STUDIES ON THE ESTIMATION OF THE LAND USE IN THE TOKYO METROPOLITAN AREA BY LANDSAT THEMATIC MAPPER DATA

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(Commission Number : 7)

1. INTRODUCTION

Since the Meiji Restoration(1867), Tokyo has continued to expand and develop as the capital city of Japan. In the Tokyo Metropolitan Area, the daytime population is 11000000 as against 8500000 of resident population, presenting a remarkable doughnut phenomenon. Particularly, during the period of high economic growth of the 1960's, various functions concentrated in Tokyo in an accelerated pace. As a result, Tokyo has grown into a mammoth, overcrowded city burdened with many strains of urbanization : for example, above-mentioned decline of population in central Tokyo due to the extension of business district, disorderly sprawl of built-up areas, outlying location of residence, deterioration of the living environment. All these problems are urged to be solved.

In this paper, therefore, the correspondence of the Detailed Digital Land Use Information data and the Landsat Thematic Mapper data is analyzed by digital image processing for the estimation of the land use. The area used for analysis is the Tokyo Metropolitan Area: gross area is nearly 600 square kilometers.

2. DATA BASES

The National Capital Region Development Law in 1956 aimed at first to restrict the expansion of the urban district by providing the Suburban Zone(green belt). But owing to the unexpected concentration of population and industries, the urban area continued to expand, for exceeding the initial expectation. Thus, the Law was extensively amended in 1965. The revised law abolished the green belt concept, and laid down to establish the Suburban Development Area in the suburbs of the existing built-up area. In connection with this, land use information is collected and opened by the Geographical Survey Institute in every five years, 1974, 1979 and 1984. This Land Use data is DDLUI (the Detailed Digital Land Use Information) data containing digital data on the state of land utilization for each 10-meter square mesh. The data, though the unit of information is small enough, is not suited for monitoring of land use changes due to the survey period of 5 years. Effective urban and regional planning depends on accurate information regarding current land usage. It is considered satellite imagery can contribute substantialy to this information base. Landsat Thematic Mapper data considered in this study was acquired on November 1984.

Table 1 shows 16 classes of DDLUI data, including residential area, industrial area, commercial and business area, etc. Whereas the data has a 10m pixel size, a spatial resolution of Landsat Thematic Mapper data is approximately 30m. This requires combining units of the DDLUI data in a neighborhood. A method of combining is as follows,

1) A mesh of 30m x 30m is made by sets of 3 x 3 units.
2) Land use of a mesh is represented to bo that of the largest number.
3) If the two or more land use selected at a mesh, the priority is given to the land use which the percentage is low in a whole study area.

The results of combining are shown in Table 2 and Table 3. This process is considered to be effective to preserve the original profile.

The data image of the Tokyo Metropolitan Area is shown in Fig.1(approximately 32km in east and west, 30km in north and south). The commercial and business areas are in the central right(Chiyoda and Chuo wards) and central left(Shinjuku ward) regions. The town greenery in the central regions are the Imperial Palace, the Meiji Shrine, The Shinjuku Imperial Gardens, etc. Low-rise residential areas are in the left and top right, as are low-rise densely residential area in the just right of the center.

Table 1 Classes of the Detailed Digital Land Use Information data.

Class	Land use
1	fields, mountain greenery
2	paddy fields
3	plowed fields
4	fields under creation and reclamation
5	unoccupied grounds, parking zone
6	industrial area
7	low-rise residential area (buildings less than 3 stories, a plottage above 100 m^2)
8	low-rise densely residential area (buildings less than 3 stories, a plottage below 100 m^2)
9	residential area(buildings over 3 stories)
10	commercial and business area
11	roads
12	public space I (park, town greenery, sports ground)
13	public space II (railroads, airport, harbor facilities)
14	revers, lakes and marshes
15	Forces
16	sea

