528.74 : 551.4(593)

Detection of Flooding and Geomorphological Aspects in the Central Plain of Thailand From Landsat Data

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Abstract

The satellite imageries are applied to analyze flooding and geomorphological aspects in the Central Plain of Thailand. The study area is located in the northern part of the plain between Latitude 14° 30' - 15° 13' N and Longitude 100°00' - 100° 30'E. Firstly the aspects of landform, hydrology and climate of the area are reviewed. Second, digital image analyses are carried out using four Landsat MSS (Multispectral Scanner) imageries that were acquired different date. It can be concluded that the geomorphological terrain can be classified by using multi-date imagery. The natural levee appears clearly in the northern part of the area. But, in the southern part, it is more dispersion mixed with other terrains. The different elevation of back marsh and swamp can be distinguished on account of the temporal change of the imagery between rainy season and dry season. But the ground truth data should be refered to measure the difference.

Key word : Remote sensing Geomorphological, Flood, Thailand, Landsat
キーワード：リモートセンシング，洪水，地形，タイ，ランドサット

1. Introduction

The Central Plain of Thailand is the large area of lowland drained by the Chao Phraya river system and the several lesser rivers that contribute to the building of the delta at the head of the Bight of Bangkok, notably the Meklong river west of the Chao Phraya and the Prachin river east of the main stream. This is the most important area for rice cultivation due to the topography and water supply. As Thailand is located in the monsoon region, the mean precipitation is almost more than 1,000㎜ per year and about 300mm per month in the rainy season (reference from Chainat gauging station during 1970-1987). It has been mentioned that the annual runoff of the river greatly fluctuates from year to year and this is result in the damage of rice harvests because of either too much or too little water. Flooding always occurred due to the widespread, intense and prolonged rainfall from southwest monsoon, monsoon trough or inter-tropical convergence zone and tropical revolving storms. Since the gradient is extremely flat, the Chao Phraya river can not keep the water within its own channel once a certain gauging height is reached and surpassed. The highest flood with the large cultivated and residence areas were damaged in a period of over 100 years occurred in 1931 with the runoff of the river was about 6,500m³ per second and the height of 5.23m. The next highest floods were recorded in 1917, 1941, 1966, 1970, 1975, 1978, 1980 and 1983; (The Royal Irrigation Department of Thailand (1985)). These occurrences were made the serious problems both in economics and politics of the country.

For the advantages of satellite data in monitoring and management the natural resources, this research has been done to study and carried out the flooding problem in the Central Plain. To work on this, the National Research Center for Disaster Prevention, Science and Technology Agency of Japan was cooperated with the National Research Council of Thailand, Ministry of Science, Technology and Energy under the national project of MOS-1 project. The study of Flooding and Geomorphological Aspects in the Central Plain of Thailand was part of the exchanging researcher program on the Joint-Research on the Enhancement and Application of the Remote Sensing Technology with ASEAN Countries : Geomorphological Land Classification in the Central Plain of Thailand Using Satellite Data. And this project was financed on Special Coordination Funds for Promoting Science and Technology of the Japanese Government.

2. Objective

The objective of this research is to combine the Landsat data with the other aspects such as the geomorphological land form, precipitation, discharge and height level of water in the Chao Phraya river for the flooding prevention planning in the Central Plain.

3. Study area

The study area is located in the Northern Chao Phraya area between Latitude 14° 30'-15°13'N and Longitude 100°00'-100°30'E. The area is approximately 4,180km² comprises with some parts of 6 provinces namely Chainat, Sing Buri, Angthong, Suphan Buri, Lop Buri and Nakhonsawan. The main rivers in the area are the Chao Phraya and the Tha Chin River. Almost of the terrain is flat and formed by deposited of sediment from the Chao Phraya river and other tributaries. The mean elevation of the flooded plain is about 11 metres above mean sea level (MSL). The highest point is about 157 m at Khao Yai, the residual monadnock in Suphan Buri province. The irrigation canal system also has constructed cover the main area. There are two gage stations for recorded the water data along the Chao Phraya river and one station for gauging precipitation. The Location map of the study area is shown in Figure 1.

3.1. Landform

The Central Plain of Thailand may be divided into two subregions: the Piedmont Plains and the Delta. The Piedmont Plains comprises the lowland around the delta. The northern portion of the Central plain to the foothills of the surrounding ranges is drained

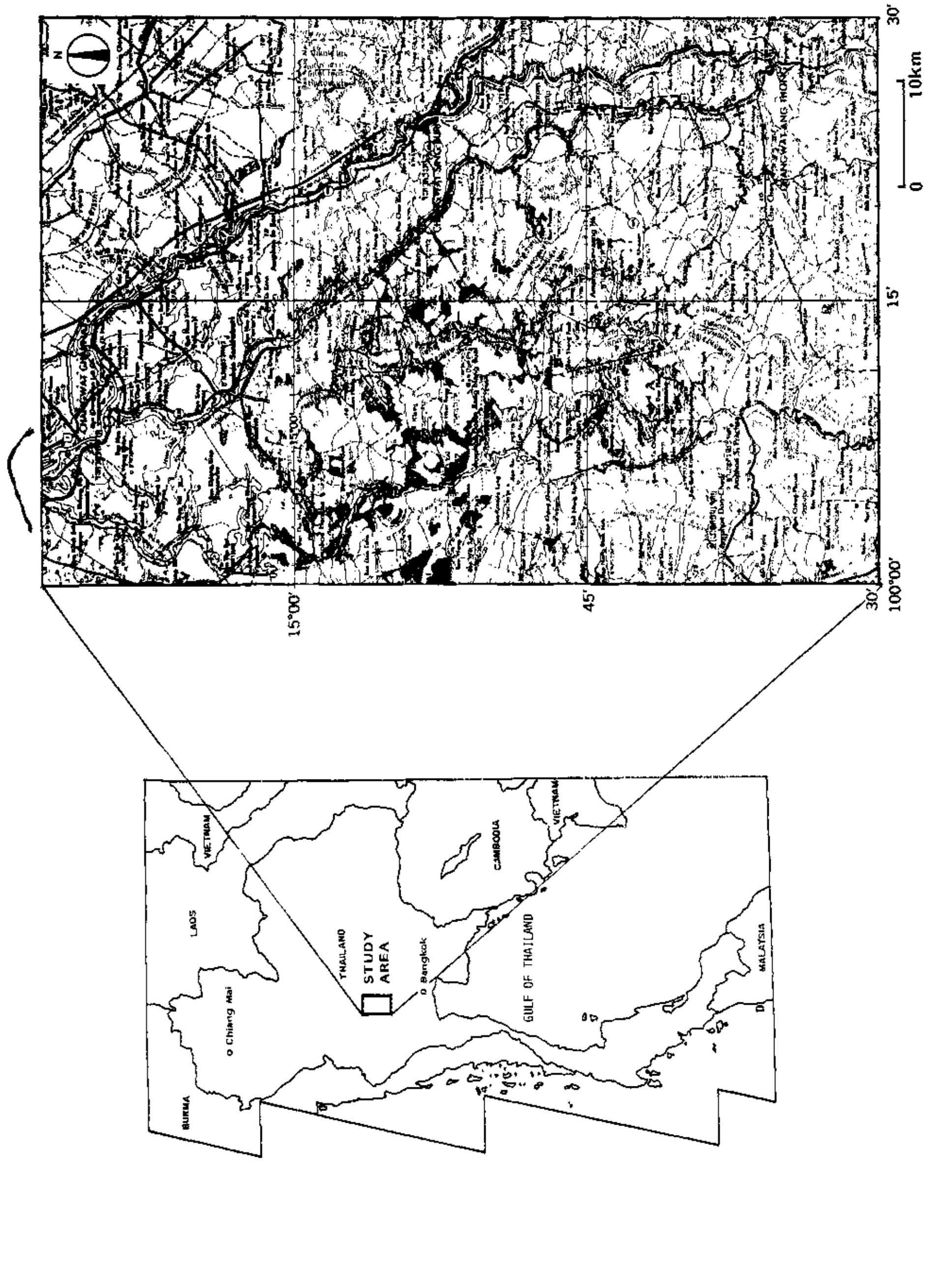


Figure 1　Location and Topographic map of the study area.

by the lower and middle reaches of the Ping and the Nan River systems which join to form the Chao Phraya approximately 50km north of the head of the delta. The Delta begins approximately 200km north of Bangkok where the Chao Phraya river bifurcates. The western tributary, that is known variously as the Nakhon Chaisi, the Suphan Buri and the Tha Chin, runs parallel to the main stream and finally meanders into the Bight some 30km west of the main mouth. The eastern branch of the Chao Phraya, the first and the most important effluent, is the Lop Buri river which branches off approximately 50 km in a straight line, from the head of the delta. In its meandering course southward the Lop Buri collects the water of the Pasak river, which drains a considerable valley to the northeast, as well as that of several effluents from the Chao Phraya and considerably swollen, rejoins the main stream approximately 75km from the Bight of Bangkok.

