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COMPARISON OF URBANIZATION OF FOUR ASIAN CITIES USING SATELLITE DATA

Makoto KAWAMURA[1], Sanath JAYAMANNA[2], Yuji TSUJIKO[3] and Akira SUGIYAMA[4]

[1]Member of JSCE, Dr. of Eng., Associate Professor, Dept. of Architecture and Civil Eng. Toyohashi University of Technology (1-1 Hibarigaoka, Tempaku Cho, Toyohashi Shi, Aichi 441, Japan.)
[2]Student Member of JSCE, M. Eng., Graduate Student, Dept. of Architecture and Civil Eng. Toyohashi Univ of Tech.
[3]Member of JSCE, M. Eng., Research Associate, Dept. of Architecture and Civil Eng. Toyohashi Univ of Tech.
[4]Student Member of JSCE, Graduate Student, Dept. of Architecture and Civil Eng. Toyohashi Univ of Tech.

This paper describes the results of the comparative study on quantitative evaluation of urbanization using satellite data for four Asian cities which are in different developing situation. In the previous paper the authors proposed urban index UI which is estimated from Landsat TM image. In this study the applicability of the index UI for different regions and seasons was examined at first. Then the relation between urbanized area and vegetation area was compared for the four cities, using UI and NDVI. Finally the distributions of urbanized area in the cities were compared applying join value analysis. As the results of the analysis, two different types of urbanization were recognized quantitatively.

Key Words: *satellite remote sensing, Landsat TM, urbanization, environmental monitoring, join concept, Asian cities.*

1. INTRODUCTION

Quantitative evaluation of urbanization and its impact on natural environment is indispensable to understand the global environmental problems. Application of satellite remote sensing analysis for this kind of purpose is effective because it is easy to analyze wide area from one satellite image, to obtain the results from the frequently observed image data and to save cost and time. In the previous studies[1),2)] the vegetation index NDVI was used to detect the urbanized area from the satellite data even though NDVI is originally an index to detect vegetation area and its activity. The authors proposed the urban index UI which is calculated from satellite data and it was shown that the index has strong relation with the building coverage ratio for the case of Colombo city[3),4)]. In this paper applicability of this index for different regions and seasons are examined at first. Then the relation between urbanization and natural environment in four Asian cities where the social and economical conditions are different, are compared using the indices UI and NDVI. Number of urbanized unit area and its balance with vegetation area are recognized through the comparison.

Not only the number of urbanized unit area and vegetation unit area but also the location and the distribution of vegetation area in a city are important factors , when balanced urban and vegetation environment in the city are discussed. In this study, join value analysis[5)] was applied to evaluate continuity of urbanized area and assemblage of vegetation area. Join value analysis was developed by Krishna Iyer in 1950. It is often used in the studies on urban planning to consider the balanced distribution of the developed area and the vegetation area. Based on the results of the analysis mentioned above, more preferable type of urbanization was discussed. This discussion will provide some basic knowledge for balanced developing of the cities.

As a comparative study, data of four Asian cities namely, Colombo city in Sri Lanka, Kuala Lumpur city in Malaysia and Nagoya and Toyohashi cities in Japan, were used to examine those quite different development conditions in the urban area. Colombo city represents a typical old colonial port city in a developing country belonging to an urban system that lacks balanced distribution of various land use[6),7)]. In Colombo city the urbanization was progressed much after the policy for economics was changed in 1997. Kuala Lumpur represents a capital city in a very rapidly developing region with a balanced development strategy where development is dispersed in outlying areas[8)]. Nagoya city has a large concentrated area of high density development in a developed Asian country. Toyohashi represents a city which has a considerably good balance between urbanization and the vegetation environment. Area and populations of the four cities are shown in **Table1**.

Table1 Area and population within the administrative boundaries of cities

	City	Area (ha)	Population
1.	Nagoya	32637	2161874
2.	Kuala Lumpur	24240	1550000
3.	Colombo	3733	665850
4.	Toyohashi	26000	343200

2. DATA USED IN THIS STUDY

Conventional data used in the study include building cover maps of Colombo city of 1970(scale 1:12672), Kuala Lumpur city of 1988 (scale 1:10000), Nagoya city of 1992 (scale 1:10000), Toyohashi city of 1990 (scale 1:10000), land use maps of the Colombo District of 1981 (scale 1:50000), Kuala Lumpur of 1984 (scale 1:50000), Toyohashi of 1982 (scale 1:25000) and detailed digital land use information data of Nagoya of 1982 and 1993. Landsat TM data used of Colombo is of December 1987, Kuala Lumpur-June 1989, Nagoya-November 1991 and July 1995, Toyohashi-November 1991 and July 1995.