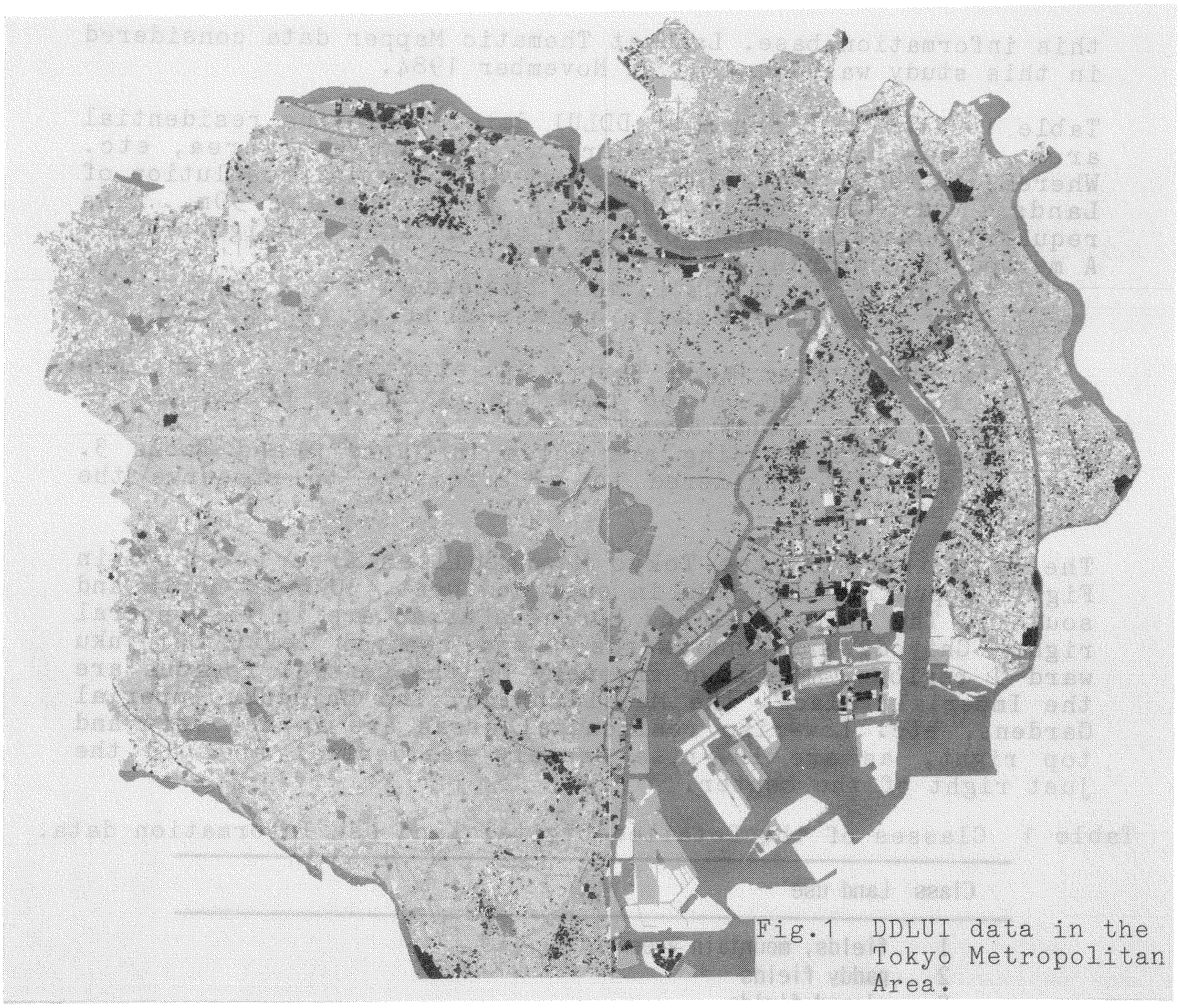

Fig.1 DDLUI data in the Tokyo Metropolitan Area.

Table 2 The change of area proportions by data combination.

