CHAPTER 4

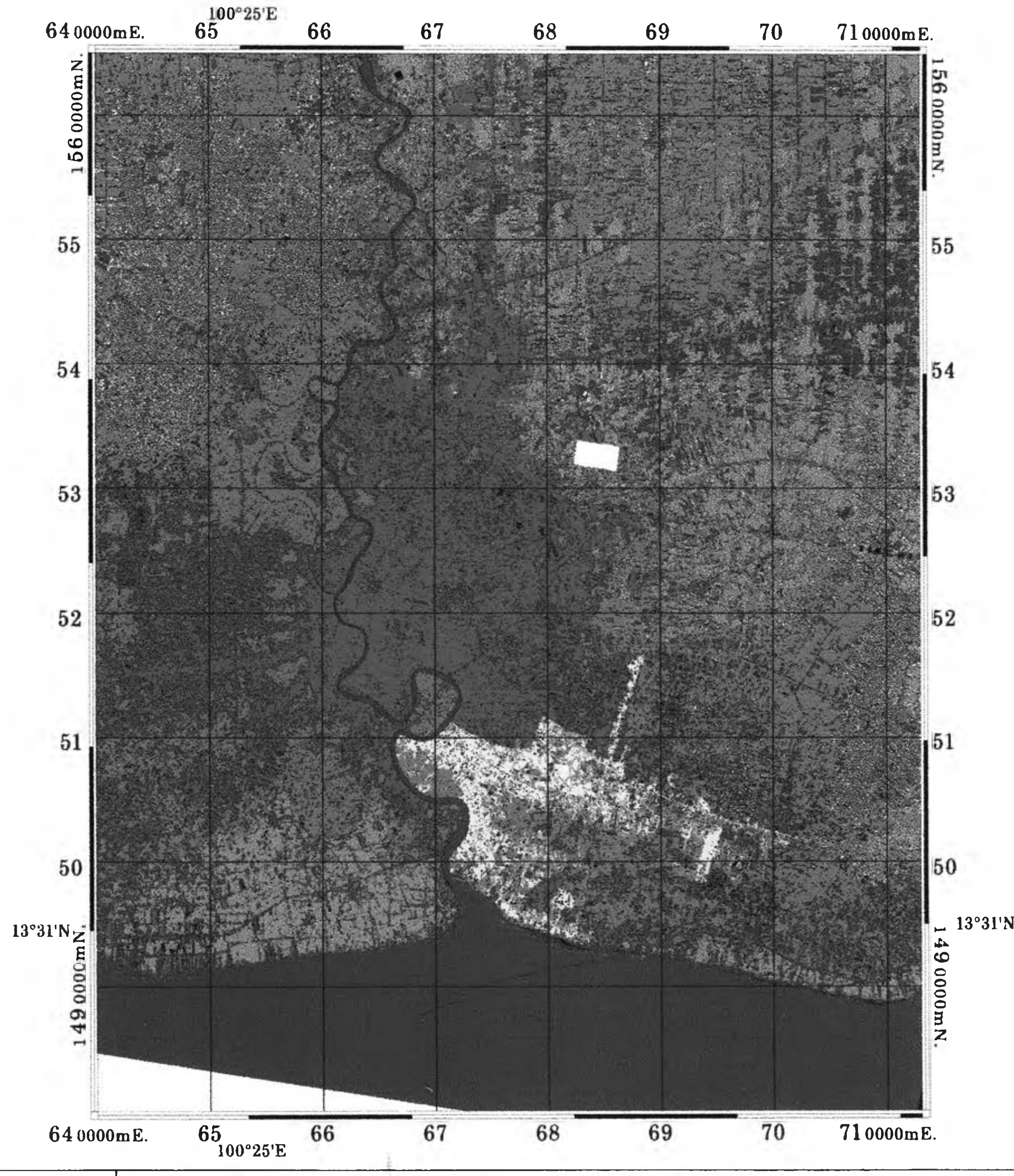
RESULTS AND DISCUSSION

4.1 Land use / land cover classification

Land use / land cover classification results of Bangkok Metropolis in 1988 and 1997 were illustrated in Plate 5 and 6 respectively. They show that the built-up environments (residential area, industrial area, and residential and industrial mixed area) locate at the center of this study area and surround with non-built-up environments. From the data obtained, it was found that built-up areas have been expanded to the non-built-up environments, in particular the agricultural area. Table 9 summarizes the area of land use / land cover type of Bangkok Metropolis in 1988 and 1997.

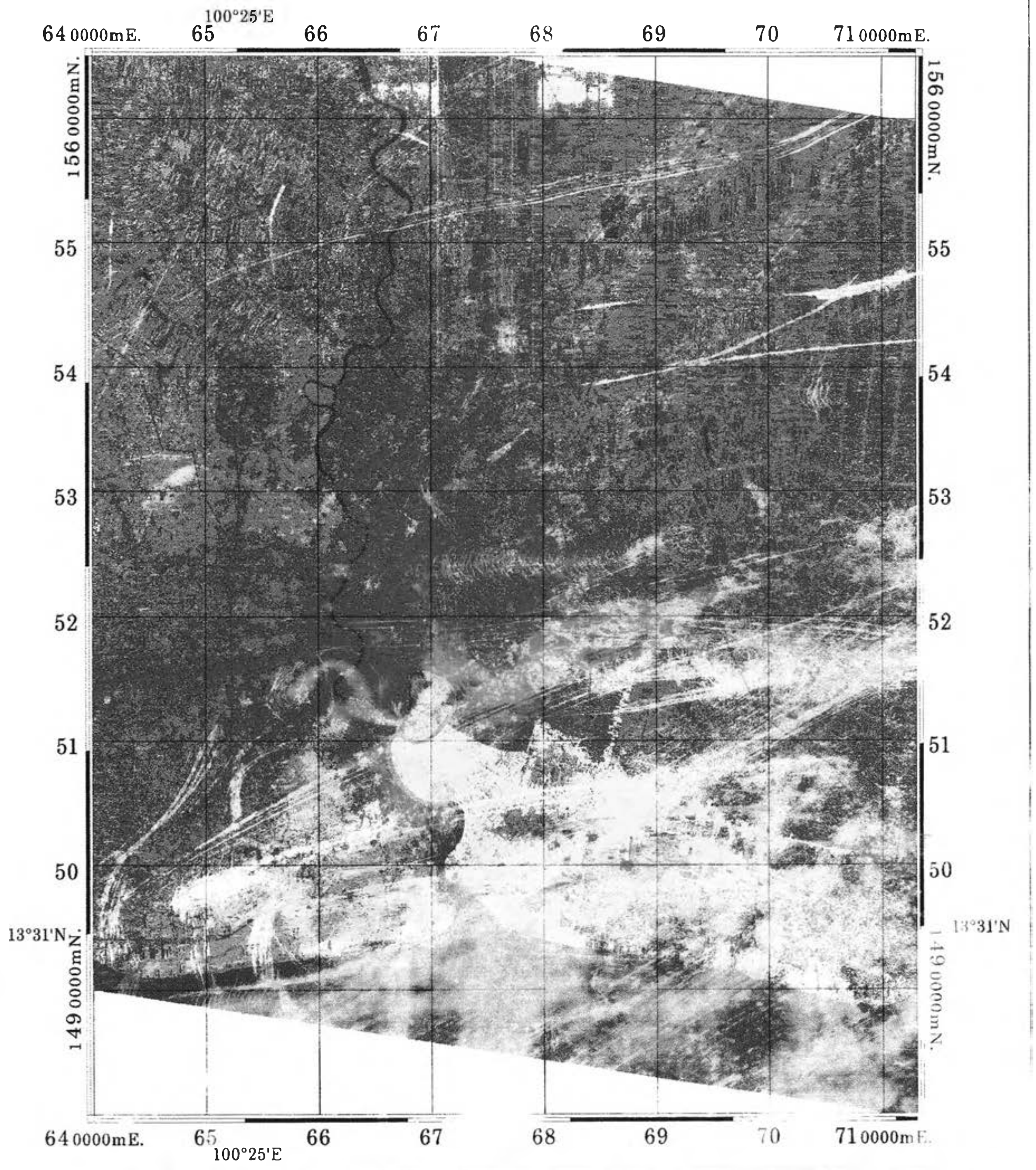
Table 9: Land use / land cover area of Bangkok Metropolis in 1988 and 1997 (Landsat TM)

Land use / land cover type	30 March 1988	24 April 1997	Area difference
	Area (sq.km.)	Area (sq.km.)	(sq.km.)
Water body	933.00	714.68	-218.32
Aqua-culture pond	227.47	197.75	-29.72
Growing paddy field or marsh land	471.87	1192.38	+720.51
Vegetation area	2096.21	1937.61	-158.6
Residential area	1280.26	1427.48	+147.22
Harvested paddy field	643.02	81.61	-561.41
Residential and Industrial mixed area	127.17	147.57	+20.4
Bare soil	343.70	30.76	-312.94
Industrial area	4.16	4.60	+0.44
Unclassified	32.69	18.97	-13.72
No data	45.45	451.59	+406.14
Total	6205	6205	



LAND USE / LAND COVER TYPE	RESIDENTIAL AREA	INDUSTRIAL AREA	RESIDENTIAL & INDUSTRIAL MIXED AREA	VEGETATION AREA	HARVESTED PADDY FIELD	BARE SOIL	GROWING PADDY FIELD / MARSH LAND	AQUA-CULTURE POND	WATER BODY	NO DATA

PLATE 5 : PSEUDO-COLOR IMAGE OF LAND USE / LAND COVER IN BANGKOK METROPOLIS IN 1988	THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS
SOURCE : LANDSAT TM ACQUIRED ON 30 MARCH 1988	10 0 10 20 KM N



LAND USE / LAND COVER TYPE	RESIDENTIAL AREA	INDUSTRIAL AREA	RESIDENTIAL & INDUSTRIAL MIXED AREA	VEGETATION AREA	HARVESTED PADDY FIELD	BARE SOIL	GROWING PADDY FIELD / MARSH LAND	AQUA-CULTURE POND	WATER BODY	NO DATA

PLATE 6 : PSEUDO-COLOR IMAGE OF LAND USE / LAND COVER IN BANGKOK METROPOLIS IN 1997	THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS
SOURCE : LANDSAT TM ACQUIRED ON 24 APRIL 1997	10 0 10 20 KM N