The Chao Phraya river is tidal for more than 90km, in a straight line, upstream and gives off no tributary within this stretch though several canals leading water east and west of the main stream. Beyond tidal influence the rivers of the delta characteristically flow above the general surface level within natural levees but within the area of tidal influence these levees are not developed. The head of the delta, approximately 200km from the Bight of Bangkok, is less than 20m above sea level, reflecting the low gentle slopes which flatten southward from somewhat more than 1:10000 to less than 1:25000. The north and west of northern Chao Phraya area present interrupted uniformity of inselbergs which appear at Khao Yai (157m) in Suphan Buri and Khao Tha Phra (202 m) in Chainat. Due to the land form in the study area, it can be divided into three parts:

- The Delta of brackish sediment occurs in the lower part of study area. It consists of dark and black clay with weathering features (yellow-brown mottles) and manganese and iron pisolitic concretions. This clay bed is characterized by basic ferric sulphate (jarosite) which gives characteristic yellow colored spots and gypsum needles.
- Delta of Fluviatile Sediments occurs on abroad zone in the upper part of the study area. It forms a gently undulating terrain with a relief altitude up to 3 m and the surface is dipping southward with a maximum slope of 3 degrees. The deposits of the delta consist of silty clays to sandy loam. The thickness is from 2 to 4 m in most outcrops. Characteristics of Pisolitic concretions of iron oxide are hard, well rounded and 0.3cm to 1.0cm in diameter.
- Floodplains occurs widely along the Chao Phraya river and its distributaries. It consists of natural levees and back swamps. Natural levees form narrow strips along the river and consist of sandy and silty layers which 2 to 3 m higher than the backswamps. Backswamps are mainly composed of silty sediments about 1 m thick.

The Geomorphological map of study area is shown in Figure 2 and 3.

3.2. Hydrology

The Chao Phraya river rises and falls with the seasonability of rainfall, but being a large, relatively slow-moving stream with many effluents, these rises and falls are not sharp and highest water levels are reached only several weeks after the monsoonal rains, during October in the upper reaches of the river and not until November in its lower reaches. The monthly discharge regimes during 1966-1985 of the Chao Phraya river recorded at Chainat and Angthong are shown in Figure 4, 5, 6 and 7. During 1966 to 1975 before the Chainat Dam construction, the data was not completed and the annual runoff was less than after the construction was finished. In Figure 4 it is shown that the lowest discharge is in during February - April where the data was about 200m^3/s in each month. These data were recorded before the construction of the Chao Phraya river Dam and the Rapheephat irrigation canal (Chainat - Pasak Canal). The Figure indicates that the

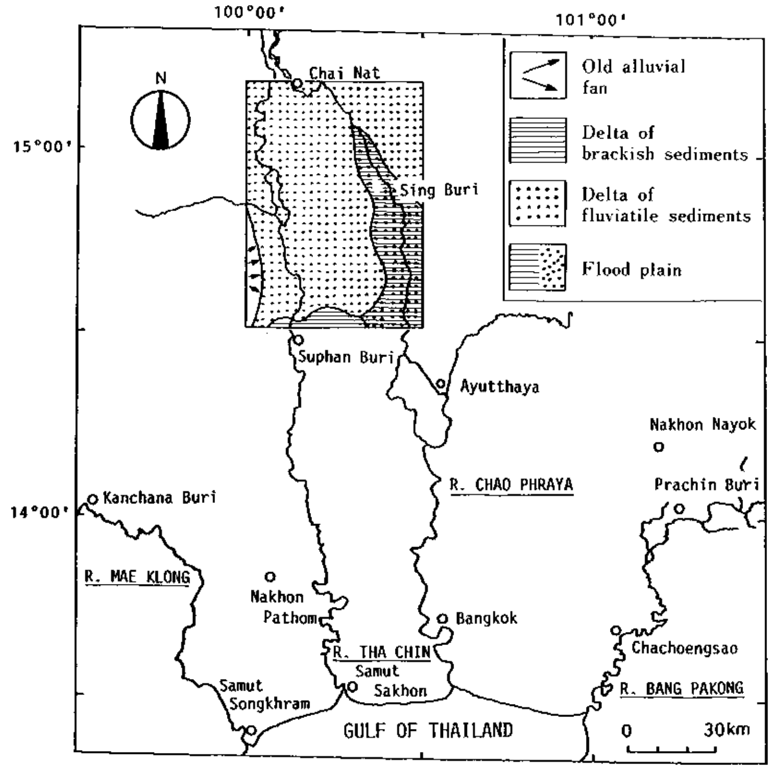


Figure 2 Comprehensive Geomorphological Land Classification in the study area.