Class	10m mesh	30m mesh
1	419,169(2.91%)	49,619(3.10%)
2	169,720(1.18%)	19,725(1.23%)
3	999,985(6.95%)	121,366(7.59%)
4	306,577(2.13%)	34,331(2.15%)
5	954,012(6.63%)	109,657(6.86%)
6	573,631(3.98%)	64,609(4.04%)
7	2,432,167(16.89%)	286,304(17.90%)
8	687,658(4.78%)	79,167(4.95%)
9	299,842(2.08%)	34,208(2.14%)
10	1,100,715(7.65%)	113,533(7.10%)
11	1,760,121(12.23%)	167,658(10.48%)
12	586,812(4.08%)	67,548(4.22%)
13	1,072,544(7.45%)	115,266(7.21%)
14	571,890(3.97%)	63,041(3.94%)
15	76,856(0.53%)	8,565(0.54%)
16	2,384,594(16.56%)	265,003(16.57%)

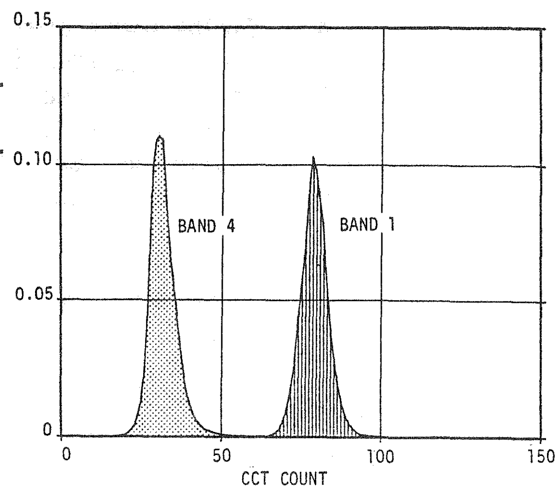

Fig.2 Probability of pixels belonging to low-rise residential area.

Table 3 Land use areas in the Tokyo Metropolitan 23 wards by the Detailed Digital Land Use Information data (unit:ha).