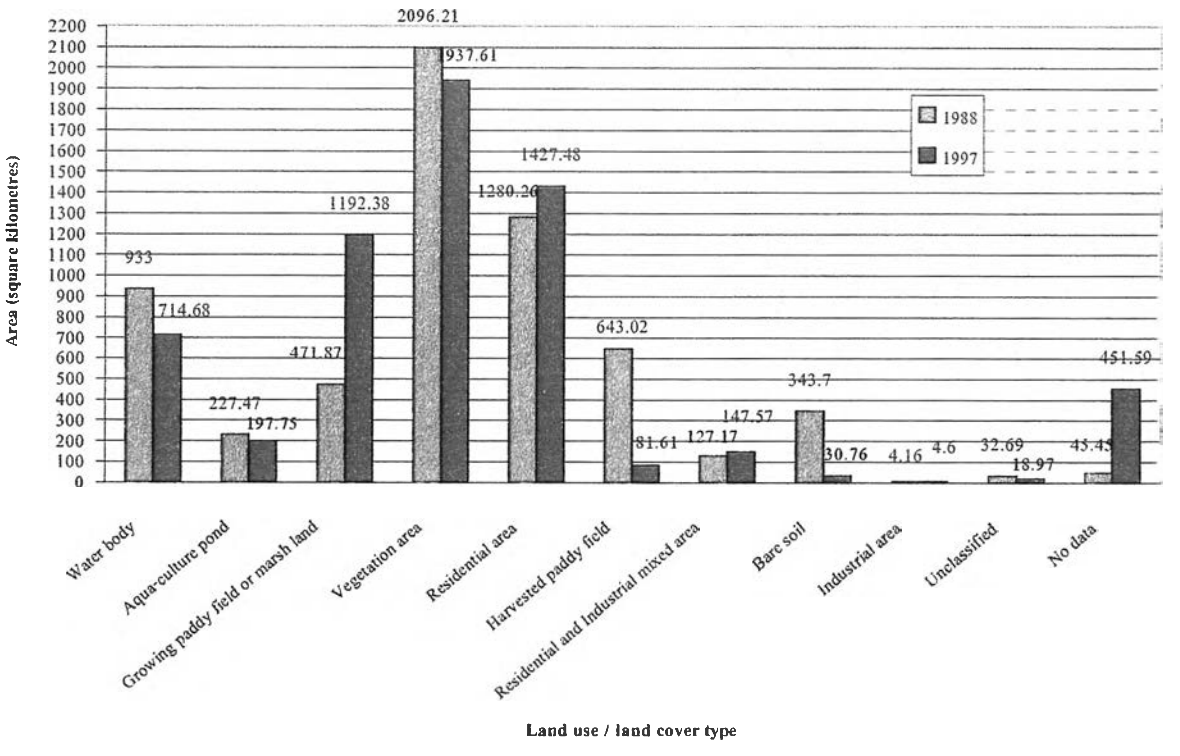


Figure 11: Land use / land cover area of Bangkok Metropolis in 1988 and 1997 (Landsat TM, 1988, 1997)

As shown in Figure 11, the expansion of built-up area was due to a great increasing of residential area (Figure 12) from 1280.26 quare kilometres to 1424.48 square kilometres . The residential and industrial mixed area (Figure 13) also increased from 127.17 square kilometres to 147.57 square kilometres during 1988 to 1997. Industrial area itself is hardly differentiated from residential area particular in Bangkok area where land use zoning was not strictly applied. Only the Bang Pu industrial estate (Figure 14), which was referred to the only land use zoning in 1993 could be isolated and hence providing a little bit change in industrial area.

Figure 12: Residential, commercial, and offices, this picture is taken in Khet Pathum Wan, Bangkok Metropolis (September, 1998)

Figure 13: Residential and industrial mixed area, this picture is taken in Amphoe Phra Pradaeng , Samut Prakan province (Septempber, 1998)

Figure 14: The Bang Pu industrial estate in Amphoe Muang, Samut Prakan province (September, 1998)

In the non-built-up environments, there were a relation in an area change among marsh land, vegetation area, harvested paddy field and bare soil as show in Figure 11. From the classification results and field survey's data, it was found that the non-built-up environments in the northern and eastern parts of Bangkok were paddy fields. They had the various land cover types, consisted of marsh land, vegetation, harvested paddy field and bare soil (Plate 5 and 6). Marsh land in paddy fields was the flooded during the period of field preparation stage or the rice growing stage (Figure 15). Green vegetation area was the area covered with rice in its full panicle (Figure 16). When the rice was harvested, the area covered with rice trash that was classed into harvested paddy field class (Figure 17). Bare soil was the open space included the paddy field (Figure 18 and 19).

Figure 15: Flooded area in paddy field during the period of field preparation stage, this picture is taken in Amphoe Thunyaburi, Pathum Thani province (April, 1998)

Figure 16: Rice in its full panicle, this picture is taken in Amphoe Thunyaburi, Pathum Thani province (April, 1998)

Figure 17: Harvested paddy field covered with rice trashes, this picture is taken in AmphoeThunyaburi, Pathum Thani province (April, 1998)

Figure 18: Bare soil, this picture is taken in AmphoeThunyaburi, Pathum Thani province (April, 1998)

Figure 19: Cleared paddy field, this picture is taken in Amphoe Thunyaburi, Pathum Thani province (April, 1998)

The classification images show the variation of these land cover types in the paddy fields during two acquiring two dates. It is assumed that there were in the different paddy growing stage in each field (National Research Council of Thailand [NRCT], 1991). The paddy fields can be covered with any land surface type depending on the paddy growing stage as above descriptions. Besides the vegetation in paddy field, most of vegetation areas were agriculture area and unused land (Figure 20 and 21) in Bangkok's vicinities. These areas decreased from 2091.21 square kilometers to 1937.61 square kilometers. The southern of study area were aqua-culture ponds (Figure 22), located along the coastline in Samut Prakan province. These areas decreased from 227.47 square kilometers to 197.75 square kilometers.

As a result, it is possible that the land use / land cover change in non-built-up environments could be due to the expansion of built-up area or agricultural season.

Figure 20: Orchard, this picture is taken in Amphoe Pak Kret, Nonthaburi province (September, 1988)

Figure 21: Unused land, this picture is taken in Amphoe Pak Kret, Nonthaburi province (September, 1988)

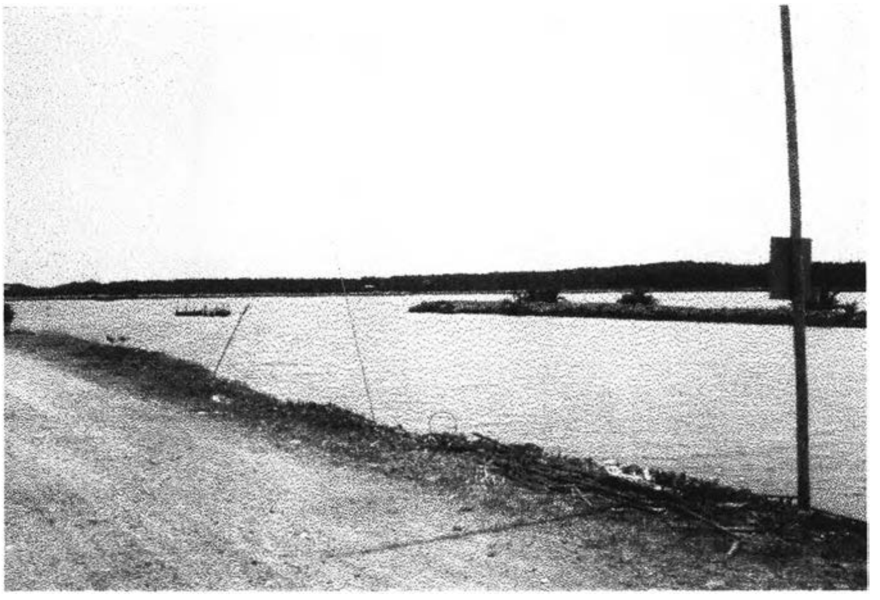


Figure 22: Aqua-culture ponds locates along the coastline, this picture is taken in Amphoe Phra Samut Chedi , Samut Prakan province (May, 1998)

Classification Accuracy Assessment

For the present study, land use zoning obtained from the Pollution Control Department and ground truth data were used as the reference data for image classification assistance and classification accuracy improving. Ground truth involved the observations about condition of agricultural crops and land uses in the study areas, this data is also used for classification accuracy assessment.

This study collected the ground truth data in April, May and September 1998. Geographic positions at field observations were marked on a map to facilitate their location in a corresponding remote sensing image. Global positioning system (GPS) and topographic map at scale 1:15,000 were used for such purpose.

The verification of information extracted from remote sensing data was presented in term of accuracy assessment. The most common way to express the accuracy of classification image is the classification error matrix or confusion matrix or contingency table (Lillesand and Kiefer, 1994).

Error matrix compare, on a category-by-category basis, the relationship between known reference data (ground truth) and the corresponding results of image classification. Several descriptive measures can be obtained from the error matrix, such as overall accuracy, producer's accuracy and user's accuracy.

Overall accuracy is the accuracy of total number of correctly classified pixels, defined as:

$$\text{Overalll accuracy} = \sum_{i=1}^{k} Xii \;/\; N$$

Producer's accuracy is measure of omission error and indicates the probability that a location on the ground is correctly categorized on the map. It defined as:

$$\text{Producer's accuracy for class i} = Xii \;/ \sum_{j=1}^{k} Xji$$

User's accuracy is measure of commission error and indicates the probability that a pixel classified into a given category actually represents that category on the ground. It defined as:

$$\text{User's accuracy for class i} = Xjj \;/ \sum_{i=1}^{k} Xji$$

where Xij	=	a value of the error matrix for an element in row i column j
k	=	the number of classes
N	=	the total number of sampling cells
i	=	class i^{th} as classified by ground truth
j	=	class j^{th} as classified by classified image

Error matrix for 1997's classification image is summarized in Table 10 and classification accuracy assessment is summarized in Table 11.

Table10: Error (Confusion) Matrix 1997 using ground truth data as the reference data

Reference data	Classified data					
	Built-up area	Vegetation area	Paddy field	Aqua-culture pond	Water body	Total
Built-up area	45	6	0	0	0	51
Vegetation area	5	38	6	0	0	49
Paddy field	3	2	14	2	0	21
Aqua-culture pond	0	0	0	7	2	9
Water body	0	0	0	0	5	5
Total	53	46	20	9	7	135

Note: Because bare soil, harvested paddy field and marsh land were in paddy field, which the land cover type vary on the paddy growing stage and it is time dependent. Since ground truthing was carried out at different time with the overpass date, details ground truthing for each of these classes was possible. Then the study aggregated these classes into a paddy field class for confusion matrix calculation.

Table 11: Classification accuracy assessment 1997 using ground truth data as the reference data

Class Name	Producer's Accuracy		User's Accuracy	
	Ratio	%	Ratio	%
Built-up area	45/53	84.91	45/51	88.24
Vegetation area	38/46	82.61	38/49	77.55
Paddy field	14/20	70.00	14/21	66.67
Aqua-culture pond	7/9	77.78	7/9	77.78
Water body	5/7	71.43	5/5	100.00

Overall Accuracy : 80.74 %

Because the land cover classification image on 1988 is too far exceeded the ability to meaningfully quantify its accuracy by ground thruthing. The study did not carry out accuracy assessment for the 1988 classification map.

4.2 Transformed vegetation index

The vegetation index' s green sensitivity is based on the red band being related to the amount of chlorophyll, and the radiance in infrared band being related to the density of green leaves. Thus the aqua-culture ponds and water body were not the principle consideration of the index.