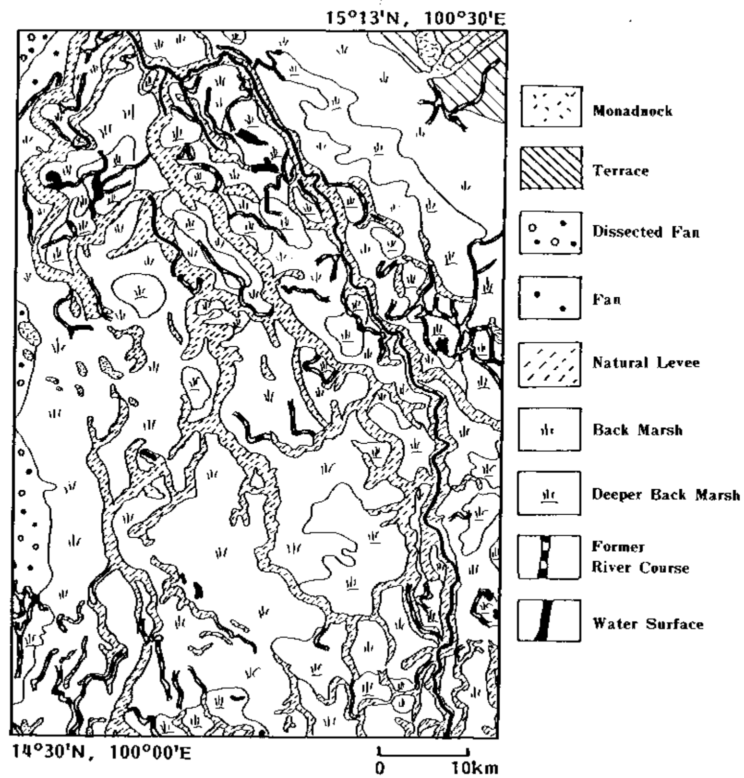
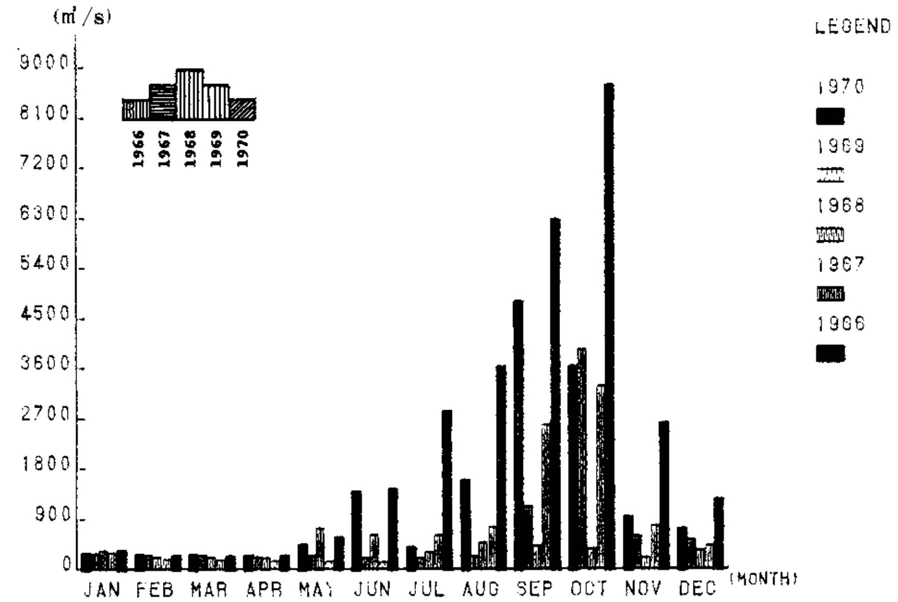
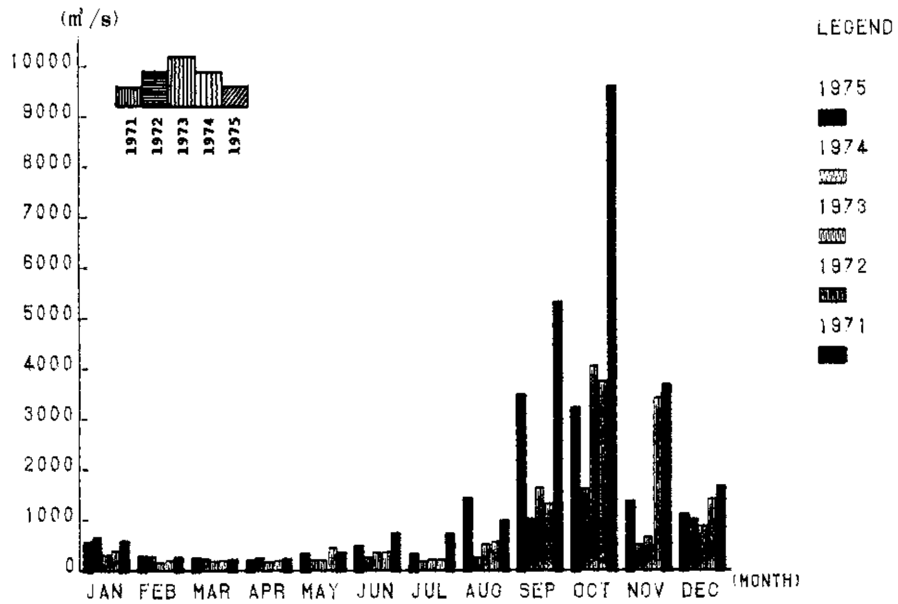


Figure 3 Geomorphological land Classification in the study area [after Ohkura et. al (1989)].

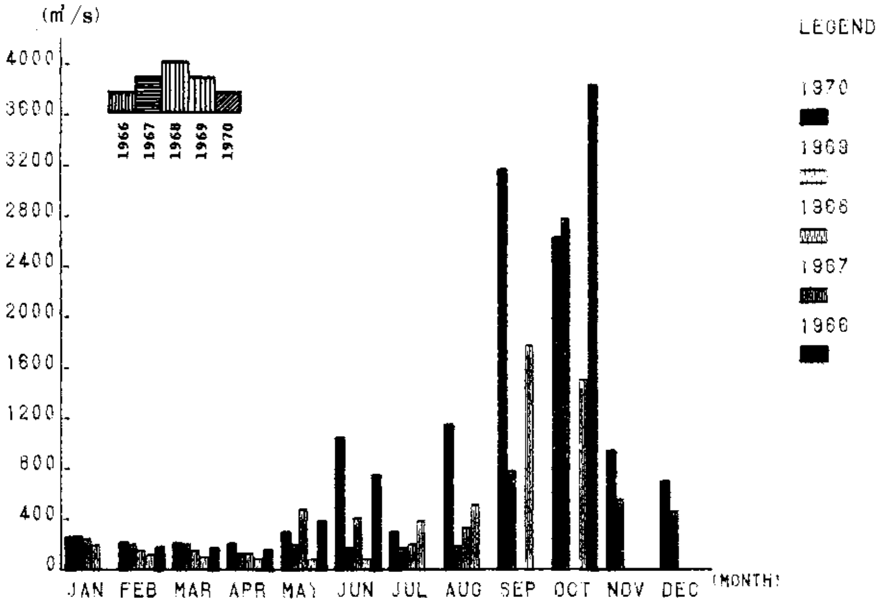


(a)

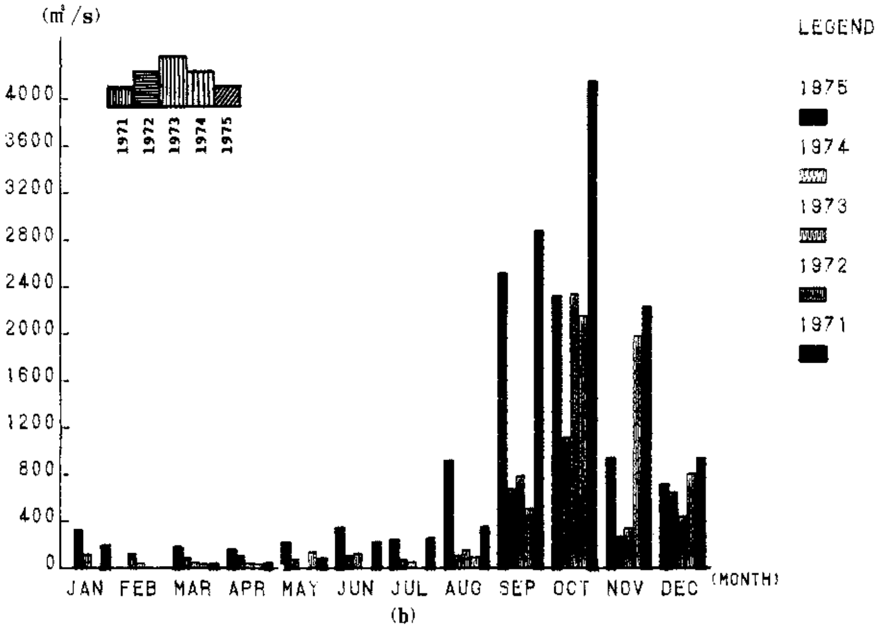


(b)

Figure 4　Discharge of the Chao Phraya River at Chainat Province during 1966-1970 (a) and 1981-1985 (b).