The areas which were reported in 'Colombo City Development Plan' as densely urbanized areas after 1970, were omitted in the analysis using the satellite data and the map of Colombo. Comparing the air photograph of Colombo in 1994 and the map of 1970 for the several areas which were used in the analysis, the effect of time difference between 1970 and 1994 for building coverage ratio was about few percentages[3]. For other cities, the effect of the time difference between the acquisition date of the satellite data and developing the building map were not adjusted because the time difference is relatively small.

3. COMPARISON OF THE STATE OF URBANIZATION

As proposed in a previous paper[3] by the authors Urban Index UI is defined by Eq.(1) exploiting the inverse relationship between brightness of urban areas in bands 7 and 4.

$$UI = \left(\frac{B7 - B4}{B7 + B4} + 1.0 \right) \times 100.0 \qquad (1)$$

The relation of UI with UD was investigated for different regions and different seasons using a grid size of 500m by 500m. UD is the percentage area covered by buildings within a grid size of 500m by 500m. The 500m grid size was selected because it is one of the smaller grid sizes that gives a good correlation with UI. In this analysis data of Colombo, Kuala Lumpur, Nagoya and Toyohashi cities were used. UD was computed from scanned building cover maps of the different cities. In the computation of UI for the corresponding grids water areas have been omitted by registering with a classified image. This is because UI values of water areas are not comparable with UI values of land areas due to the very low UI values of water areas. The reason for this is the absorption of band 4 and band 7 by water. The 500m by 500m grids were selected for the computation only if all the TM pixels within the grid are completely within land areas.

Table2 B values for average UI of vegetation class

City	Average UI of vegetation area	B
Colombo	50.09	55.2
Kuala Lumpur	49.05	56.1
Nagoya (summer)	62.71	44.1
Nagoya (autumn)	66.78	62.5
Toyohashi (summer)	48.50	29.7
Toyohashi (autumn)	45.51	63.5

(1) UI-UD relation for different regions

The UI-UD relation for different regions is shown in **Figs.1**(a),(b),(c) and (d). The TM data of Colombo is of December 1987. Kuala Lumpur is of June 1989. Nagoya is of July 1995(summer) and Toyohashi is of July 1995(summer).These figures show that the UI-UD relation can be assumed to be of the form,

$$UI = \begin{cases} A \times UD + B & (0 < UD \le K) \\ C & (UD > K) \end{cases} \qquad (2)$$

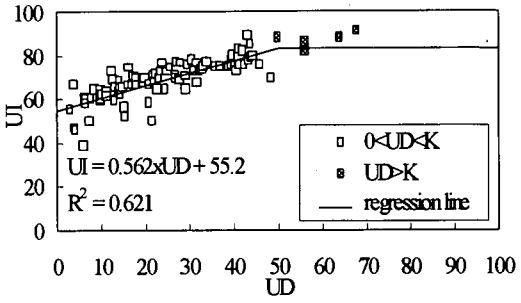
where C and K are almost 90 and 50 respectively for all the cities.

(2) UI-UD for different seasons

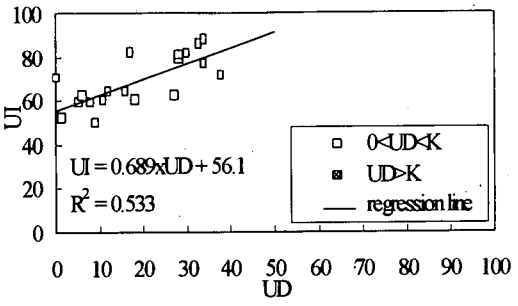
Using TM data of November 1991, autumn season, of Nagoya and Toyohashi cities the UI-UD relation is shown in **Figs.1**(e) and (f). These figures can be compared with **Figs.1**(c) and (d), where the TM data used is of the summer season. The C and K values of these UI-UD relations for the winter season are almost 90 and 50 respectively as before.