Table 12: The percentage of transformed vegetation index (TVI) of each land use / land cover type (Landsat TM, 1988, 1997)

Land use / Land cover type	30/3/1988		24/4/1997	
	% TVI	Std. dev.	% TVI	Std. dev.
Water body	5.48	5.89	8.02	6.88
Aqua-culture pond	12.51	5.35	13.37	6.46
Vegetation area	39.85	5.18	41.55	7.08
Growing paddy filed or marsh land	25.68	5.74	30.19	6.81
Residential area	30.15	7.10	29.43	7.19
Harvested paddy field	27.61	1.35	27.86	1.11
Residential and Industrial mixed area	30.37	7.26	29.43	7.57
Bare soil	26.60	3.13	24.32	2.60
Industrial area	23.93	5.14	24.36	5.21

As shown in Table 12, the vegetation area were approximated 40-42 percent of TVI, which were the highest TVI in this study. Residential area and residential and industrial mixed area were approximated 30 percent of TVI. This area appeared the moderate of TVI, because there are the vegetation areas such as park, recreation area or agriculture area distributed in the two land use type. This is well agree with the data reported by Anuchat Pongsomlee and Ross (1992) that there are pockets of agricultural or unused land remain quite close to the inner zone of city. Moreover, there are the vegetation in some areas such as offices in low-density areas as well as school and universities (Figure 23), which give rise to higher TVI. In particular, Bang Kra

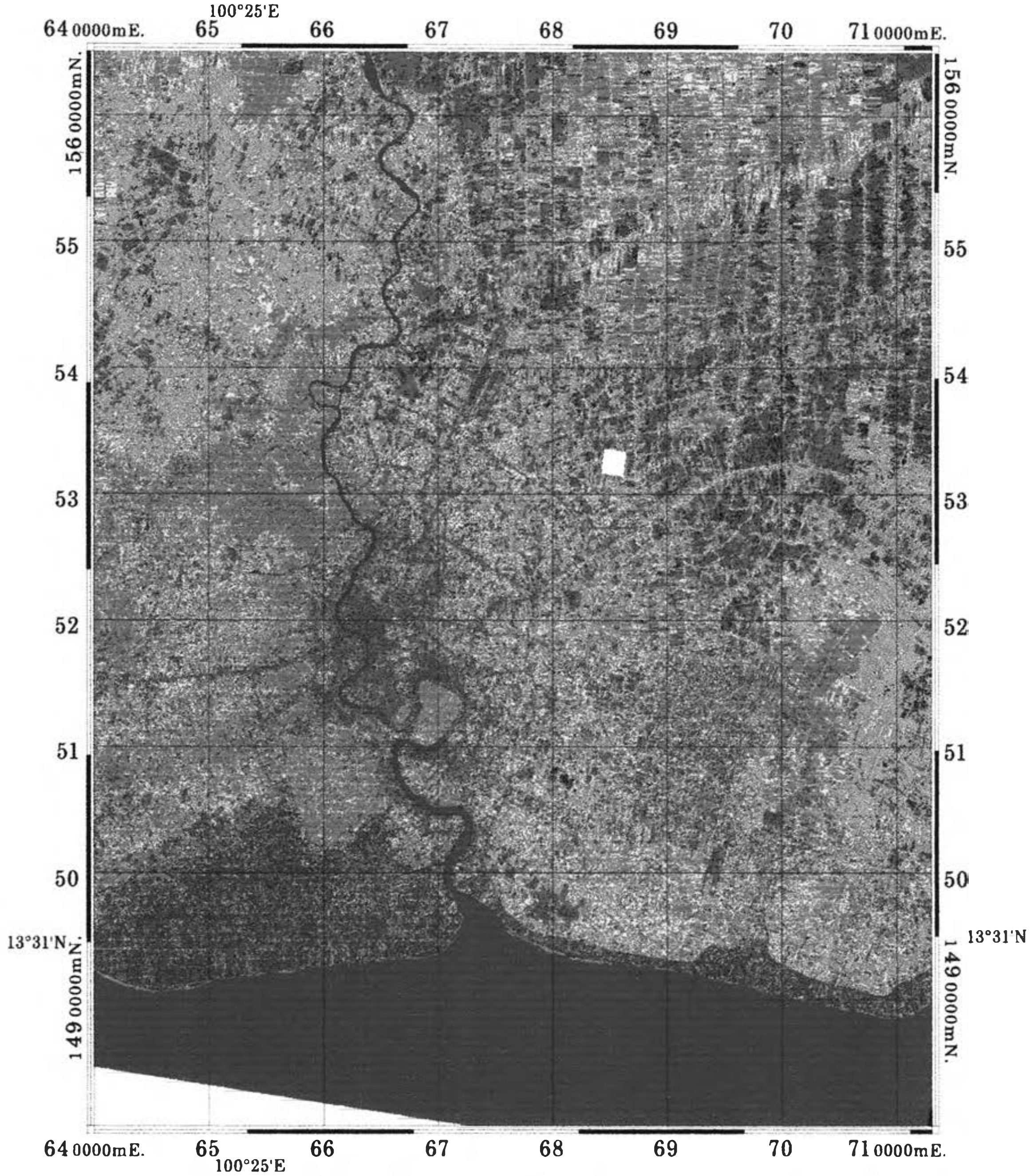
Chao area is the largest green area that located near the center of Bangkok. It looks like a sac shape with high TVI as shown in Plate 7 and 8. The lowest TVI of built-up environment was the Bang Pu industrial estate with approximately 24 percent of TVI

Figure 23: Green area in the inner zone of Bangkok, this picture is taken at Chulalongkorn University (September, 1998)

For non-built-up environments, marsh land had larger area and also higher TVI in 1997 than 1988. It is possible that some marsh land in 1997 were in the rice growing duration that effected TVI values (Figure 24). The lowest TVI appeared in non-built-up environment was bare soil, generally was the non-vegetation area.

Although, water body and aqua-culture pond were the water land cover type but they appeared the different TVI. It can be explained that the energy absorption of water depends on the water condition and wavelength. Absorption in visible portion of the spectrum varies quite dramatically with the characteristics of water body, particular red band. Thus this have effect to the TVI that calculates from IR and red band difference ratio.

Figure 24: Early rice growing stage paddy field, this picture is taken in Amphoe Thunyaburi, Pathum Thani province(April, 1998)



TRANSFORMED VEGETATION INDEX (%)	0 - 10	10 - 15	15 - 20	20 - 25	25 -30	30 -35	35 -40	40 - 45	45 - 50	> 50	NO DATA

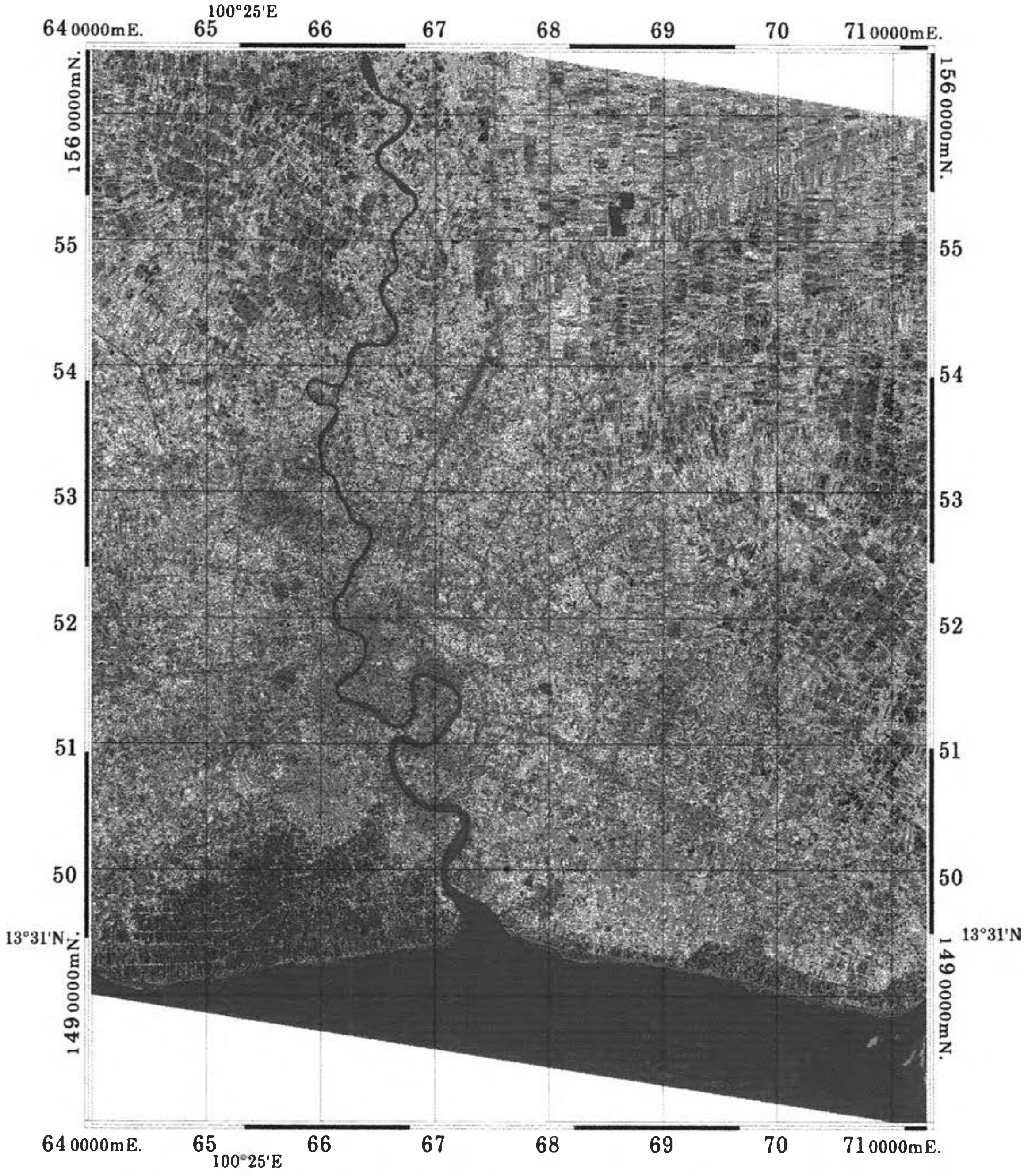
PLATE 7 : PSEUDO-COLOR IMAGE OF TRANSFORMED VEGETATION INDEX IN BANGKOK METROPOLIS IN 1988

THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS

SOURCE : LANDSAT TM ACQUIRED ON 30 MARCH 1988

10 0 10 20 KM

N



TRANSFORMED VEGETATION INDEX (%)	0 - 10	10 - 15	15 - 20	20 - 25	25 -30	30 -35	35 -40	40 - 45	45 - 50	> 50	NO DATA

PLATE 8 : PSEUDO-COLOR IMAGE OF TRANSFORMED VEGETATION INDEX IN BANGKOK METROPOLIS IN 1997

THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS

SOURCE : LANDSAT TM ACQUIRED ON 24 APRIL 1997

10 0 10 20 KM

N

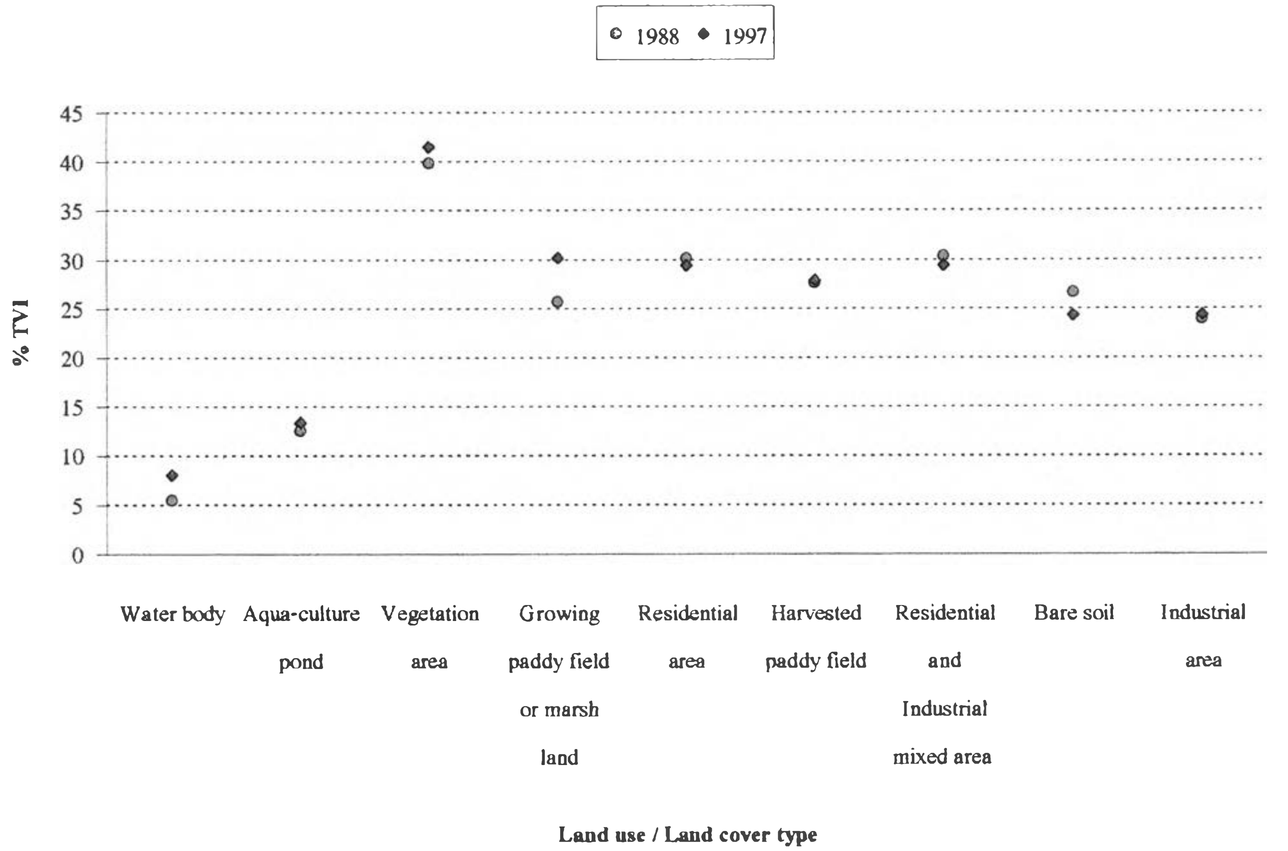


Figure 25: The comparison of %TVI of Bangkok Metropolis between 1988 and 1997 (Landsat TM)

Although, TVI values in 1988 and 1997 are different, but they appear a similar tendency of TVI in each land use / land cover type. That is the high TVI responded to the vegetation area, whereas the low TVI respond to non-vegetation area such built-up surface or bare soil, as show in Figure 25.

4.3 Surface radiant temperature

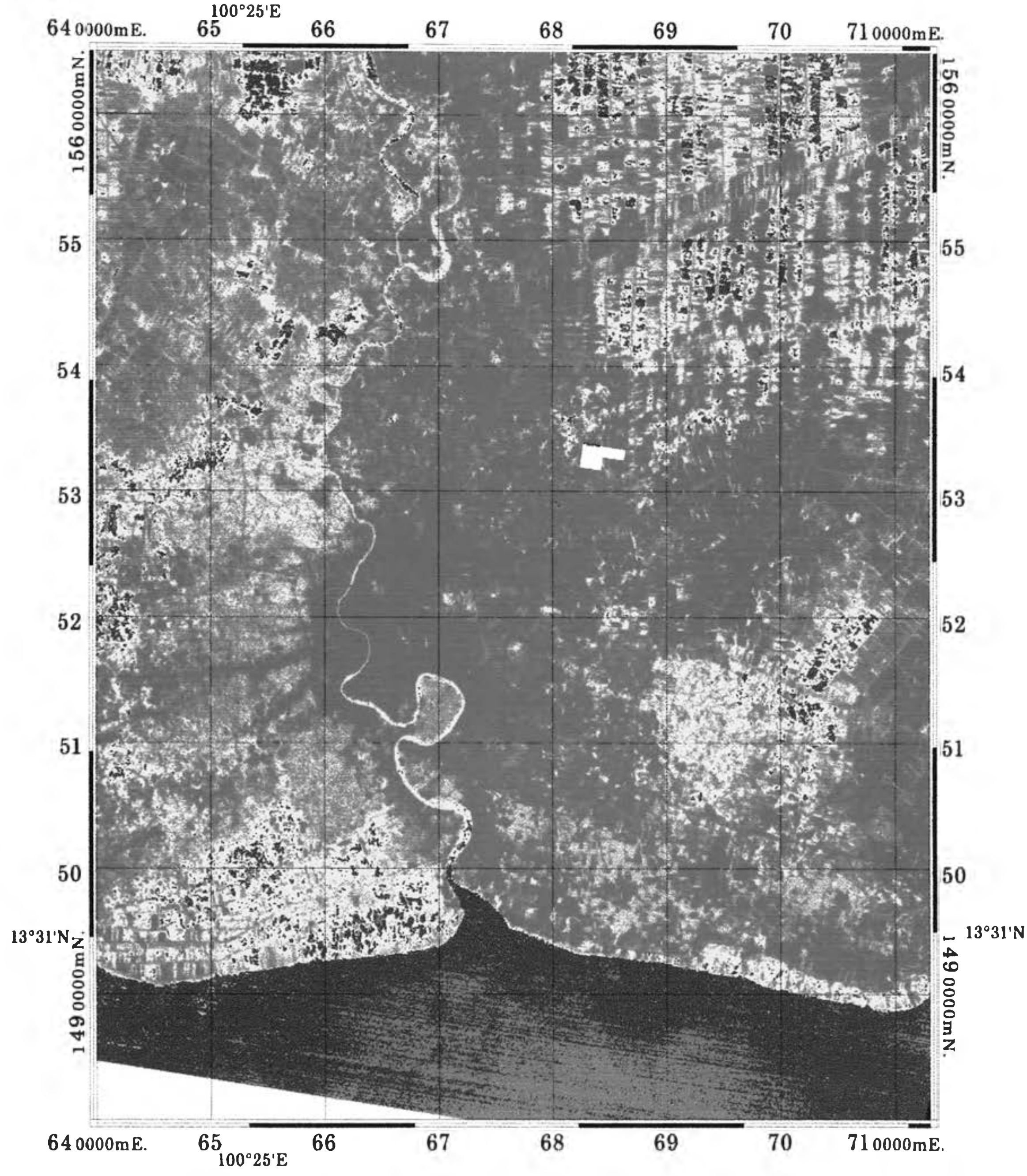
The surface radiant temperature of Bangkok Metropolis, which derived from two dates of Landsat TM band 6 were illustrated in Plate 9 and 10.

From the both plates, they show very distinct color that represented the degree of temperature. The surface radiant temperature of each land use / land cover type in 1988 was averaged 5°C higher than in 1997. (Table 13)

Table 13: Mean surface radiant temperature on each land use / land cover type in 1988 and 1997 (Landsat TM band 6)

Land use / Land cover type	30/3/1988		24/4/1997	
	Mean surface radianttemperature (°C)	Std. Dev	Mean surface radiant temperature (°C)	Std. Dev
Water body	30.08	5.708	25.94	3.468
Aqua-culture pond	31.06	3.262	26.31	3.258
Vegetation area	32.60	5.675	27.58	4.934
Growing paddy field or marsh land	32.39	6.202	27.94	6.434
Residential area	35.17	3.57	29.25	6.038
Harvested paddy field	34.01	6.432	29.27	3.913
Residential and Industrial mixed area	35.66	6.03	29.87	5.541
Bare soil	35.94	6.636	30.54	8
Industrial area	36.57	5.257	31.16	3.826

When considered the climatological condition at ground station that obtained from the Department of Meteorology (Table 14), it was found the relation between the climatological condition and surface radiant temperature in both years. This relation are consistent with the data observed by Carnahan and Larson (1990) that the climatological conditions prior to the satellite overpass are of the extreme importance in understanding surface temperature.



