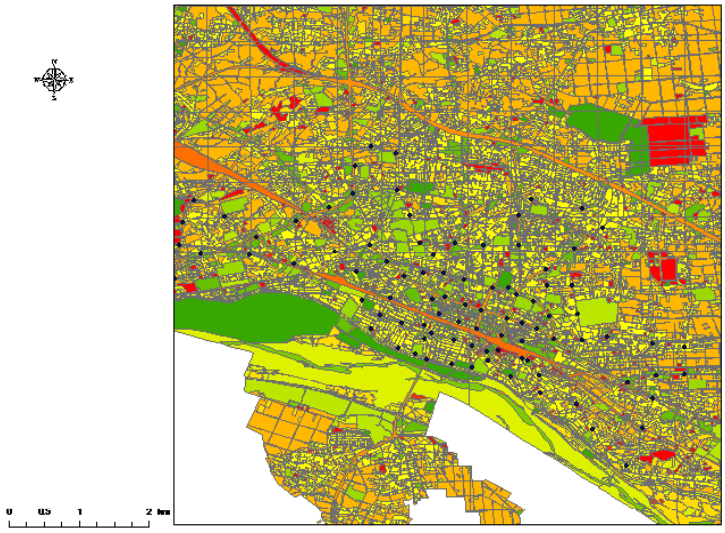

Fig 7. Existing land use map of Kumagaya

5. Conclusion

In this study, not only heterogeneity of land cover but also heterogeneity of land use was paid attention. Air temperature and the rate of the land use formed around the observation point were evaluated by using the land use figure by multiple linear regression analysis to examine the relation between the temperature and the land use.
As a result, a deep relation between the temperature and the land coating parameter could not be seen in many points.
However, due to the multiple linear regression analysis by stepwise method of land use and temperature, it was possible to delete many parameters due to multicollinearity, and the road site, traffic facility site, and rice field natural site were deduced.

As a result, it was confirmed that the existence of a rice field and natural ground have influenced the temperature training at the same time as road building ground and traffic facilities site's influencing the temperature rise in Kumagaya City August 24, 2001.

It was able to be confirmed that the traffic facilities site influenced the temperature rise, and the existence of a rice field and natural ground influences the temperature relaxation effect in Kumagaya City August 24, 2001.

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References

1)Kazuya Kumagai: : GIS analysis concerning urban climate and land use in Saitama Prefecture, Faculty of Geo-environmental Science, Rissho University graduation thesis,2002.
2)*Oke, T. R. : City size and the urban heat island, Atmos. Environ, 7, 769-779, 1973.*
3)*Brunt, D;Physical and dynamic meteolorgy, Canbridge at the Univ. press, pp125-129, 1934.*
4) Takeshi KAWAMURA*:* Some prospect concerning component of city temperature in Kumagaya City, Geogr. Rev. Japan, vol37 no10, pp560-564 1964.
5) *H. Lettau : None on aero-dynamic roughness-parameter* estimation on the basis of roughness-element description, J. Appl. Meteorol, Vol. 8, pp. 828～832, 1969.
6) Takahashi, M. K. Sekine, T. Iwata, Y. Kosaka, and S. Fukawabi: The roughness parameter in Ogaki City, Geogr. Rev. Japan, 54, 579–594,1981.