(3) Uniform UI-UD relation

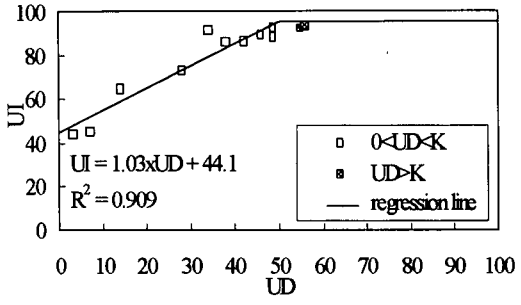
As shown in **Fig.1** there is a strong relation between UI and UD in different region and different season. Value of B which is determined by the regression line in **Fig.1**, and the average UI value of the vegetation area are shown in **Table 2**. The vegetation area was separated by the land cover



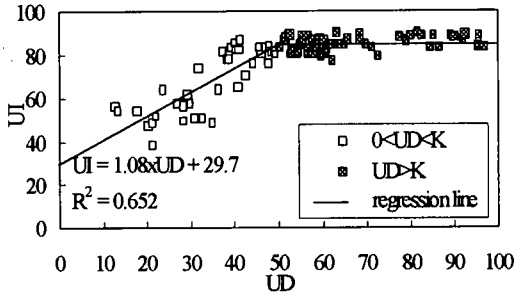
(a)Colombo



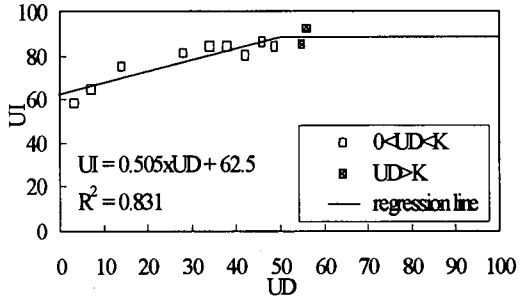
(b)Kuala Lumpur



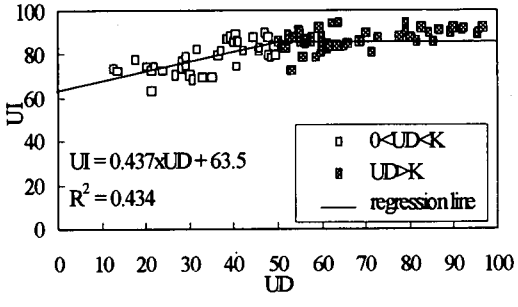
(c)Nagoya(summer)



(d)Toyohashi(summer)

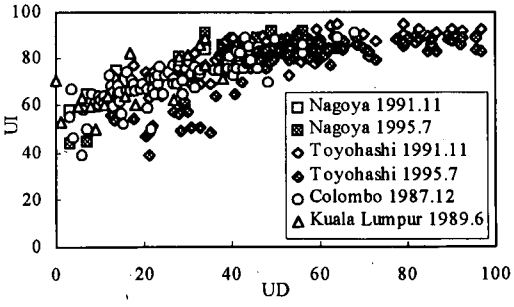


(e)Nagoya(autumn)

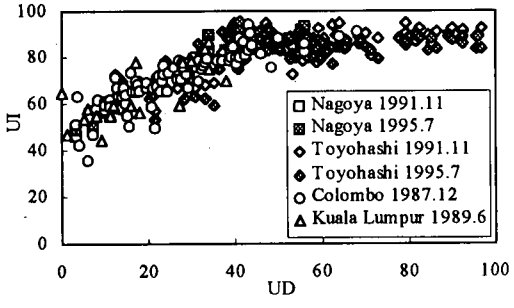


(f)Toyohashi(autumn)

Fig.1 UI-UD relation(K=50)