SURFACE RADIANT TEMPERATURE (°C)	22-24	25	26	27	28	29	30	31	32	33	34	35	36-38	NO DATA

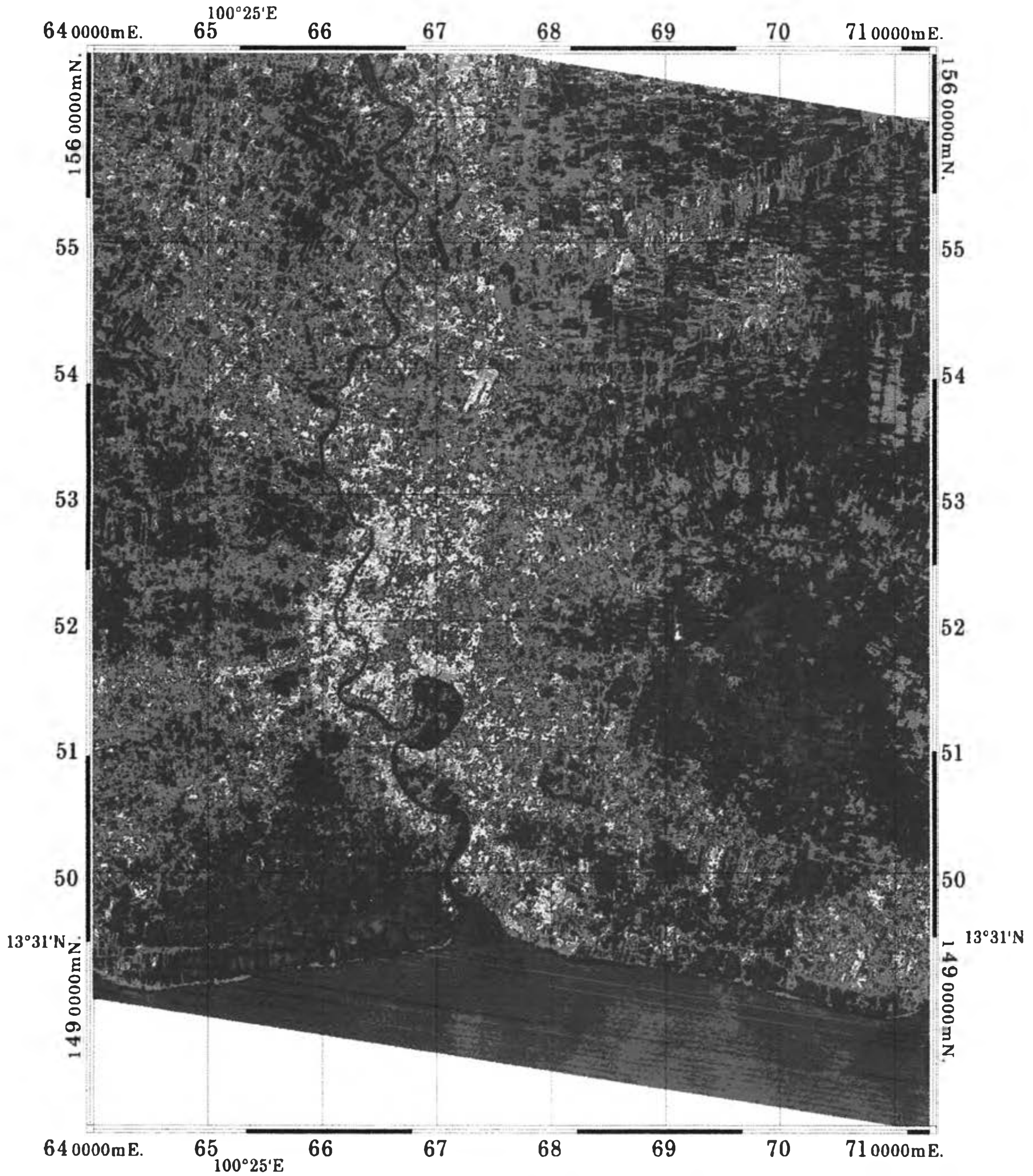
PLATE 9 : PSEUDO-COLOR IMAGE OF RADIANT SURFACE TEMPERATURE IN BANGKOK METROPOLIS IN 1988

THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS

SOURCE : LANDSAT TM BAND 6 ACQUIRED ON 30 MARCH 1988

10 0 10 20 KM

N



SURFACE RADIANT TEMPERATURE (°C)													
	22-24	25	26	27	28	29	30	31	32	33	34	35	36-38	NO DATA

PLATE 10 : PSEUDO-COLOR IMAGE OF RADIANT SURFACE TEMPERATURE IN BANGKOK METROPOLIS IN 1997

THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS

SOURCE : LANDSAT TM BAND 6 ACQUIRED ON 24 APRIL 1997

10 0 10 20 KM

N

Table 14: The meteorological condition before satellite overpass on 30 March 1988 and 24 April 1997of Bangkok Metropolis obtained from Bangkok Metropolis station (The Department of Meteorology)

Time	Temperature (C)		Relative humidity (%)	
	30-Mar-88	24-Apr-97	30-Mar-88	24-Apr-97
1:00	28.8	26	80	76
2:00	28.6	25.9	81	73
3:00	28.3	25.5	83	76
4:00	28.1	25.2	79	74
5:00	27.6	25	77	76
6:00	27	23.9	73	85
7:00	26.7	24.1	77	86
8:00	28.2	25.5	67	80
9:00	30	27.1	57	73
10:00	32	28.6	52	67
11:00	33.5	31.5	45	60
12:00	34.7	33.1	43	48

As shown in Table 14, air temperature at 6.00 A.M. in 1988 was 27.0°C, where as it was 23.9°C in 1997. Before the time of the satellite overpass the study area at 10.00 A.M., the temperature had risen to 32.0 °C in 1988, and 28.6 °C in 1997. The data presented that the air temperature during 6.00 A.M. to 10.00 A.M., before the satellite overpass in 1988 had an average 3.0°C higher than those in 1997.

When considered the relative humidity values, they appeared conversely with air temperature values. At 6.00 A.M., the relative humidity was 73 % in 1988 and 85 % in 1997.

temperature had inversely relation with relative humidity. As noted earlier, the higher air temperature and lower humidity in 1988 have been clearly linked to higher surface radiant temperature than those in 1997.

It can be proved that the meteorological conditions from day to day influence on the magnitude of surface temperature apart from surface properties. As Gallo (1993) found that the urban heat island development varies from day to day meteorological conditions.

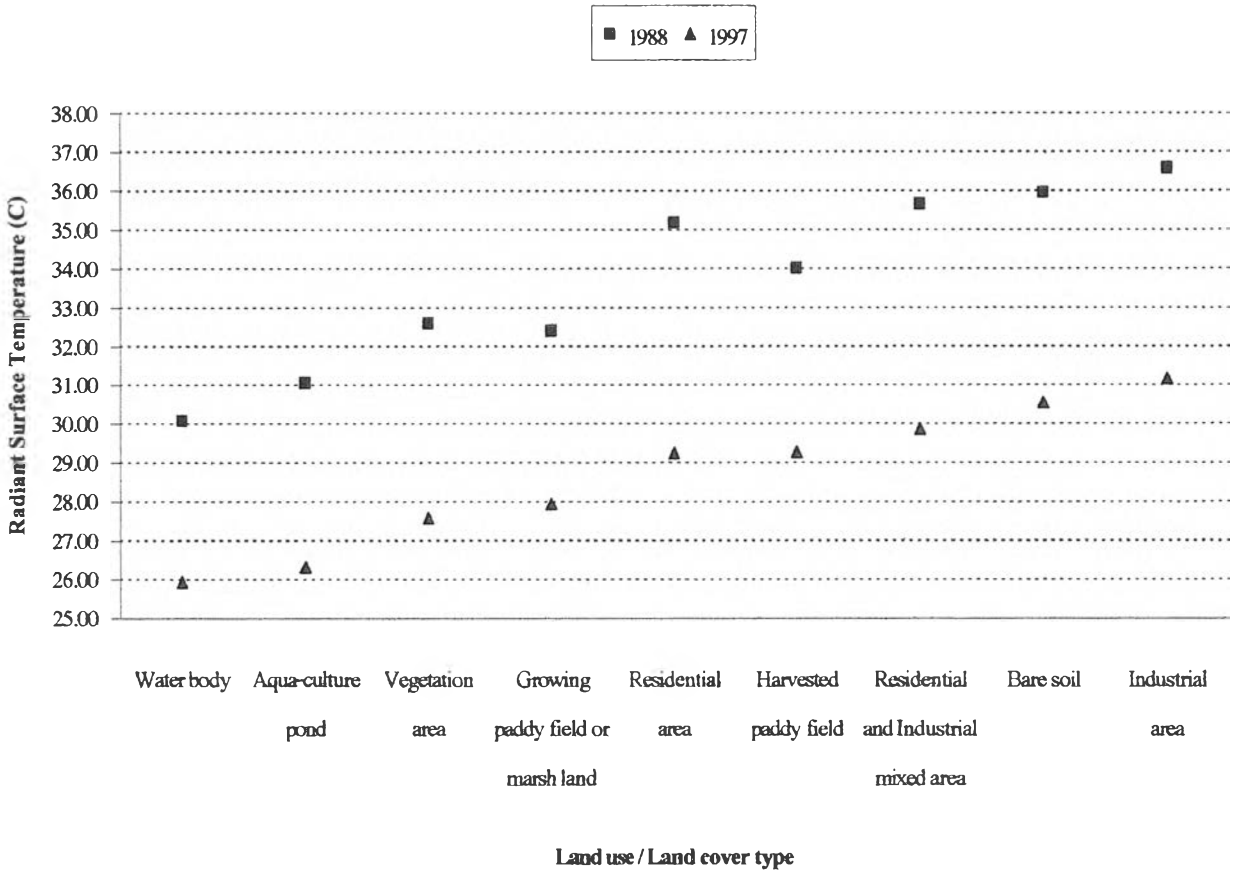


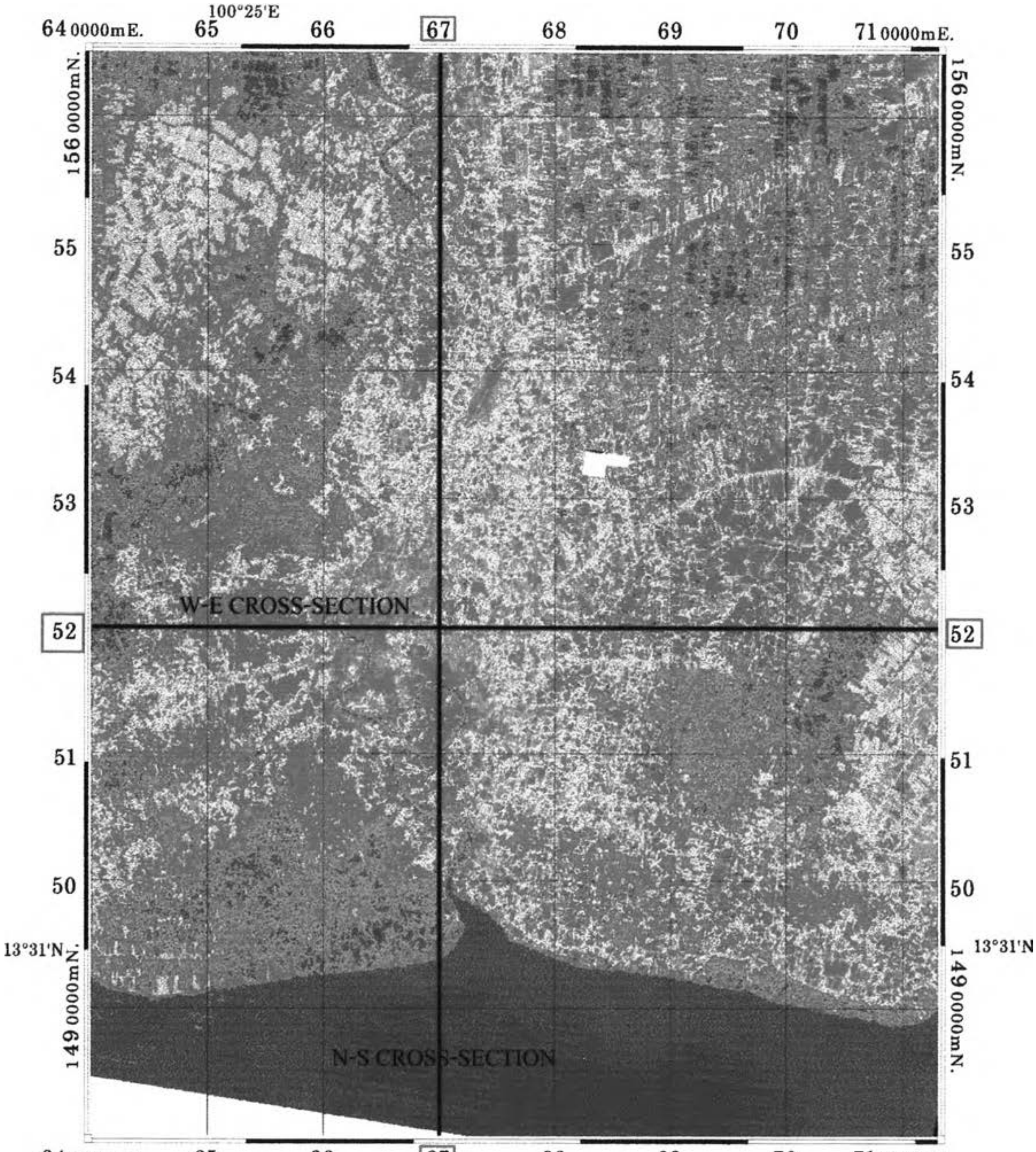
Figure 26: The comparison of surface radiant temperature of Bangkok Metropolis between 1988 and 1997 (Landsat TM band 6)