Ward	Class 1	2	3	4	5	6	7	8	9	10	11	12	13,15	14	Total
Chiyoda	0.09	–	–	–	7.11	0.09	29.43	7.92	10.35	311.04	273.96	88.02	334.17	72.99	1135.17
Chuo	–	–	–	–	21.15	21.78	1.80	29.16	18.45	399.78	269.37	44.82	51.39	106.65	964.35
Minato	22.59	–	–	5.13	63.00	26.73	206.82	127.98	96.75	488.97	364.32	169.38	440.01	2.79	2014.47
Shinjuku	8.64	–	–	3.51	35.91	10.17	383.58	131.58	108.09	317.88	413.46	134.55	262.80	7.02	1817.19
Bunkyo	6.93	–	–	–	7.92	9.18	175.14	95.13	30.60	185.58	300.60	127.35	188.55	1.98	1128.96
Taito	0.18	–	–	2.88	4.14	2.88	9.63	74.52	4.23	386.28	257.94	138.69	96.93	38.34	1016.64
Sumida	3.78	–	–	5.67	36.90	153.00	17.73	258.30	29.97	274.23	288.72	74.25	114.39	112.95	1369.89
Koto	47.97	–	0.09	576.00	559.53	495.18	128.34	172.98	163.08	529.38	561.69	148.95	406.80	226.53	4016.52
Shinagawa	6.84	–	4.14	52.38	95.58	86.76	424.98	217.89	54.27	481.05	282.24	151.92	380.34	23.40	2261.79
Meguro	16.38	–	3.42	–	37.17	17.73	671.40	120.87	47.61	162.00	141.93	46.80	204.89	8.73	1473.93
Ota	10.80	1.80	13.50	699.21	211.86	392.85	1330.92	251.01	83.97	416.88	693.00	275.58	796.23	287.91	5465.52
Setagaya	145.26	1.98	340.92	3.69	266.40	29.43	2686.86	245.43	189.18	365.58	542.97	358.65	552.96	77.67	5806.98
Shibuya	6.93	–	0.18	–	35.28	11.43	355.50	176.40	74.43	160.92	288.27	186.93	205.83	0.45	1502.55
Nakano	21.42	–	22.77	1.35	47.70	7.56	567.27	143.73	60.93	110.61	352.53	55.80	161.46	5.04	1558.17
Suginami	64.17	–	95.58	0.45	132.03	27.36	1769.94	108.81	55.80	207.45	478.71	188.82	264.24	12.87	3406.23
Toshima	3.96	–	0.18	0.18	26.28	13.41	358.65	167.76	30.69	212.31	270.36	59.13	166.32	0.36	1309.59
Kita	9.90	–	0.99	–	40.32	138.51	319.41	314.28	131.40	192.78	301.41	158.67	297.27	169.29	2074.23
Arakawa	–	–	–	5.40	22.32	67.86	113.40	148.95	15.30	187.83	186.30	56.52	158.04	53.01	1014.93
Itabashi	31.95	0.27	85.77	2.16	241.92	235.53	621.90	363.42	169.47	335.34	502.38	224.01	287.46	126.18	3227.76
Nerima	108.99	0.27	781.56	26.28	434.34	31.68	1485.00	386.37	73.17	263.25	674.28	171.90	364.50	10.80	4812.39
Adachi	4.32	13.59	292.77	21.24	734.04	266.13	703.89	602.55	230.85	569.25	810.81	279.72	353.97	441.90	5325.03
Katsushika	23.94	2.88	142.20	7.20	246.24	201.15	754.65	307.17	92.79	278.55	502.92	211.23	305.10	403.56	3479.58
Edogawa	14.58	4.59	259.20	234.27	548.01	307.98	993.15	122.22	89.37	335.25	671.04	245.97	261.81	695.16	4782.60
Total	559.62	25.38	2043.27	1647.00	3855.15	2554.38	14103.40	4574.43	1860.7	7172.19	9429.21	3597.66	6650.46	2885.58	60964.50

3. ANALYTICAL METHOD

The purpose of analysis is to be able to identify land utilization by Landsat Thematic Mapper data. If for each pixel measurements of reflection at several wavelengths are available, then it shall be a relatively easy matter to discriminate fundamental land cover types. However, DDLUI data dealt in this paper is a data of land utilization, not a data of cover types. Therefore, it becomes necessary to treat a mixel data itself as a training data.

To categorize pixels in an image into land use classes, the maximum likelihood classification method, using Mahalanobis classifier as the discriminant function, was taken in this study. The percentage of correct classifications is calculated by the matching of land use data and the Landsat TM data, pixel by pixel.

In order to correct geometric distortion, 80 ground control points are selected, for example, small lakes, bends in rivers, prominent coastline features. The chosen mapping polynomial has order of third degree.

$$f(x,y)=a_0+a_1x+a_2y+a_3x^2+a_4y^2+a_5xy+a_6x^3+a_7y^3+a_8x^2y+a_9xy^2$$

Errors of the coordinate conversion were within plus or minus 1 pixel. Moreover, nearest neighbor method was used in the resampling.

For training data, 21 samples were obtained and used in each class. Since spectral classes in remote sensing data are modeled by multidimensional normal distribution, one of the distributions of training data is shown in Fig. 2.

4. ANALYTICAL RESULTS

Table 4 is a confusion matrix based on 16 classes. The percentages listed in Table 5 represent the proportion of ground truth pixels, in each case, correctly labeled by the classifier. Fig. 3 shows a portion of the Tokyo Metropolitan Area image classified into 16 land use types. The upper image is DDLUI data and the lower image is an analyzed result. The percentages of correct classifications are low all over. Even in "low-rise densely residential area", only the percentage of 36% is obtained. Therefore, combination of the classes was done and 8 classes were newly laid down as follows; (1) field, (2) industrial area, (3) low-rise residential area, (4)low-rise densely residential area, (5) residential area, (6) commercial area and road, (7) park, (8) water surface.