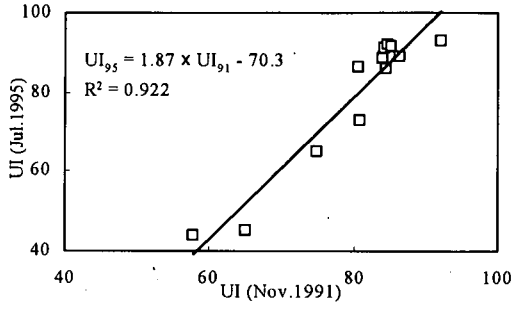


(a)Before modification

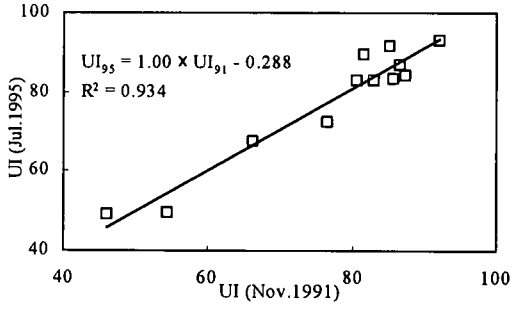


(b)After modificaion

Fig.2 UI-UD relation for cities

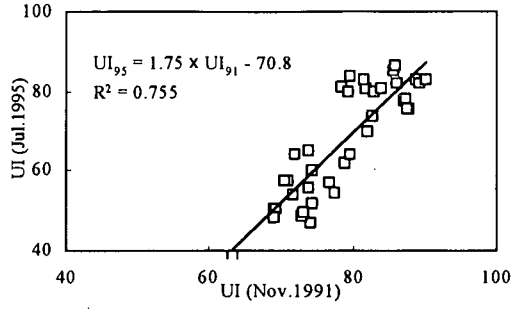


(a) Before modification

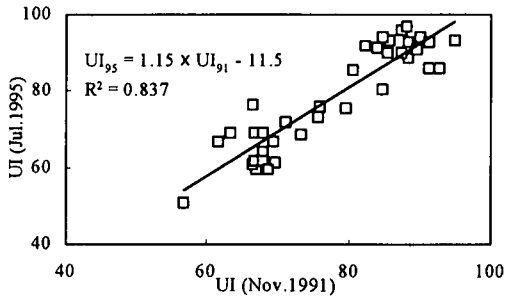


(b) After modification

Fig.3 Effect of modification of UI for Nagoya



(a)Before modification



(b)After modificaion

Fig.4 Effect of modification of UI for Toyohashi

classification explained later. The value of B for 500m grids does not correspond with the average UI value for each pixel with 30m resolution, because the grid size is different for the two values and the values are slightly affected by detailed type of the vegetation area such as paddy area and forest area. In this study we assumed B=50.0, referring the average B value. If the domain of UD<K are modified by Eq.(3) as follows,

$$UI = \left(0.8 \times UD\right) + 50 \qquad (3)$$

all of the target images are compared easily. **Fig.2**(a) shows all of the data and **Fig.2**(b) shows the data modified by Eq.(3).

(4) Verification of modification

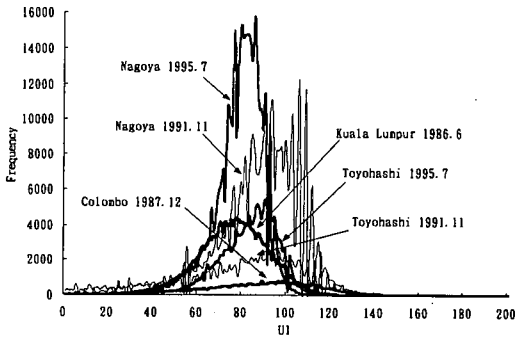
The uniform relation obtained by the modification was verified using winter and summer data of Nagoya and Toyohashi cities to examine whether same values can be obtained for UI in the two seasons using the modification. The UI values for the 500m by 500m grids shown in the UI-UD relation for Nagoya and Toyohashi cities in the summer and winter seasons are shown in the scatter diagrams of **Fig.3** for Nagoya and **Fig.4** for Toyohashi. From these figures it can be seen that the modified UI values are almost same for the two different seasons. Therefore the modified equation can be directly applied in different regions where seasonal differences may exist to estimate UI within the urban areas and to compare the physical development in the areas.

4.COMPARISON OF CITIES USING THE INDICES UI AND NDVI

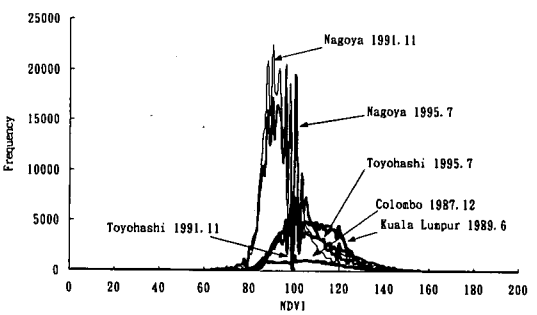
In this chapter it is shown how UI can be used with NDVI to compare the state of urbanization of the cities at a regional level. For this purpose, first, the distribution of UI and NDVI for urban and vegetation classes of land cover in different region and different season is examined.