From Figure 26, it can be noticed that if the same land cover type had the different activities / land use, it can cause a difference in surface radiant temperature. As seen in built-up surface with the different land use type; residential area, residential and industrial mixed area, and industrial area all had different surface radiant temperature. Industrial area had the highest surface temperature, the residential and industrial mixed area had higher temperature than residential area. On the other hand, for the same land use with consisted of the different land cover type, it also appeared the different surface temperature. As seen in paddy field with the different land cover type; marsh land, vegetation area, harvested paddy field and bare soil, all appeared to have different temperatures. Bare soil and harvested paddy field had high surface temperature whereas vegetation area and marsh land had low surface temperature.

However, the tendencies of surface radiant temperature with respect to land use / land cover types in 1988 were similar to those in 1997 (Figure 26). That is the built-up surface or non-vegetation area had the higher surface temperature than vegetation area or flooding area.

To ease the comparison of surface temperature pattern between the two dates, the surface radiant temperatures of the two dates were normalized to reproduce by a new set color tone. Plate 11 and 12 displayed the magnitude of surface radiant temperature in 1988 and 1997, which represented by the new color tones. They were found that the center of an urban area both in 1988 and 1997 appeared the higher temperature than the surrounding environments. The warmth of the city projects distinctly out of the cool of the surrounding landscape, obviously demonstration of urban heat island.

The cross-sections of surface radiant temperature were determined along N-S and W-E directions. The N-S begin from 670000E, 1565000N to 670000E, 1480000N and W-E direction begin from 640000E, 1520000N to 710000E, 1520000N. Plate 11 and 12 are also showing the line of temperature cross-section in N-S and W-E directions.



TEMPERATURE MAGNITUDE	1 2 3 4 5 6 7 8 9 10 11 NO DATA COOL → HOT

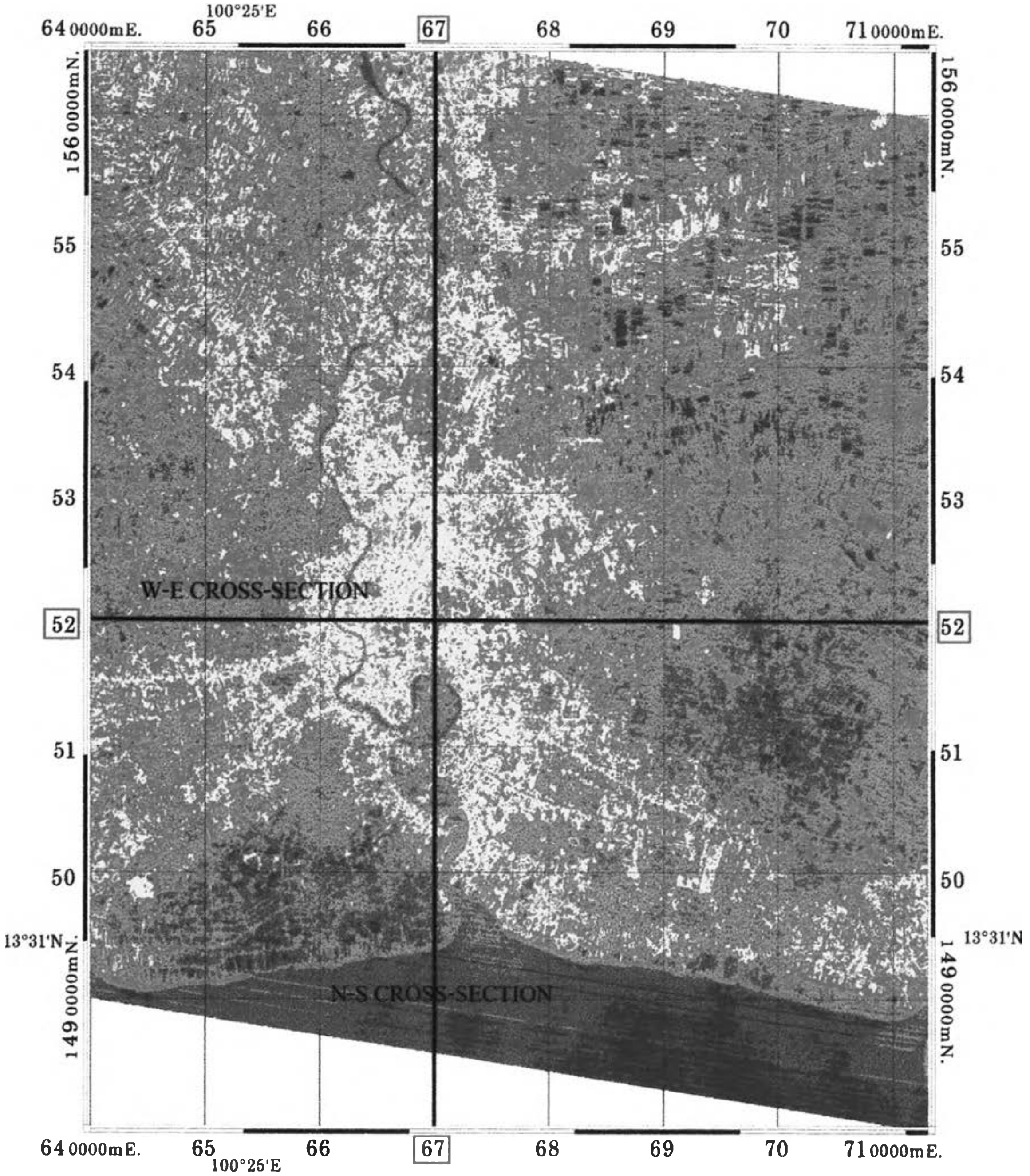
PLATE 11 : PSEUDO-COLOR IMAGE OF RADIANT SURFACE TEMPERATURE IN BANGKOK METROPOLIS IN 1988

THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS

SOURCE : LANDSAT TM BAND 6 AQUIRED ON 30 MARCH 1988

10 0 10 20 KM

N



TEMPERATURE MAGNITUDE	1	2	3	4	5	6	7	8	9	10	11	NO DATA
	COOL	→									HOT	

PLATE 12: PSEUDO-COLOR IMAGE OF RADIANT SURFACE TEMPERATURE IN BANGKOK METROPOLIS IN 1997

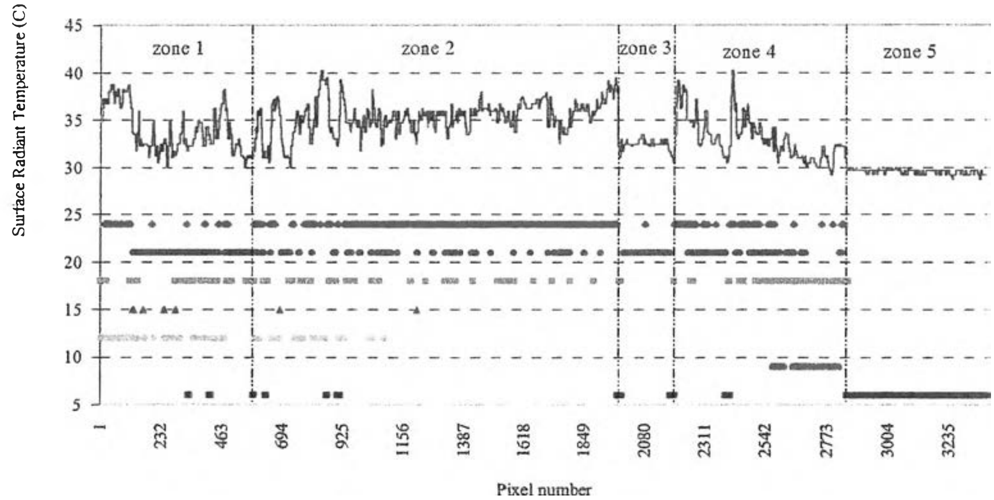
THE EFFECTS OF LAND COVER ON URBAN HEAT ISLANDS IN BANGKOK METROPOLIS

SOURCE : LANDSAT TM BAND 6 AQUIRED ON 24 APRIL 1997

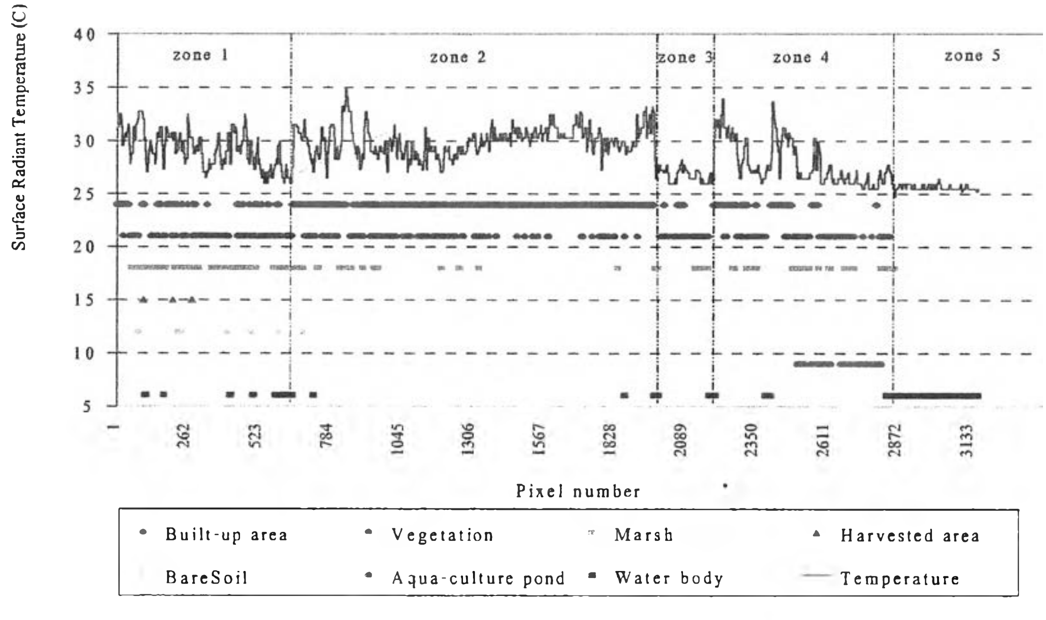
10 0 10 20 KM

N

The cross-section of surface radiant temperature results in N-S and W-E directions in 1988 and 1997 were displayed in Figure 27 and 28 respectively.