The results are shown in Table 6, 7 and Fig.4. The percentages of correct classifications rose approximately 50% in "low-rise residential area" and "low-rise densely residential area". However, judging from the Mahalanobis distance between the classes listed in Table 7, re-combination of the classes were seemed to be required. On this account, the classification based on the 5 classes, namely, (1) field, (2) residential area, (3) commercial area and road, (4) park, (5) water surface, were put to the analysis (Table 8 and Fig.5).

Whereas the percentage of the correct classifications concerned with residential area became to indicate a higher value of 79%, that of commercial area remained a low value of 31%.

A major cause of this turned to the characteristics of the training classes that the classes don't mean land covers, but land utilization. For example, in central regions, "commercial area" is almost covered by concrete buildings. However, in suburbs, "commercial area" is sometimes formed by detached houses with tiled roofs. Consequently, maximum likelihood classification was applied to each ward(Table 9). In the midtown area such as Chiyoda and Chuo ward, the percentage of correct classifications in class "commercial area and road" attained 58% and 70% in each.

Table 4 Confusion matrix resulting from classifying DDLUI data.

Clsss	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1706	567	775	422	124	7	1009	184	367	40	40	36	734	1	205	0
2	8	90	87	2	26	2	27	6	7	2	4	0	21	0	0	0
3	3205	4036	6898	481	739	59	4108	1024	490	61	137	18	1381	0	65	0
4	684	4332	2397	3138	2314	322	347	182	308	907	421	5	2672	165	3	103
5	2187	6950	7682	1866	3006	500	6881	3444	1188	1057	1506	22	6463	9	46	24
6	805	1894	3042	85	918	1375	3544	4585	714	1786	1971	0	7632	8	6	15
7	12141	6612	17133	678	1154	1229	45277	30141	6908	2433	3353	24	29514	4	147	4
8	1943	1571	4918	107	288	791	7615	18504	1091	1988	982	1	5578	5	34	5
9	1367	1011	1789	59	257	233	3963	1997	2293	1098	982	1	5578	5	34	5
10	2086	2459	4273	102	987	2242	7509	14310	2770	14233	10019	4	18513	37	67	66
11	4611	5110	7538	511	1380	1823	15244	17112	4870	13392	9758	22	23004	65	165	164
12	6271	7433	5618	3098	982	125	4028	1205	2582	519	492	474	5258	53	1793	39
13	3809	7790	6868	1812	2525	2682	7551	5082	3795	4949	3954	47	19301	36	276	87
14	1558	2695	2322	746	522	301	443	282	1361	3649	2176	13	2775	9328	96	3792
15	677	245	408	225	105	19	235	99	193	24	77	201	450	11	531	1
16	489	1472	539	269	292	732	138	83	603	2804	1857	1	1151	5463	7	59505

Table 5 Pixels labelled correctly in 16 classes.

Class	Pixels of DDLUI data	Correctly labelled pixels
1	6,217	1,706(27.44%)
2	282	90(31.91%)
3	22,702	6,898(30.38%)
4	18,300	3,138(17.15%)
5	42,831	3,006(7.02%)
6	28,380	1,375(4.84%)
7	156,752	45,277(28.88%)
8	50,821	18,504(36.41%)
9	20,672	2,293(11.09%)
10	79,667	14,223(17.85%)
11	104,749	9,758(9.32%)
12	39,970	474(1.19%)
13	70,384	19,301(27.42%)
14	32,059	9,328(29.10%)
15	3,501	531(15.17%)
16	76,394	59,505(77.90%)

Table 6 Pixels labelled correctly in 8 classes.