(1)Relation of UI and NDVI with land cover type in different region and season

Landsat TM data was initially classified into six categories such as commercial, industrial, residential, paddy, farm and forest areas for Colombo, Kuala Lumpur, Nagoya and Toyohashi cities by a neural network. For the classification a back propagation neural network was employed for

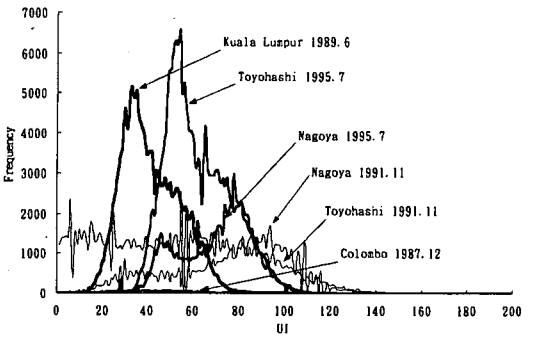


(a)UI distribution

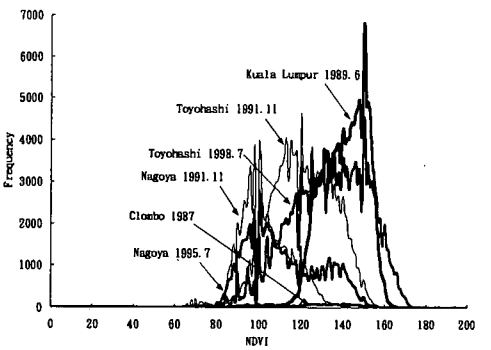


(b)NDVI distribution

Fig.5 Histograms of UI(NDVI) for urban class



(a)UI distribution



(b)NDVI distribution

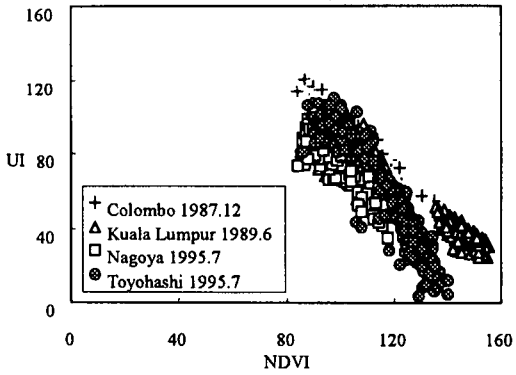
Fig.6 Histograms of UI(NDVI) for vegetation class

the learning of the network. The network consists of six input units, which are six bands of TM data except band 6, twenty hidden units and six output units which correspond to the number of categories. Then the classified images were used to identify the urban class and the vegetation class within the administrative areas of the cities. The urban class of land cover consists of commercial, industrial areas. The vegetation class consists of paddy, farm and forest areas. The UI distribution within the administrative areas of the cities was analyzed for urban and vegetation classes to see the influence of season and region on UI. Histograms of UI and NDVI for each 30m by 30m pixels in Nagoya, Toyohashi, Colombo and Kuala Lumpur cities were compared to see the influence of region and seasons as shown in **Fig.5** and **Fig.6**. In these figures the values of UI were modified as discussed in chapter 3.

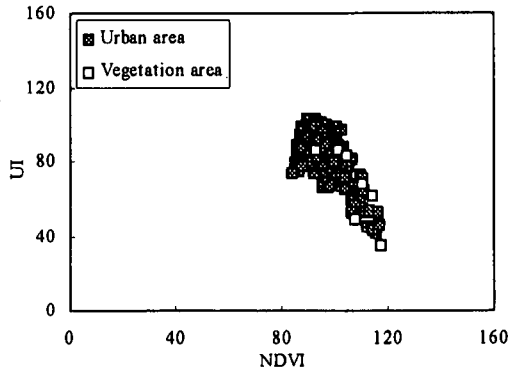
As shown in **Figs.5**(a) and (b) the value of UI is greater than 40 and the value of NDVI is smaller than 120 for most of urbanized area. This characteristics is effective to identify urban areas on the UI-NDVI diagram, which is explained later. For the most of vegetation area, the value of NDVI is greater than 100 as shown in **Fig.6**(b). Based on these characteristics, it is considered that the Urban Index UI together with NDVI can be used to compare the urbanization condition in the different cities. As seen in **Fig.5(a) and Fig.6(b)**, urbanized area in Nagoya is much larger than in other cities and the vegetation in Nagoya is less active than in other cities. In Toyohashi and Kuala Lumpur large vegetation areas are located comparing the urban areas. In Colombo urbanized area is dominant.