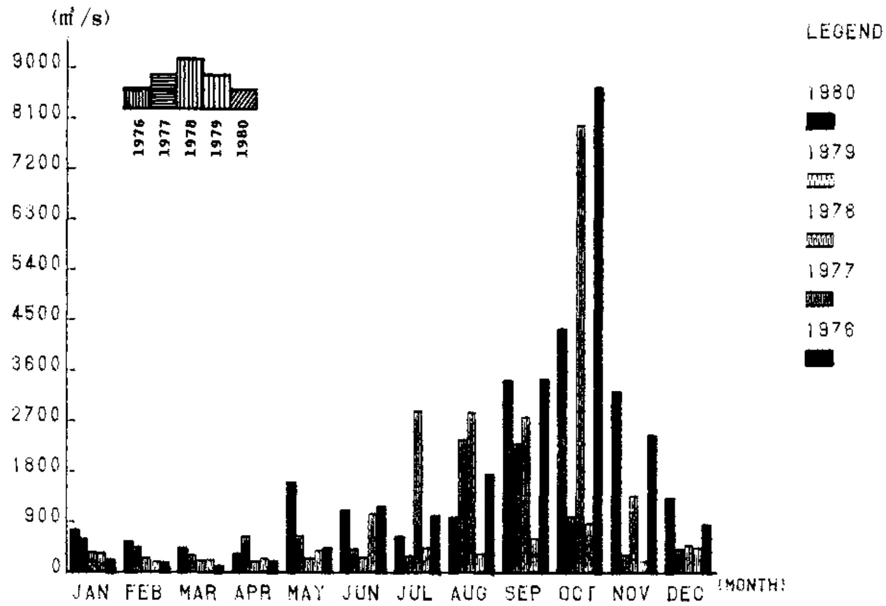


(a)

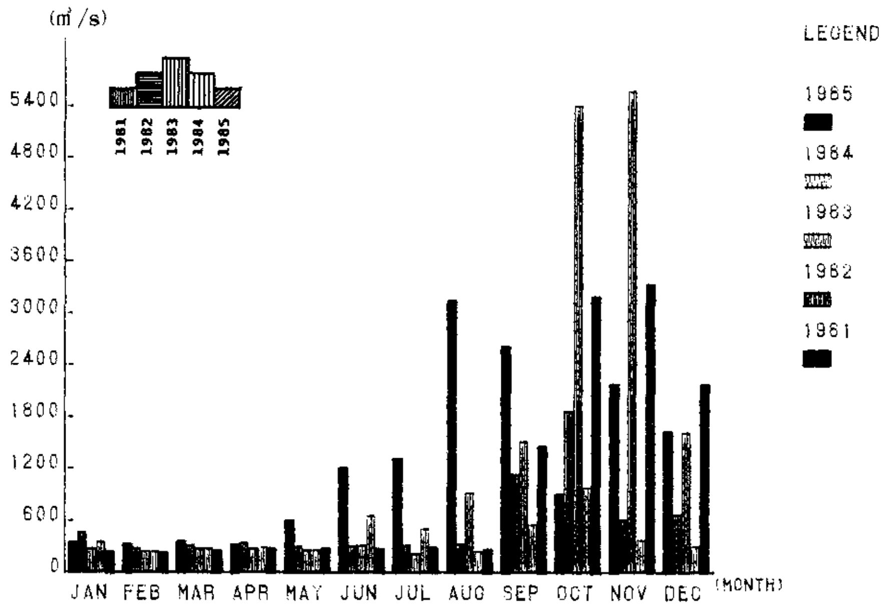


(b)

Figure 5 Discharge of the Chao Phraya River at Angthong Province during 1966-1970 (a) and 1971-1975 (b).

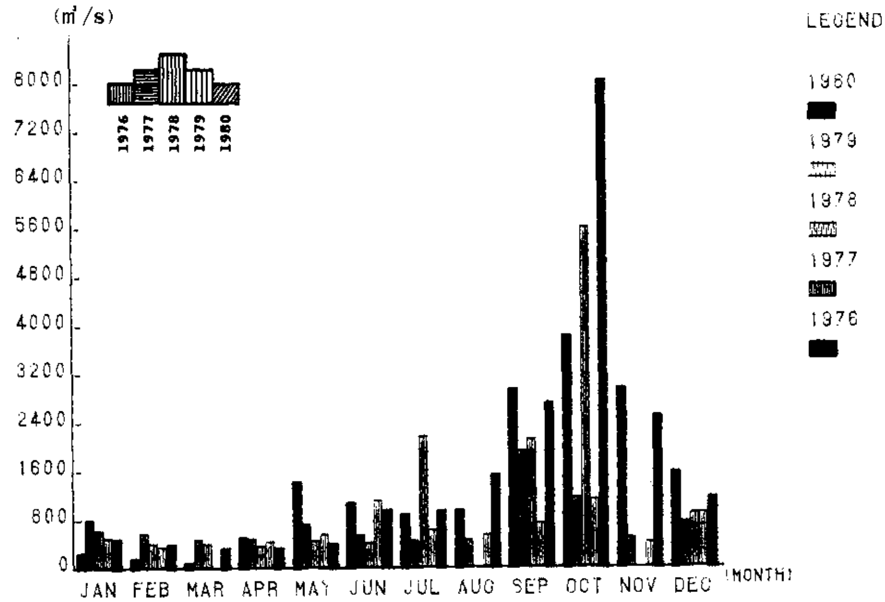


(a)

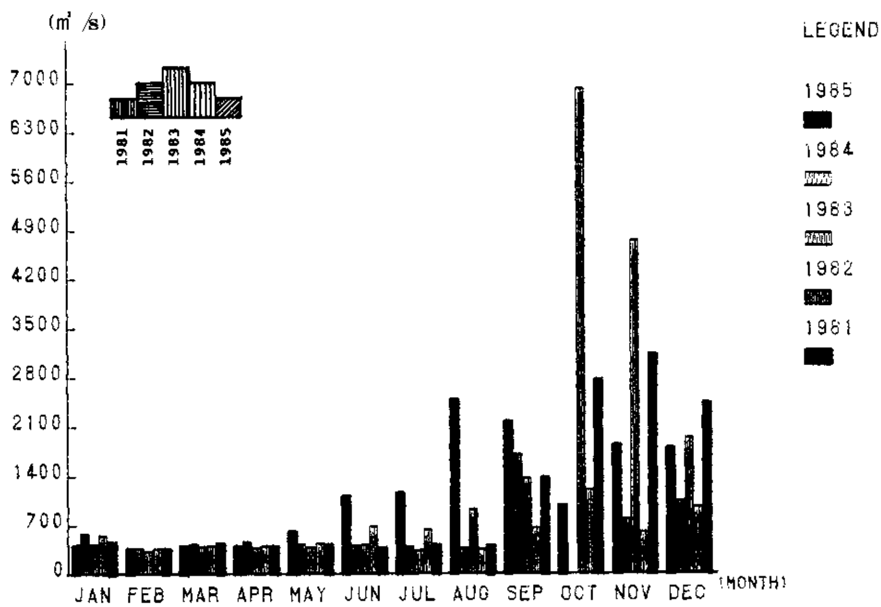


(b)

Figure 6　Discharge of the Chao Phraya River at Chainat Province during 1976-1980 (a) and 1981-1985 (b).



(a)



(b)

Figure 7 Discharge of the Chao Phraya River at Angthong Province during 1976-1980 (a) and 1981-1985 (b).

discharge in dry season was less and still in along time from November until August. The curve was continued regularly in every month. In the case of 1970, the discharge was high up to 8,500m³/s in October and caused the large area flooding. For second cropping it should be notified that the water was not sufficiently in 1968. From Figure 4 (b) the flooding in October, 1975 had shown distinctly and also the water was not sufficiently since January until July. About 95km south of Chainat, another gage station was located at Angthong, the lower part of study area. Figure 5 (a) shows the discharge data recorded at Angthong province during 1966-1970. The discharge in September 1970 was decreased from 8,500m³/s. to 3,800m³/s. when flown passed Angthong. It should be considered that where the water was gone. As the Geomorphological map of the study area in Figure 3, it can be concluded that some of water has flown to the marsh and backswamp between the Chao Phraya River and the Noi River because the topography of this area consists of former river channel under mean sea level (MSL). And also, some water had drained to the distributaries, Noi River which is diverted at Sing Buri. The same case had occurred in 1975 and caused a large flooding in the study area. In the dry season, the difference of water discharge in each month is not much due to the water level which lower than MSL. Figure 6 (a) shows the discharge in first period (1976-1980) after the dam and the irrigation canal were constructed. The water control still has some problems during the dry and flood season as in 1978 and 1980. After first period the Figure 6 (b) shows the discharge at Chainat during 1981-1985. It had a good result because the flooding in 1981, 1983 and 1985; the discharge was not more than 5,400m³/s. Figure 7 (a) shows the discharge at Angthong during 1976-1980. After 1977 the discharge curves in dry season were more continued regularly due to the drained water from the dam. The flooding also occurred in 1980 which the discharge up to 8,000m³/s when the monsoon trough had come. Figure 7 (b) is the discharge during 1981-1985. The curve in dry season also shows regularly and flooding in November, 1983 had been decreased by dam.