Class	Reference code No. of 16 classes	Pixels of DDLUI data	Correctly labelled pixels
1 field	1,2,3,4,5	90,332	23,031(25.50%)
2 industrial area	6	28,380	4,080(14.38%)
3 low-rise residential area	7	156,752	79,416(50.66%)
4 low-rise densely residential area	8	50,821	25,201(49.59%)
5 residential area	9	20,672	5,249(25.39%)
6 commercial area and road	10,11,13	254,800	66,676(26.17%)
7 park	12,15	43,471	2,511(5.78%)
8 water surface	14,16	108,453	69,641(64.21%)

Table 7 Mahalanobis distances.

Class	1	2	3	4	5	6	7	8
1	–	8.09	8.16	8.99	6.09	8.31	5.49	9.19
2	65.66	–	21.08	7.72	31.12	4.60	86.91	10.03
3	9.99	9.02	–	3.33	3.30	8.53	10.36	20.52
4	17.73	6.17	5.02	–	10.04	5.26	27.00	17.06
5	11.57	9.62	4.64	5.75	–	5.02	9.76	16.65
6	27.55	6.03	10.10	6.22	12.90	–	37.00	5.48
7	8.76	19.20	17.11	18.66	13.38	18.18	–	19.45
8	75.75	23.43	35.64	26.38	39.97	12.73	89.96	–

Table 8 Pixels labelled correctly in 5 classes.

Class	Reference code No. of 16 classes	Pixels of DDLUI data	Correctly labelled pixels
1 field	1,2,3,4,5	90,332	44,052(48.77%)
2 residential area	7,8,9	228,245	181,853(79.67%)
3 commercial area, road	6,10,11,13	283,180	89,286(31.53%)
4 park	12,15	43,471	6,343(14.59%)
5 water surface	14,16	108,453	79,292(73.11%)

Table 9 The correct percentages in Chiyoda and Chuo wards.

Class	The correct percentages	
	Chiyoda ward	Chuo ward
1 field	5.00%(4/ 235)	11.91%(28/ 235)
2 industrial area	0 %(0/ 1)	12.40%(30/ 242)
3 low-rise residential area	29.66%(97/ 327)	25.00%(5/ 20)
4 low-rise densely residential area	13.64%(12/ 88)	22.53%(73/ 324)
5 residential area	35.65%(41/ 115)	21.46%(44/ 205)
6 commercial area and road	58.92%(5360/9097)	70.48%(5643/8006)
7 park	24.32%(435/1789)	12.85%(64/ 498)
8 water surface	11.84%(96/ 811)	70.73%(1629/2303)

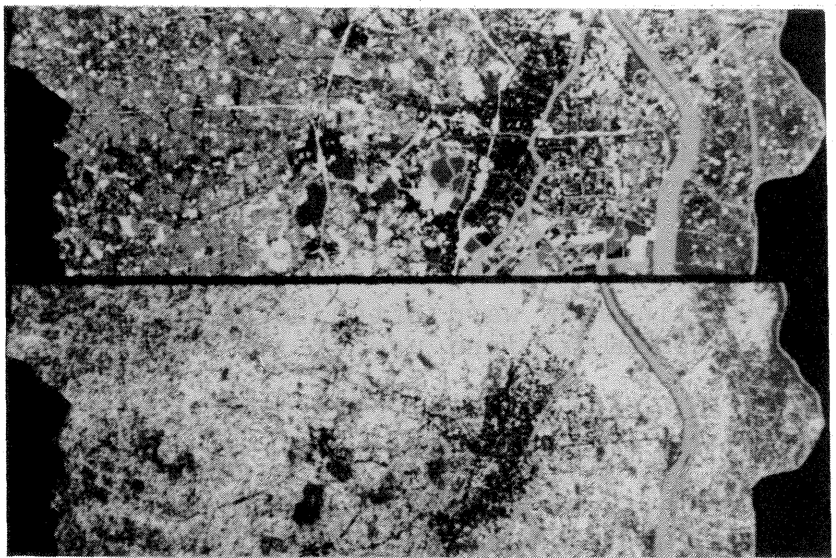

Fig.3 Classification map based on 16 classes. The lower image is a classified map and the upper is DDLUI data.