(2) Comparison of urbanization at regional level using the relation between UI and NDVI

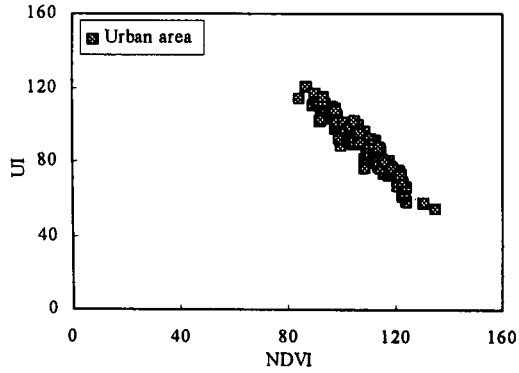
The UI-NDVI relation for Colombo, Kuala Lumpur, Nagoya and Toyohashi cities is shown in **Fig.7**. The size of the TM images used is 1024 by 800 pixels. Since Colombo and Kuala Lumpur cities are from the tropical region, summer data of Nagoya and Toyohashi cities have been used to reduce the influence of seasonal differences. The area within the administrative boundaries of the cities was considered. Each point shown in the



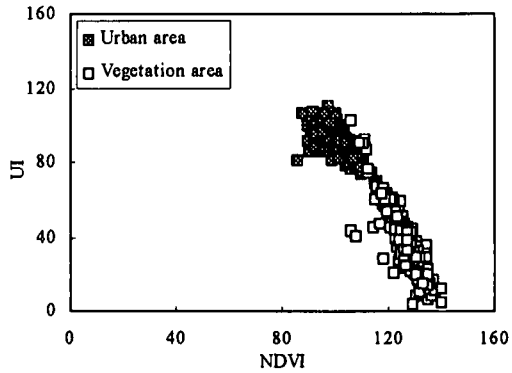
(a) UI-NDVI Relation for cities



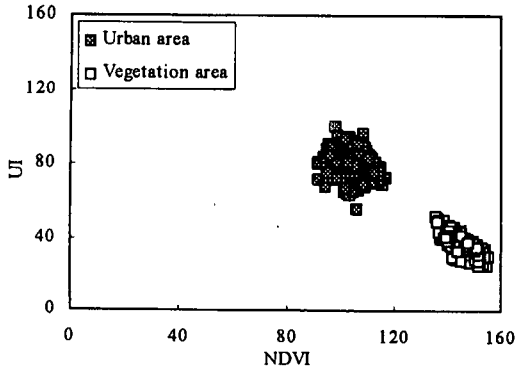
(d) Nagoya



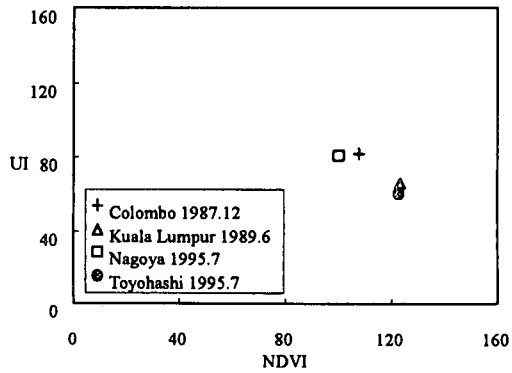
(b) Colombo



(e) Toyohashi]



(c) Kuala Lumpur



(f) Average UI-NDVI Relation for city areas

Fig.7 UI-NDVI relation

figures represents approximately 500m grid. The grids were separated as belonging to urban or vegetation classes based on the land cover classification mentioned before. If more than 70% of the 17 by 17 TM pixels within the approximately 500m grid belong to a class, then the grid is classified as belonging to that class. **Fig.7**(a) shows the UI-NDVI relation for the four cities in which modified UI values have been used. The UI-NDVI relation for each city is separately shown in **Figs.7**(b) to (e). In the **Figs.7**(b) to (f) the most of urban areas located the zone where UI is greater than 40 and NDVI is less than 120. On the other hand the vegetation area is in the zone where UI is less than 40 and NDVI is greater than 120. The UI-NDVI relation represents the intensity of urbanization in the city, that is, the number of urbanized unit area. The relation for Colombo city can be seen in **Fig.7**(b). The absence of vegetation area pixels indicate that there are no large areas of vegetation within the city limits. As shown in **Fig.7**(c) Kuala Lumpur has large areas of both urban and vegetation classes within the city. The UI-NDVI relation for Nagoya city in **Fig.7**(d) shows that Nagoya city has large urban areas and a few vegetation areas. The UI-NDVI relation of **Fig.7**(e) of Toyohashi city shows that the city has both large urban areas as well as vegetation areas indicating a good balance between urban development and the natural environment. From all these figures it can be seen that in all the cities UI is high and NDVI is low in the urban class and also that UI is low and NDVI is high in the vegetation class. **Fig.7**(f) shows the average UI and NDVI values for the administrative areas of the cities. The average values are divided into two group. UI values of Nagoya and Colombo cities are relatively high because these cities are highly urbanized. On the other hand NDVI values of Kuala Lumpur and Toyohashi are relatively high because the large vegetation areas are mixed with the urbanized areas. This characteristics is explained in the following chapter. The relation between UI and NDVI shows the urbanization condition of the urban areas at a macro level, which is the state of urbanization at a regional level.