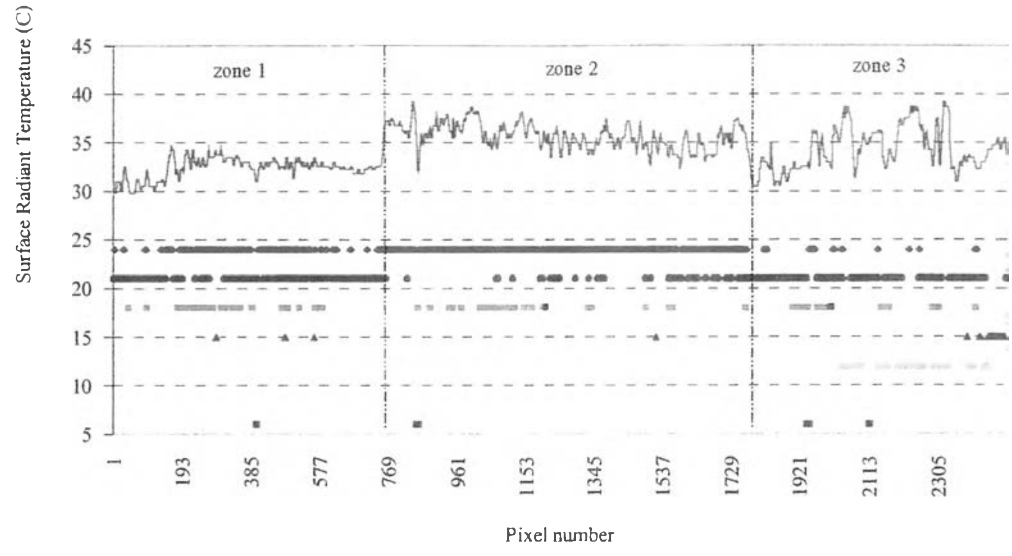


(a) 1988

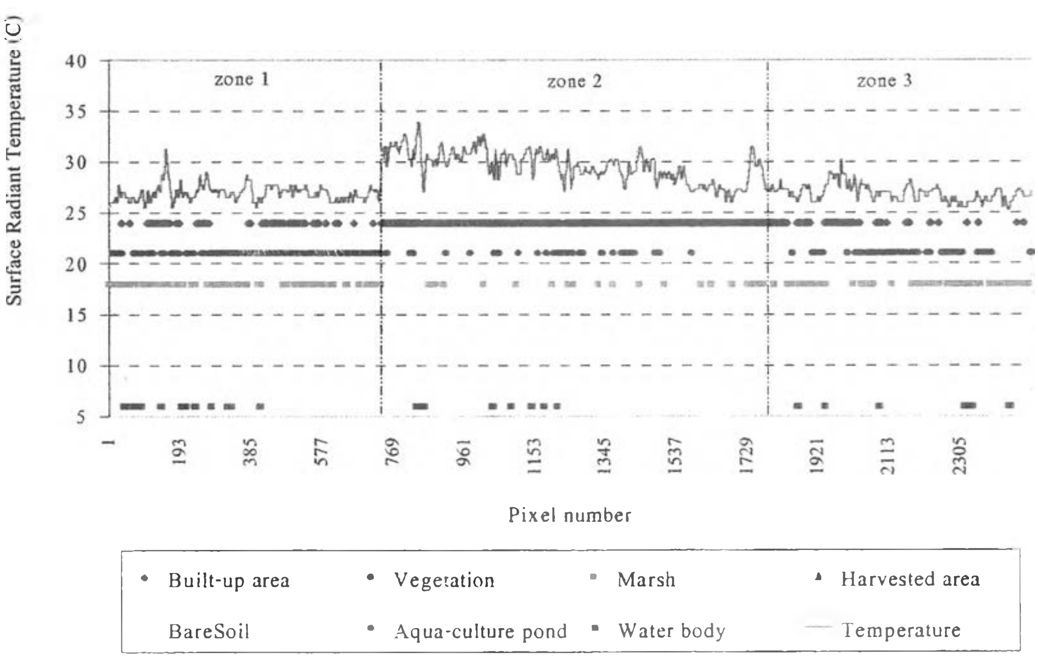


(b) 1997

Figure 27: Cross-section of surface radiant temperature in N-S direction of Bangkok Metropolis (a) in 1988 and (b) in 1997



(a) 1988



(a) 1997

Figure 28: Cross-section of surface radiant temperature in W-E direction of Bangkok Metropolis (a) in 1988 and (b) in 1997

The surface radiant temperature cross-section of both image were determined along N-S direction and W-E directions. The N-S direction begins from 670000E, 1560000N to 670000E, 1480000N and the W-E direction begins from 640000E, 1520000N to 710000E, 1520000N. Transects cross the whole spectrum of land use / land cover of the study area. Therefore, they can be used as representatives of temperature profiles to depict heat island effects. The temperature profiles along N-S and W-E direction in 1988 and 1997 were displayed in Figure 27 and 28.

As displayed in Figure 27 and 28, the type of land use / land cover affected to the variation of surface temperature. For N-S direction (Figure 27), the temperature variation patterns in 1988 and 1997 were similarly. The temperature zones were divided base on different temperature patterns appearance. When considered each temperature zone, it was found that the temperature curve in zone 2 showed the geomorphic analogy of an island, since the relative warmth of city projects out of the cool 'sea' of the surrounding landscape. This is because the temperature zone covered the high density of built-up area and low density of vegetation area, which could raise the surface temperature in urban area. This area consisted of Khet Don Muang, Khet Chatuchak, Khet Huai Khwang and Khet Khlong Toei in order of distance from north to south. The urban area also appeared as a 'plateau' of warm air with a steady but weaker horizontal gradient of increasing temperature towards the city center. The uniformity of the 'plateau' is interrupted by the influence of different intra-urban land use.

The rural / urban boundary are the area between zones 1 and 2 and zones 2 and 3. They showed a steep temperature gradiant, or a 'cliff' of the urban heat island. The temperature curve in zone 1 was sharply fluctuated because this area covered the distinct various type of land cover such as built-up area, vegetation area, marsh, harvested area, bare soil and water body. This zone covered area of Amphoe Khlong Luang and Amphoe Lum Luk Ka in Pathum Thani province. For zone 3, the temperature curve appeared as the minimum temperature and also found that the temperature cross-section line in zone 3 passed through Bang Kra Jao green area in Amphoe Phra Pradaeng, Samut Prakan province. From this result, it can be attribute that the vegetation can cool down the surface temperature on that land cover. For zone 4, most of area in this zone was the residential and industrial mixed area in Amphoe Phra Pradaeng and Amphoe Phra Samut

Chedi in Samut Prakan province. This land use type was consistent with the rather high temperature. The temperature reduced when the area became lower density of built-up land cover in rural area until the surface temperature appeared the lowest values in the Gulf of Thailand.

When considered the temperature cross-section in W-E direction, they appeared the distinctly heat island in zone 2 (Figure 28). The urban area appeared as a 'plateau' of warm air but its uniformity is interrupted by the influence of different intra-urban land use. Thus the temperature curve showed the slight fluctuation. This zone covered Khet Bang Kok Noi, Khet Phra Nakhon, Khet Pom Prap Sattru Phai, Khet Pathum Wan, Khet Ratchathewi, Khet Huai Khwang, Khet Bang Kapi, and Khet Prawet in order of the distance from west to east.

The rural / urban boundaries are the temperature zone between zone 1 and 2, and zone 2 and 3. They appeared a steep temperature gradiant or 'cliff' of the urban heat island. Zone 1 covered the area of Khet Taling Chan and Khet Phasi Charoen, which consisted of the moderate density of built-up and high density of vegetation. Thus the temperature were lower than those in the inner zone of Bangkok, which had higher density of built-up area and lower density of vegetation. For zone 3, the temperature curve in 1988 had higher temperature than those in 1997. As shown in Figure 28, the temperature zone 3 in 1988 covered a large bare soil while in 1997 it covered a large marsh land. Change of land cover reflected different paddy growing state. It can be assumed that bare soil may raise the surface temperature while the marsh land may cool down the surface temperature.

From these results, it can be summarized that the land use / land cover type have the effect to the variation of surface temperature. It was found that the high surface temperature corresponded to built-up area and bare soil and also the high activities area such industrial area. While the low surface temperature corresponded to vegetation area and low activities area such rural area.

4.4 The relationship between transformed vegetation index and surface radiant temperature

As the previous results, it was found that the individual land use / land cover appeared the inverse relationship between TVI and surface radiant temperature. The high values of TVI were associated with the low values of surface radiant temperature, on the contrary, the low values of transformed vegetation index were associated with the high values of surface radiant temperature. (Figure 29 and 30)

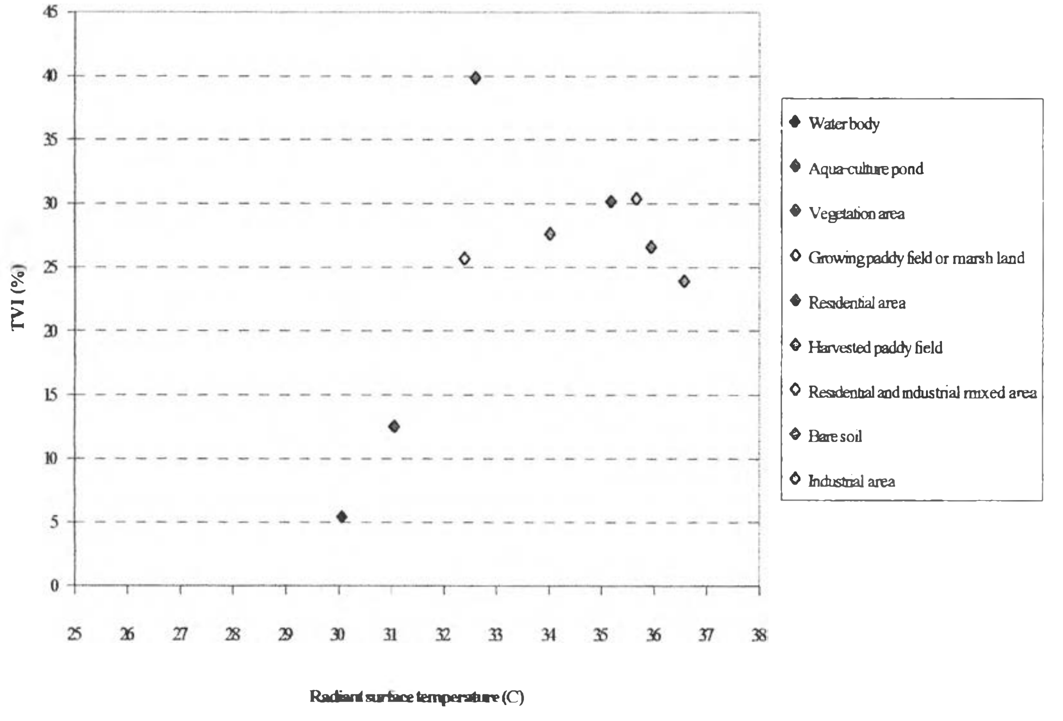


Figure 29 : Relationship between TVI and surface radiant temperature on each land use/ land cover type in 1988