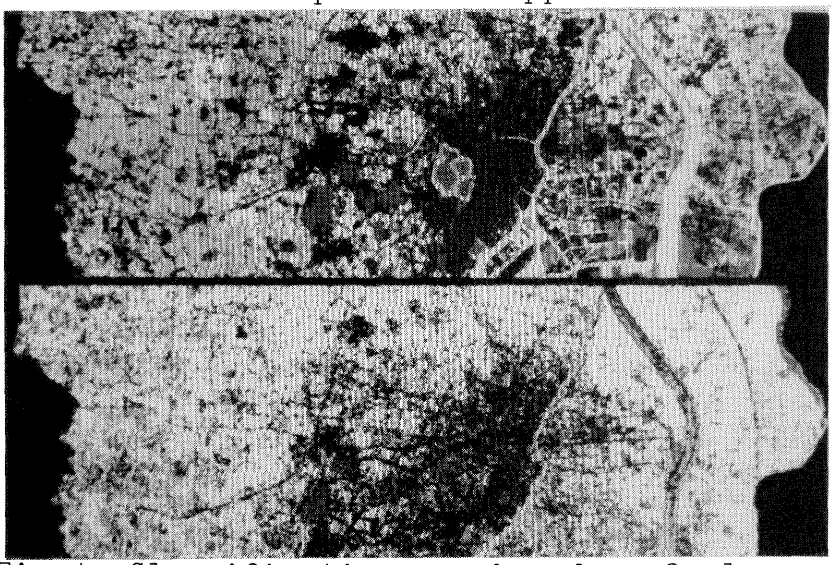

Fig.4 Classification map based on 8 classes.

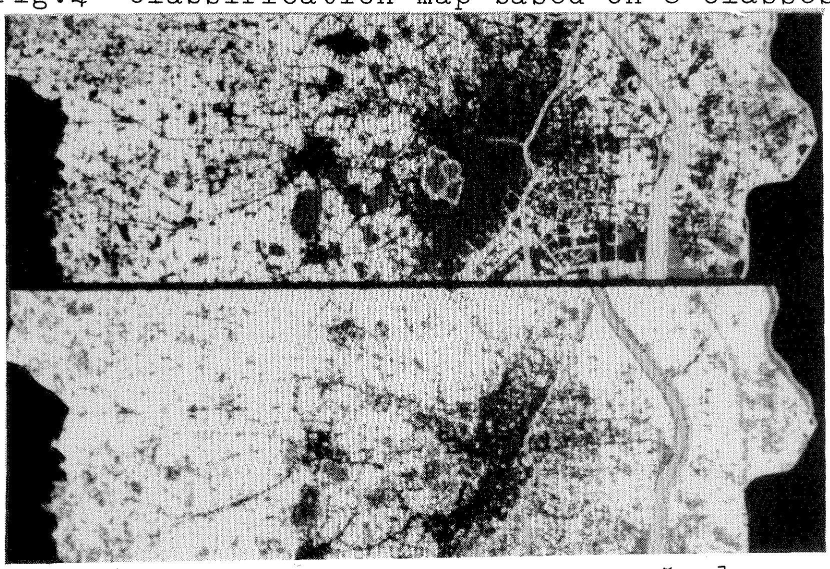

Fig.5 Classification map based on 5 classes.

5. CONCLUSIONS

This paper is summarized as follows;

1) As one example of the applications of the Landsat Thematic Mapper data to a large city, DDLUI data in the Tokyo Metropolitan Area was used as the ground truth data.
2) In the supervised classification of the Landsat TM data, combination of the land use classes were analyzed by the percentage of correct classifications and Mahalanobis distances.
3) An analysis in each ward often lead to a rise in correct percentage of peculiar land use to the ward.

Analyses in this paper were done by pixel by pixel. However, judging from the mixel conditions in urban areas and uncertainties on the process of correction of geometric distortion, analysis assuming divergence of near 1 pixel remains as a coming problem. It is considered such a analysis method may be effective to estimate the thermal environment in urban areas.