3.3. Climate

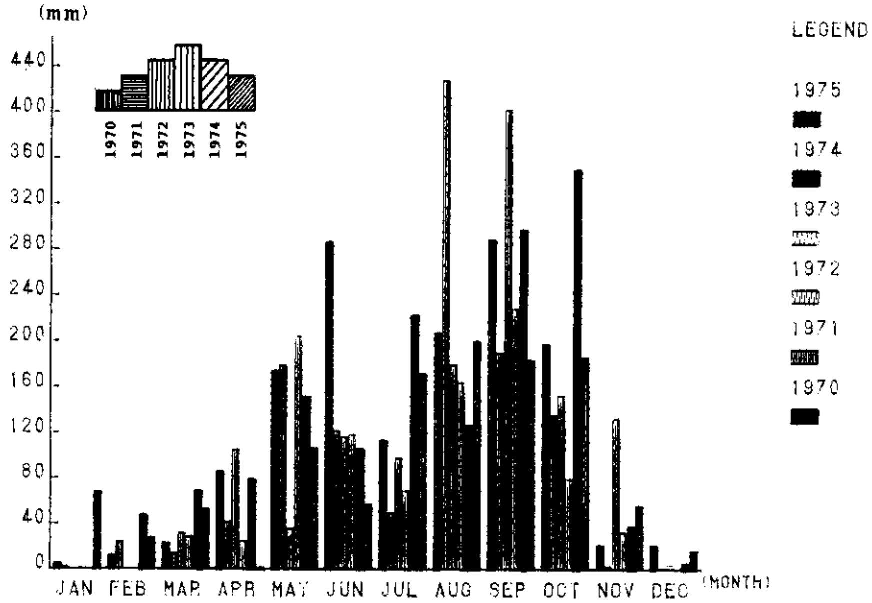
According to the Koppen classification of the world climates, the study area has a tropical savanna type (Aw), which means that the coolest month has a mean temperature higher than freezing point. The characteristics of climates are under the influence of monsoon winds. In the Northwest monsoon season from October until February, cool dry air from inner Asia blows persistently and it is the cold season. The Southwest monsoon season begins in mid May to the end of September and it is the rainy season. During the transitional season between Northeast and Southwest monsoon (May - June and September - October), it will be heavy rain due to the monsoon trough and tropical cyclone. Figure 8 (a), (b) and (c) show the precipitation recorded at Chainat during 1970-1985. The highest rain fall during rainy season is about 400mm. per month and the average rainfall is about 1,400mm. per year. About 90% of precipitation falls in the rainy season.

The mean annual temperature ranges from 28 - 30°C; maxima rises up to 39°C in April. The minimum temperature is about 9.9°C in December and January.

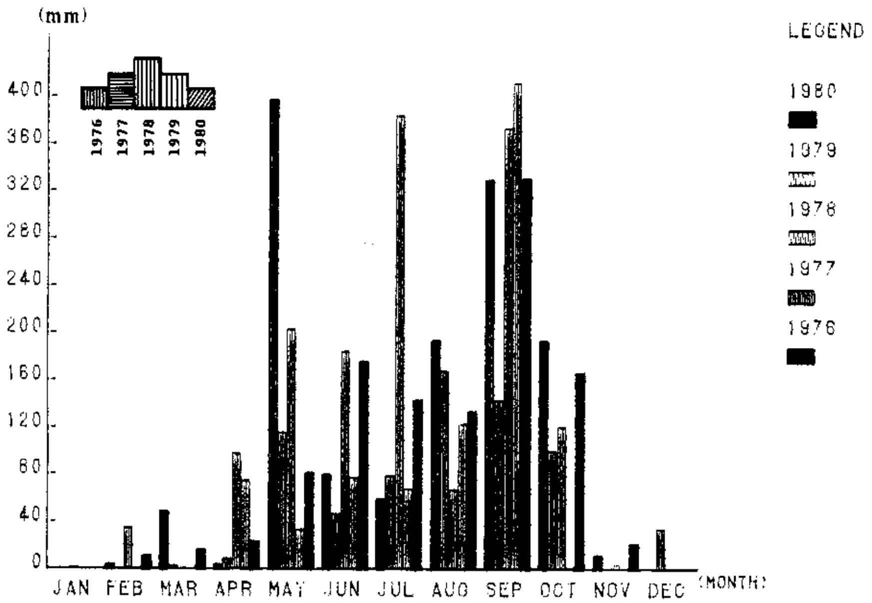
4. Methodology

4.1 Data Utilized for Analysis

The four bulks of Landsat Computer Compatible Tape (CCT) of path-row 129-50 and 129-51 from the Multispectral Scanner (MSS) system were used for study.



(a)



(b)

Figure 8 Rainfall at Chainat Province during 1970-1975 (a) and 1976-1980 (b).

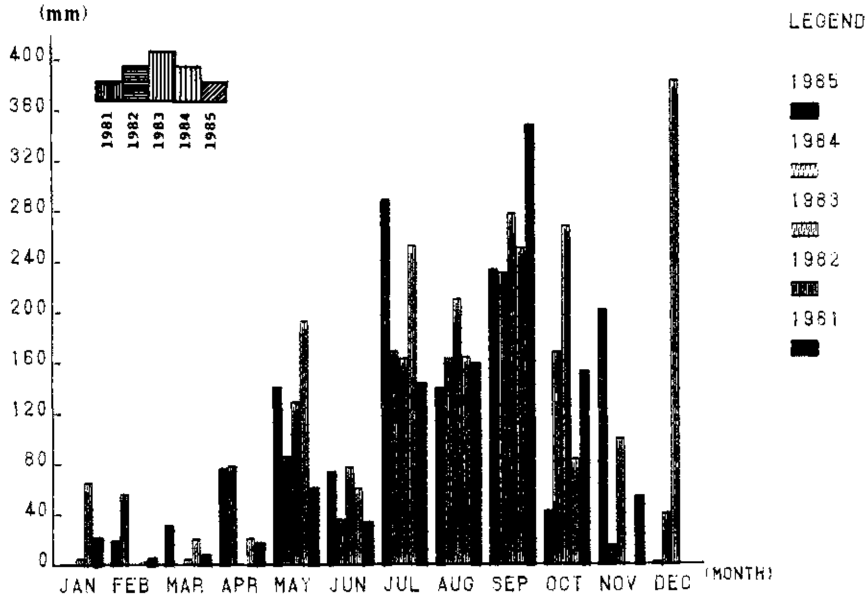


Figure 9 Rainfall at Chainat province during 1981-1985.

These data were acquired in various times as follow:
- April 12, 1984: for dry season.
- October 21, 1984: for rainy season and flooding time.
- February 02, 1985: for the early dry season and second cropping time.
- December 03, 1985: for the late of rainy season and harvesting time.

Other reference data were: -

1) Topographic map of the Central Plain at a scale 1:250,000 produced by the Royal Survey Military Department of Thailand in 1973.
2) Discharge data of the Chao Phraya River at Chainat and Angthong station between 1960-1985, collected by the Royal Irrigation Department of Thailand in 1987.
3) Gage Height data in meter above mean sea level of the Chao Phraya river at Chainat and Angthong station between 1984-1986, collected by the Royal Irrigation Department of Thailand in 1987.
4) Annual precipitation data during 1984-1986, at Chainat gauging station, collected by the Meteorological Department

of Thailand in 1987.

5) A Geomorphological Land Classification for the Flood-inundated Area in the Central Plain of Thailand using Satellite Remote Sensing Technology: A Geomorphological Survey Map of the Central Plain of Thailand Showing Classification of Flood-inundated Areas (at a scale 1:250,000), by Hiroshi Ohkura *et. al*.