5. COMPARISON OF THE SPATIAL PATTERN OF URBANIZATION WITHIN THE CITIES

To compare the pattern of spatial development within the cities, the join concept[5] was used. The join value for a particular category of land cover

0	1	0
1	1	1
0	1	0

where 0=vegetation class
1=urban class

(a) classified results for 3 by 3 pixels

0	1	0
1	4	1
0	1	0

join value of mesh cell=8

(b) Join values of each pixel for urban class

Fig.8 Sample calculation of join value

within the urban area measures the agglomeration of that land cover in the urban area. The way in which each pixel within the mesh cell is joined to its surrounding pixels was examined. A sample calculation of join value is shown in **Fig.8**. If an urban class pixel is surrounded by 4 urban class pixels the join value of this pixel is 4. If it is not surrounded by any urban class pixels then the join value is zero. The summation of all the join values within the mesh cell is the join value for the mesh cell. For simplicity in this example the calculation of the join value of urban class for 3 by 3 pixel mesh is shown. A high join value indicates the high concentration of the urban class. From an examination of the distribution of the urban join value the characteristic pattern of physical development within the urban area can be recognized.

In this study 2 sizes of mesh cell were considered corresponding to 2 sizes of pixels to calculate the join value for each mesh cell. In all cases each mesh cell comprises of 10 by 10 pixels. The pixel sizes considered are about 30m (one TM pixel) and about 90m (3 by 3 TM pixels). The 90m pixels were assigned to each of the 2 classes based on the class of the majority of TM pixels within nine 30m pixels. **Fig.9** shows the relation between the join value of the urban class and the percentage of urban area for the two mesh cell sizes of 10 by 10 pixels. The black dots in the relation between join value and percentage of urban area in mesh cell represent high frequency. The white triangle zone in the **Fig.9** represents the area where the join value can be obtained. The large number of black dots with high join value for Nagoya city shown in **Figs.9**(a) and (b) indicate large concentrated developed areas. The spatial distribution of these areas can be seen in the