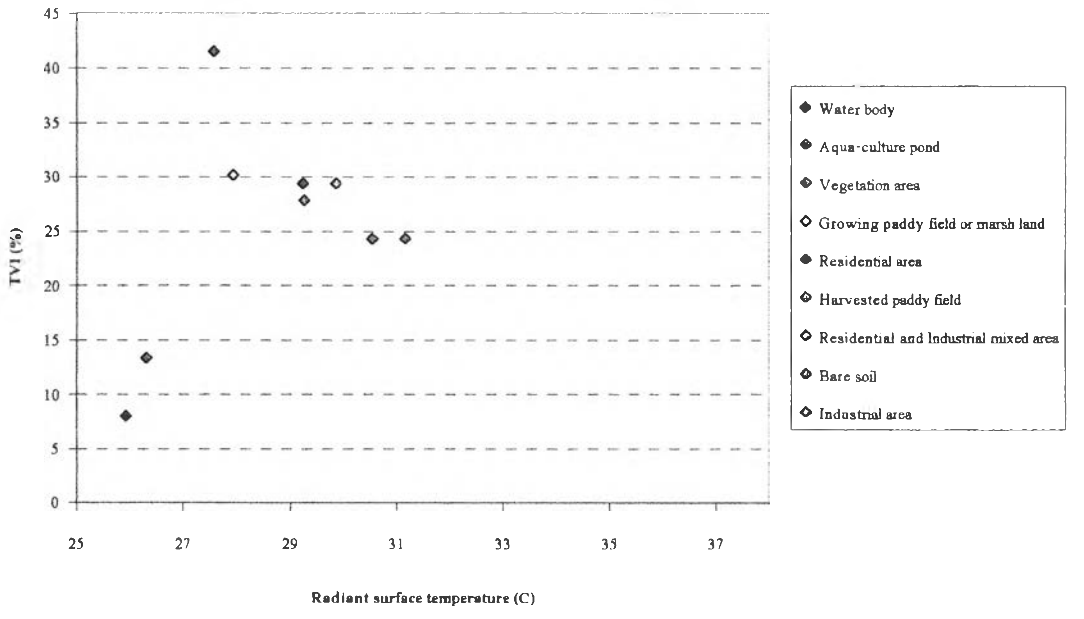
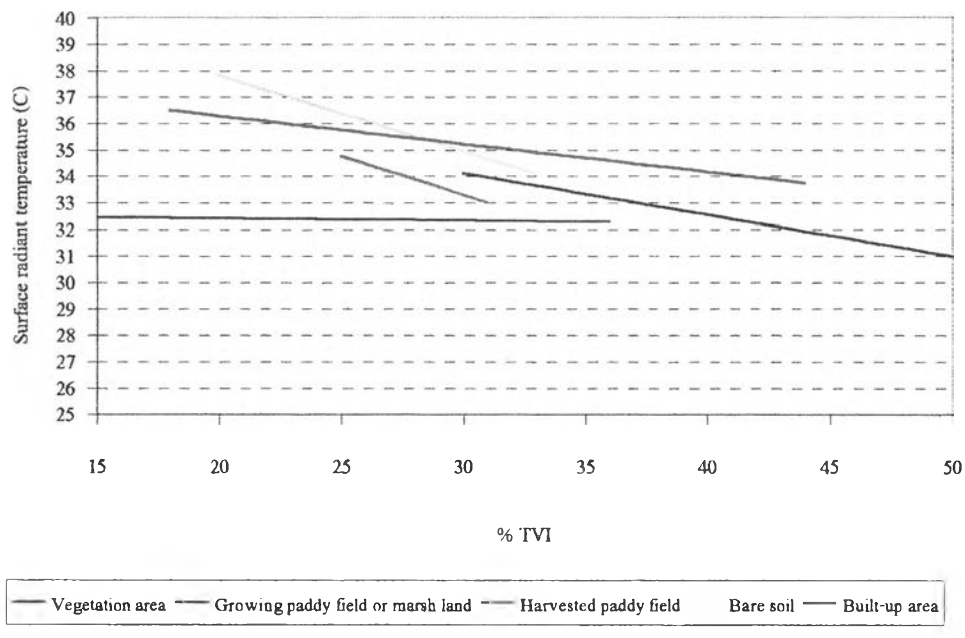


Figure 30: Relationship between TVI and surface radiant temperature on each land use / land cover type in 1997

From the figures, it was also found that the high TVI and low surface radiant temperature corresponded to vegetation area, while the low TVI and high surface radiant temperature corresponded to built-up area and bare soil. These results can be attributed that the presence of vegetation can cool down the surface temperature on that land cover type.

Linear regression analysis was used to determine the relation between TVI and surface radiant temperature on land use / land cover type. The results showed in Figure 31 and 32 for 1988 and 1997 respectively.



Relationship between TVI and surface radiant temperature of vegetation area

Y = 155.277817 – 0.624772X   r = -0.5221   coeff of det (r^2) = 27.26%   n = 3353930

Relationship between TVI and surface radiant temperature of growing paddy field or marsh land

Y = 130.404251 – 0.032865X   r = -0.0332   coeff of det (r^2) = 0.11%   n = 754996

Relationship between TVI and surface radiant temperature of harvested paddy field

Y = 168.195770 – 1.164492X   r = -0.4409   coeff of det (r^2) = 19.44%   n = 549916

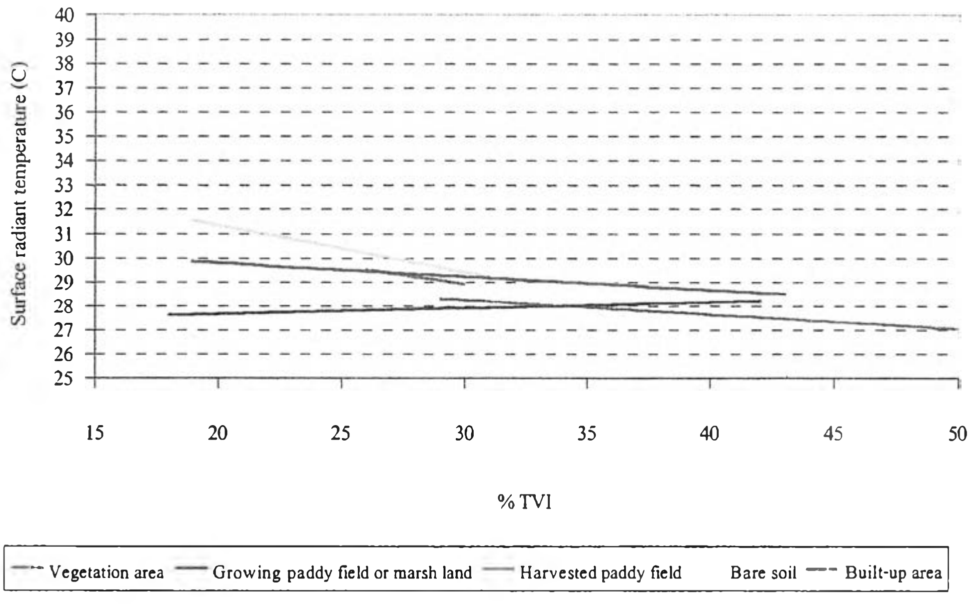
Relationship between TVI and surface radiant temperature of bare soil

Y = 174.338470 – 1.148985X   r = -0.5423   coeff of det (r^2) = 29.40%   n = 1028826

Relationship between TVI and surface radiant temperature of built-up area

Y = 153.631561 – 0.421594X   r = -0.4678   coeff of det (r^2) = 21.88%   n = 1883472

Figure 31: Relationship between %TVI and surface radiant temperature in 1988



Relationship between TVI and surface radiant temperature of vegetation area

Y = 120.269058 – 0.240571X r = -0.3452 coeff of det (r^2) = 11.92% n = 3100172

Relationship between TVI and surface radiant temperature of growing paddy field or marsh land

Y = 108.660789 – 0.102428X r = -0.1083 coeff of det (r^2) = 1.17% n = 1907800

Relationship between TVI and surface radiant temperature of harvested paddy field

Y = 133.512131 – 0.590146X r = -0.1670 coeff of det (r^2) = 2.79% n = 49212

Relationship between TVI and surface radiant temperature of bare soil

Y = 141.016815 – 0.774576X r = -0.2519 coeff of det (r^2) = 6.35% n = 130572

Relationship between TVI and surface radiant temperature of built-up area

Y = 123.764359 – 0.223311X r = -0.2752 coeff of det (r^2) = 7.57% n = 2527456

Figure 32: Relationship between %TVI and surface radiant temperature in 1997

Relationships between %TVI and surface radiant temperature of each land cover type were presented by linear regression analysis (Figure 31 and 32). It was found that the TVI has a negative correlation with surface radiant temperature. Low TVI values are consistent with high surface temperature whereas high TVI values are consistent with low surface temperature. The coefficients of determination (r2) values of all results were low (less than 30%). This mean that only values of TVI on land use / land cover only slightly predict the trend of surface radiant temperature on that land use / land cover type. But the different TVI on each land use / land cover type can use as an indicator of the different surface properties among these land use / land cover type. The different surface properties are identified as the factors influencing the different surface radiant temperature.

When determined the difference of TVI and surface temperature between urban area and rural area of the both dates, it was found that the TVI values in urban area were lower than rural area, while the surface temperature values in urban area were higher than rural area.(Table 15).

Table 15: The urban-rural difference of TVI and surface temperature

Location	Transformed vegetation index		Surface radiant temperature (^{o}C)	
	1988	1997	1988	1997
Urban area	30.72	32.37	35.12	29.45
Rural area	32.87	33.54	33.41	27.92
Urban-rural differences	-2.15	-1.18	1.71	1.53

Because the atmospheric conditions between the two dates were different, thus they can not compare the heat island intensity between 1988 and 1997. The results from only two dates of image were also still inadequate to indicate change of urban heat island effect in Bangkok Metropolis during 1988 and 1997. However, it was found that the values of TVI in urban area were lower than those in rural area for 2.15% and the surface radiant temperature in urban area were higher than those in rural area by 1.71 ^{o}C in 1988. Whereas the values of TVI in urban area were lower than those in rural area for 1.18% and the surface radiant temperature in urban area were higher than those in rural area by 1.53 °C in 1997. From the results have shown the urban area warmer than rural area that consistent the characteristic of urban heat island phenomenon.