4.2. Digital data Analysis

To study the relationship between the geomorphological aspects such as the natural levee, terrace, lowland, marsh etc; and the flooding in the Central Plain of Thailand, the image taken on 841021 (841021 means October 21, 1984) was used for classifying flooded level due to the period of rainy season in the area. But, because the pattern of cultivation in the area is mostly paddy field, it will be very difficult to separate the stage of water. To solve this problem, the image of 851203 was used for extracting the paddy field in the lowland. For classified the depth of marsh and pattern of natural levee, the image taken on 840412 was used by compared with the temporal change of image on 850202. The other reference data including the Geomorphology map, discharge and rainfall data were also used for decision making in the classification. Figure 10 shows the flow chart of digital data analysis.

The techniques of digital data analysis employed in this study were as follow:-

4.2.1 Data Preprocessing.

The three images of CCTs (851203, 850202 and 840412) used in this analysis had been corrected the geometric distortions and enhancement by NRCDP (National Research Center for Disaster Prevention). This preprocessing had done newly only for the CCT taken on 841021 in the same way as on 850202 and 840412. The CCTs taken on 851203 that had been already corrected the geometric distortion was chosen for master image in correcting the geometric distortion and image-to-image registration. In Figure 11, distinctly recognizable control points were selected on the master image in reference with the corresponding image (841021). The number of control points were 15 over the area of approximately 4,180㎢. Figure 12, shows the location of control points on corresponding image. The points' data and the correlation of geometric distortion were shown in Table 1. The coefficients transfer were decided based on the Least Square Method. The mean square error is 0.7841 in pixle size and maximum error is 1.4370. To resampling the image, the Nearestneighbor method was applied. This algorithm is the one pixel, being the nearest position from the point where the output pixel should occupy in an exact case, was selected as the output one.

4.2.2 Classification

The classification was carried out for each sub scene to separate the step of flooding and the geomorphological terrain by Maximum Likelihood Method. This method requires an operator to supervise the training areas of categories on the image, in order to train statistics, population means and covariance matrices, of the areas to a classifier on a computer. The classifier calculates statistical distances between a pixel and the training areas using by spectral signature of the pixel and the statistics, and labels the pixel to the category of the area that has the shortest distance.

For classifying flooding step, the spectral signature of data on 841021 was used. The 36 mean values of training areas for Landsat MSS bands shown in Figure 13 are given

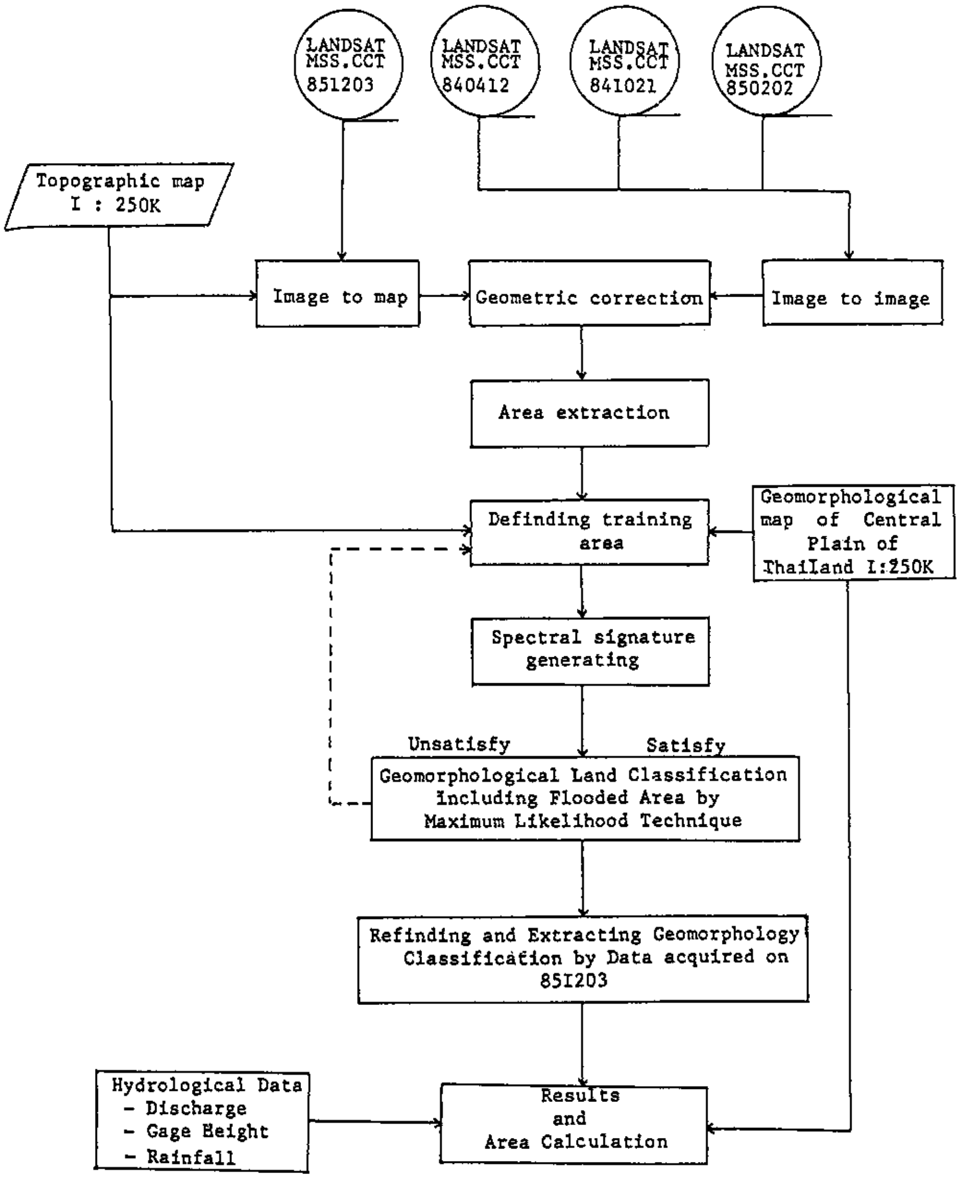


Figure 10　　Flow chart of digital data processing.

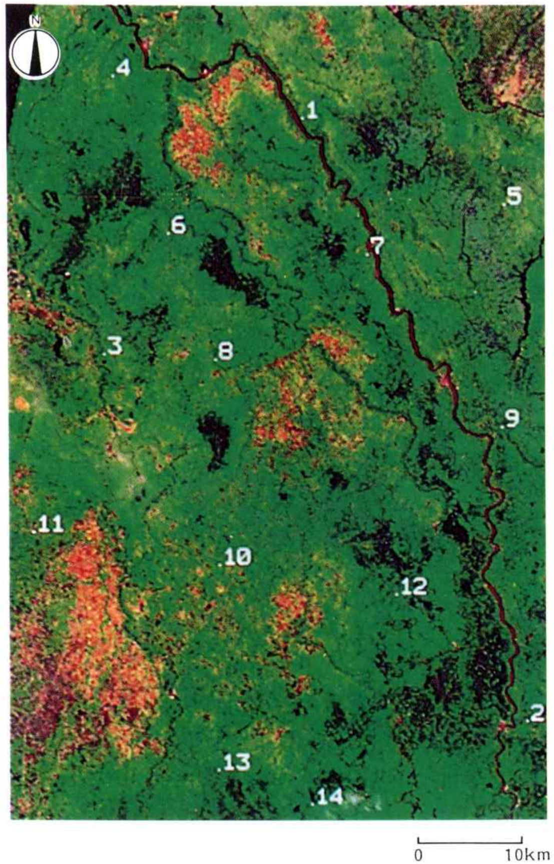


Figure 11　Location of geometric control points of image on October 21, 1984 by master image on December 3,1985.
Band 4, 5 and 7 are assigned to Blue, Red and Green, respectively.