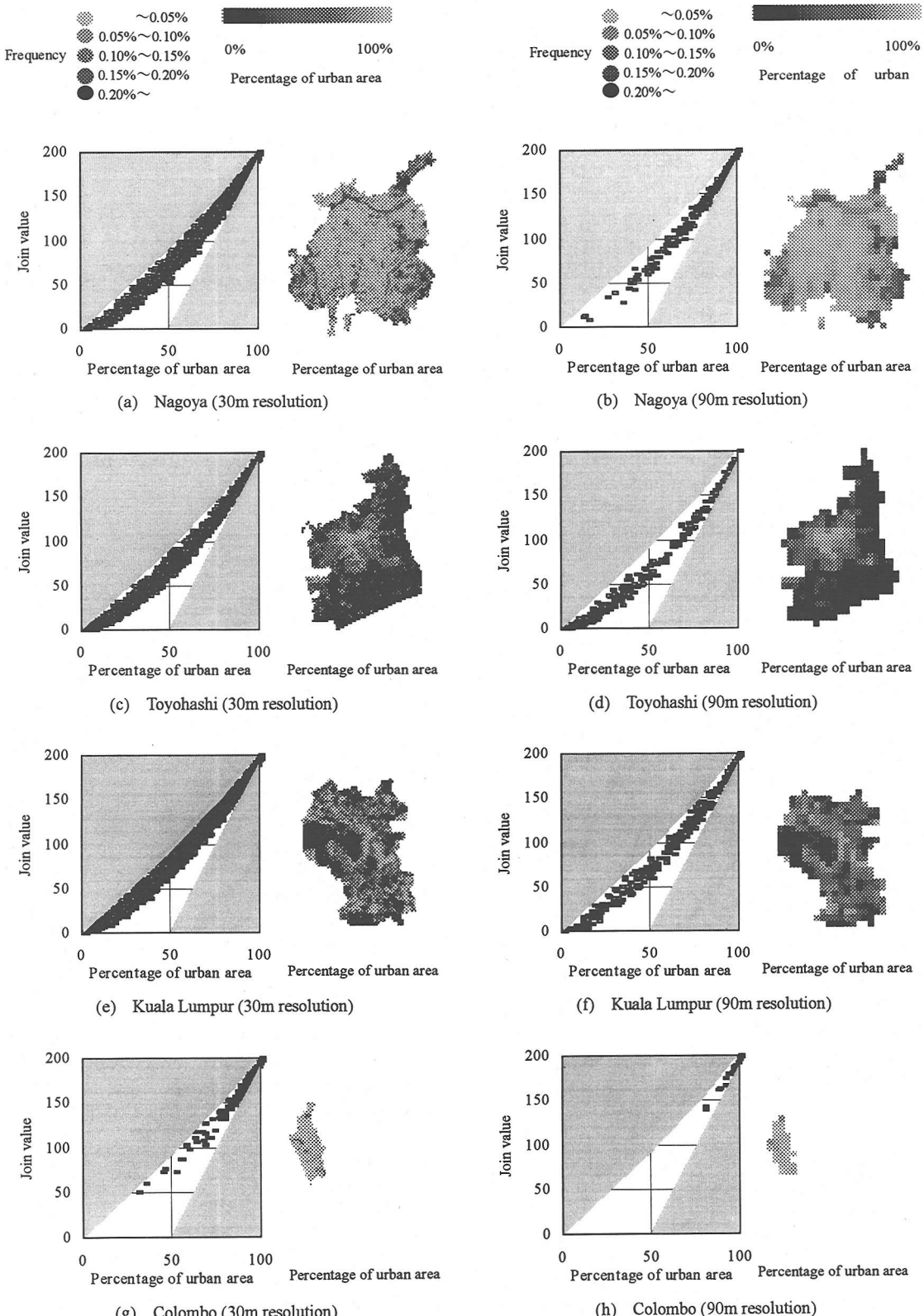


Fig.9 Relation between join value and percentage of urban area

urban area image on the right side of the figures. The white areas in the images show where the percentage of urban area is high. As the mesh size becomes larger the mixture of the type of land category becomes more and if the urban area has a large concentration of developed areas a high join value is clearly seen. If the join values is small for a certain percentage of urban area, the urban areas scatters in the small cell. In the case of Toyohashi and Kuala Lumpur black points appears at the broad range. This characteristics implies that the urban area are located well mixed with vegetation area as shown in the urban area image.

Join value analysis is effective to know the distributions of urbanized areas and vegetation area. In Toyohashi and Kuala Lumpur urbanized areas and vegetation areas are located with good balance.

6. CONCLUSION

(1) It was shown that the urban index UI is applicable to evaluate the urbanization quantitatively for different regions and seasons and direct comparison of UI values is effective if the values are modified based on the UI-UD relation of each case.

(2) The relation between numbers of urbanization area and vegetation area in the cities were compared on the UI-NDVI diagram. This diagram shows the characteristics of intense of urbanization.

(3) The distributions of highly urbanized areas in the cities were evaluated by join values. The high join values represent the concentration of urbanized area.

(4) Based on the above analysis, two types of urbanization were recognized. In Nagoya city and Colombo city highly urbanized areas are located at the center of cities and they spread close to the administrative boundaries of cities, where the large vegetation areas are few. In Toyohashi city and Kuala Lumpur city urbanized areas and vegetation area are not concentrated but mixed in good balance.

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衛星データによるアジアの４都市の都市化に関する比較研究

河邑 眞・サナス ジャヤマンナ・辻子 裕二・杉山 晃

この論文は,衛星データを用いた都市化の定量的評価についてアジアの４つの都市を対象として比較研究を行なった結果を示したものである.筆者らは以前の論文でランドサットＴＭデータから算出される都市化指標ＵＩを提案している.この論文では,まずこの都市化指標が異なる地域,異なる季節に対して適用可能かについて検討した.つぎに,この都市化指標ＵＩと植生指標ＮＤＶＩを用いて都市における都市化と植生環境の関係を４つの都市について比較検討した.最後に都市化した地域の分布状態を調べるためにジョイン値を用いた解析を行った.以上の検証の結果,二つの都市化のタイプが定量的に認識された.