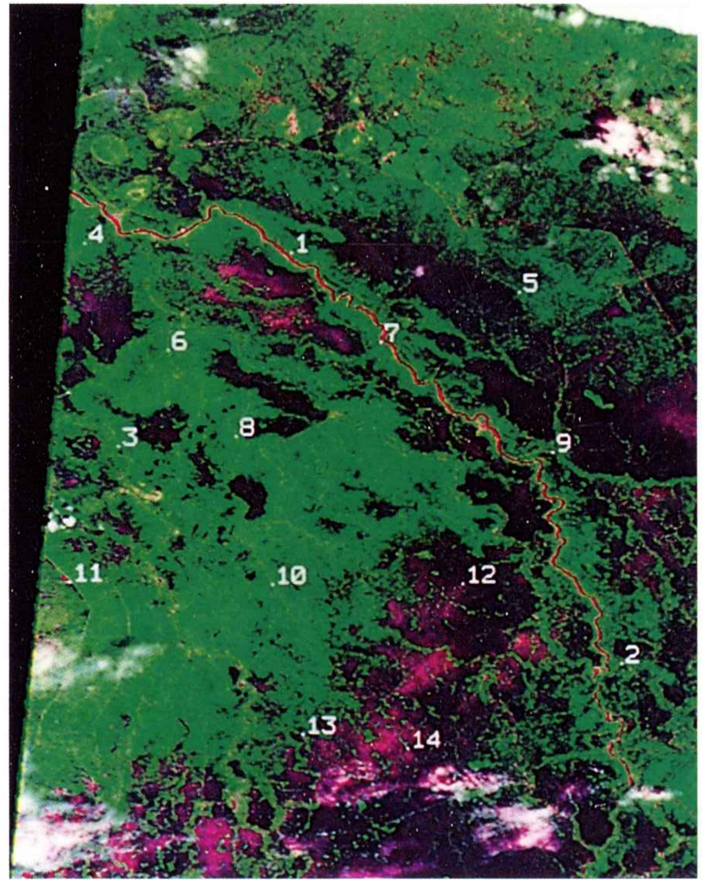


Figure 12　Location of geometric control point of image taken on October 21, 1984 (841021).
Band 4, 5 and 7 are assigned to Blue, Red and Green, respectively.

Table 1. The correlation of geometric distortion.

```
*********   CHECK GCP (AFFINE/LINEAR)   ********
            (RUN AT 03/15/88  16:43:16)

FILE OF GCP-TABLE (NAMEGC) =REMO/BUFF/THAI/CO-RES/I841021

FILE OF ORIGINAL IMAGE      =REMO/BUFF/THAI/CO-RES/O841021
     NUMBEROFPIXEL&LINE     =3600,2286

THAILAND  100 00 00 - 100 30 00 E    I840412
           14 30 00 -  15 13 00 N

PX, PY     : GCP POSITION IN MASTER IMAGE.
PU, PV     : GCP POSITION IN ORIGINAL IMAGE.
XU, YV     : CORRECTED POSITION OF PU AND PV.
DXU, DYV : ERRORS (XU-PX, YV-PY).
```

NO	PX	PY	PU	PV
[1]	520.0000	1214.0000	568.0000	1890.0000
[2]	920.0000	184.0000	1107.0000	1238.0000
[3]	169.0000	815.0000	286.0000	1587.0000
[4]	189.5000	1286.5000	238.0000	1905.0000
[5]	881.5000	1065.5000	942.0000	1825.5000
[6]	285.0000	1019.0000	369.0000	1735.0000
[7]	634.0000	984.0000	713.0000	1747.0000
[8]	365.0000	805.0000	477.0000	1600.0000
[9]	878.0000	692.0000	993.0000	1575.0000
[10]	372.0000	458.0000	534.0000	1368.0000
[11]	48.0000	515.0000	210.0000	1374.0000
[12]	685.0000	408.0000	846.0000	1366.0000
[13]	367.0000	94.0000	581.0000	1123.0000
[14]	534.0000	32.0000	753.0000	1099.0000

NO	XU	YV	PX	PY	DXU	DYU
[1]	518.9128	1214.9396	520.0000	1214.0000	-1.0872	0.9396
[2]	920.2647	182.9964	920.0000	184.0000	0.2647	-1.0036
[3]	169.8344	814.6902	169.0000	815.0000	0.8344	-0.3098
[4]	190.2246	1285.9904	189.5000	1286.5000	0.7246	-0.5096
[5]	881.1687	1065.0849	881.5000	1065.5000	-0.3313	-0.4151
[6]	285.2791	1018.3460	285.0000	1019.0000	0.2791	-0.6540
[7]	633.8796	984.6188	634.0000	984.0000	-0.1204	0.6188
[8]	364.7573	805.2134	365.0000	805.0000	-0.2427	0.2134
[9]	878.3724	691.8602	878.0000	692.0000	0.3724	-0.1398
[10]	371.9909	458.0975	372.0000	458.0000	-0.0091	0.0975
[11]	47.3943	515.1181	48.0000	515.0000	-0.6057	0.1181
[12]	685.3813	408.7027	685.0000	408.0000	0.3813	0.7027
[13]	366.3589	93.4964	367.0000	94.0000	-0.6411	-0.5036
[14]	534.1808	32.8451	534.0000	32.0000	0.1808	0.8451

MEAN SQUARE ERROR=0.7841 PIXEL
MAXIMUM ERROR   =1.4370 PIXEL

Table 2 The total number of mean values of training area corresponding to Figure 12.

*** SPECTRUM OF TRAINING AREAS (RUN AT MAR/26/88 10:56:23) ****

BASE IMAGE FILE (NAMEIN) =REMO/BUFF/THAI/CO-RES/N841021
NUMBER OF PIXEL & LINE=960,1408

FILE OF TRAINING AREA =REMO/BUFF/THAI/CO-RES/TRATBL

		--RECTANGLE AREA--										
		LOWER L.		UPPER R.		TOTAL		----CCT COUNT----				
NO	NAME OF AREA	(JOX,JOY)		(JEX,JEY)		PIXEL	BAND	MEAN	MAX	MIN	SIGMA	
1	LEVEE	393	861	399	867	49	4	52	59	46	0.41	
							5	39	44	32	0.37	
							6	133	155	115	1.41	
							7	122	144	99	1.95	
2	LEVEE	837	626	840	633	32	4	57	69	44	1.16	
							5	52	72	34	1.69	
							6	101	121	68	2.65	
							7	85	113	58	3.10	
3	LEVEE (UP)	295	1224	299	1232	45	4	50	67	39	1.09	
							5	38	66	30	1.17	
							6	117	135	95	1.38	
							7	109	129	82	1.66	
4	MARSH 1	259	1168	264	1179	72	4	48	57	40	0.45	
							5	37	42	32	0.24	
							6	97	133	76	1.11	
							7	81	110	56	1.19	
5	MARSH 1.5	208	1168	213	1179	72	4	50	56	45	0.36	
							5	39	45	30	0.35	
							6	84	101	69	0.74	
							7	64	86	47	0.96	
6	MARSH 1.8	212	1124	217	1135	72	4	45	52	41	0.27	
							5	36	42	33	0.25	
							6	48	64	33	0.84	
							7	28	53	13	0.93	
7	MARSH 2.0	195	1070	199	1074	25	4	48	56	43	0.70	
							5	36	41	32	0.57	
							6	38	57	29	1.36	
							7	21	28	15	0.75	
8	MARSH AND CANN.	536	798	543	805	64	4	50	60	39	0.56	
							5	38	47	32	0.39	
							6	126	147	104	1.41	
							7	115	144	85	1.47	
9	MARSH WEST SING	647	660	657	670	121	4	47	54	32	0.33	
							5	35	41	28	0.23	
							6	121	140	94	0.96	
							7	109	140	76	1.31	

(*continue*)

10	MARSH PAROM	738	547	748	557	121	4	45	52	39	0.24
							5	34	40	30	0.21
							6	68	93	47	0.85
							7	53	72	30	0.92
11	MARSH UP	299	1034	309	1044	121	4	49	56	42	0.34
							5	37	42	32	0.23
							6	96	134	59	1.54
							7	80	121	39	1.61
12	MARSH UP MIDDLE	351	999	361	1009	121	4	50	60	42	0.34
							5	38	46	32	0.26
							6	90	128	61	1.47
							7	75	120	40	1.77
13	MARSH MIDDLE	371	958	382	969	144	4	48	57	41	0.28
							5	37	43	32	0.19
							6	64	94	45	0.70
							7	45	76	28	0.73
14	MARSH LOW MIDDLE	403	929	413	939	121	4	48	58	40	0.36
							5	37	48	32	0.28
							6	56	83	41	0.84
							7	37	60	22	0.81
15	MARSH LOW	479	847	489	857	121	4	43	49	39	0.18
							5	32	37	29	0.19
							6	49	76	30	0.84
							7	32	55	17	0.74
16	MARSH EARLY P.1	477	403	487	413	121	4	53	60	45	0.30
							5	41	50	33	0.34
							6	95	121	56	1.17
							7	73	106	35	1.29
17	MARSH EARLY P.2	517	299	527	309	121	4	53	59	42	0.32
							5	40	47	33	0.29
							6	110	146	68	1.35
							7	89	123	54	1.42
18	MARSH EARLY P.3	580	234	590	244	121	4	60	76	50	0.45
							5	54	74	41	0.60
							6	78	102	62	0.74
							7	48	68	27	0.95
19	MARSH EARLY P.4	623	137	633	147	121	4	47	53	39	0.30
							5	37	44	31	0.22
							6	52	74	35	0.86
							7	32	53	13	0.81
20	MARSH CHAI. UP	381	1259	391	1269	121	4	50	57	42	0.32
							5	36	46	31	0.26
							6	131	149	107	0.87
							7	118	141	90	1.10
21	MARSH CHAI. PUR.	434	1215	444	1225	121	4	51	57	43	0.29
							5	40	49	33	0.26
							6	66	96	41	1.02
							7	45	78	16	1.07
22	MARSH CHAI. L.B.	408	1189	416	1198	90	4	73	93	57	1.00
							5	75	102	50	1.37
							6	88	115	69	1.03
							7	55	72	31	0.94

(*continue*)

23	MARSH CHAI. DOWN	505	1134	513	1143	90	4	50	57	44	0.35
							5	42	48	33	0.36
							6	28	55	17	0.87
							7	11	33	0	0.93
24	MARSH RAPE. C. 1	709	1325	717	1334	90	4	49	56	44	0.27
							5	39	44	34	0.23
							6	94	119	77	1.04
							7	77	101	58	1.08
25	MARSH RAPE. C. 2	729	1182	737	1191	90	4	48	55	36	0.37
							5	38	46	33	0.28
							6	57	72	45	0.67
							7	37	53	27	0.53
26	MARSH RAPE. C. 3	642	1175	650	1184	90	4	48	64	40	0.41
							5	39	48	33	0.34
							6	43	52	21	0.66
							7	24	36	6	0.68
27	MARSH RAPE. C. 5	787	1079	795	1088	90	4	46	59	41	0.32
							5	35	39	31	0.23
							6	50	70	38	0.65
							7	32	48	18	0.68
28	MARSH RAPE. C. 6	859	776	867	784	81	4	42	48	37	0.24
							5	32	38	27	0.25
							6	50	64	33	0.58
							7	33	44	16	0.59
29	PREPARE RAPE.	815	1194	822	1207	112	4	50	57	41	0.33
							5	39	57	34	0.35
							6	114	130	97	0.73
							7	100	118	81	0.88
30	FAN 1	8	430	23	448	304	4	61	76	48	0.30
							5	57	76	39	0.37
							6	118	140	93	0.47
							7	95	124	66	0.73
31	FAN 2	92	430	102	443	154	4	53	62	41	0.30
							5	41	50	33	0.31
							6	134	162	114	0.71
							7	120	140	99	0.63
32	MARSH UNDER FAN	130	401	151	421	462	4	51	61	41	0.18
							5	37	50	29	0.18
							6	130	153	88	0.47
							7	116	147	74	0.59
33	MONADROCK	184	718	188	723	30	4	49	55	42	0.60
							5	39	45	33	0.58
							6	124	151	104	2.29
							7	110	140	92	2.54
34	PURPLE IN 841021	465	1058	471	1062	35	4	72	90	60	0.87
							5	76	92	60	1.34
							6	98	126	70	2.30
							7	63	88	38	2.07
35	PURPLE IN 841021	564	1011	569	1020	60	4	65	74	54	0.60
							5	58	74	46	0.65
							6	43	58	31	0.79
							7	19	36	7	0.89
36	SINGBURI	772	765	776	768	20	4	83	98	67	1.74
							5	88	100	80	1.29
							6	104	120	92	2.16
							7	74	92	64	1.99

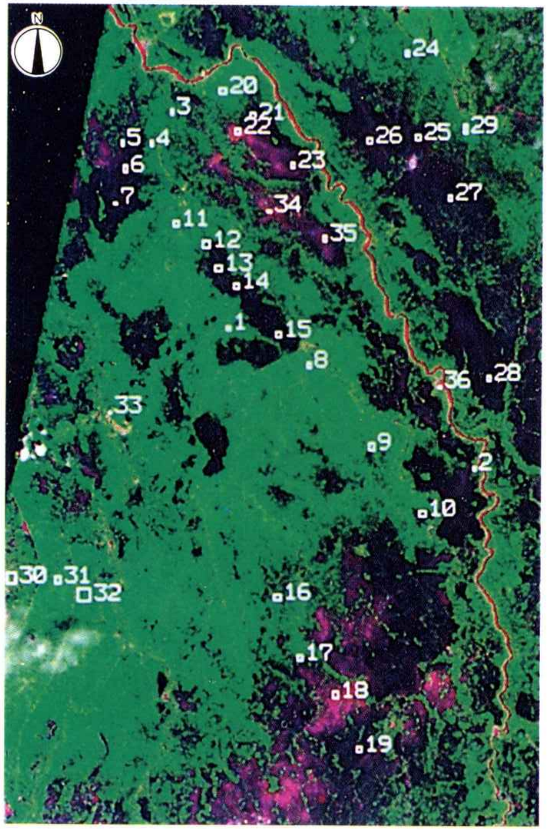


Figure 13　Location of training areas on image of Landsat MSS band-7, October 21, 1984 (841021).
Band 4, 5 and 7 are assigned to Blue, Red and Green, respectively.

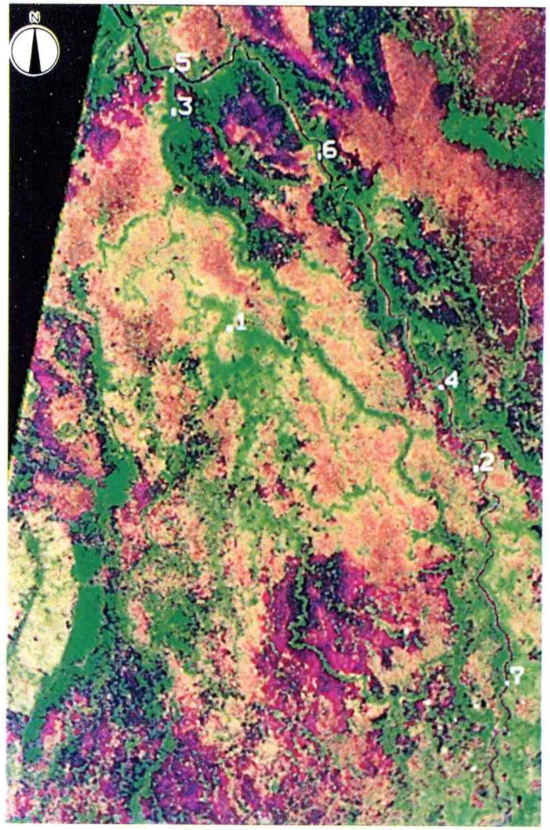


Figure 14　Location of training areas for natural levee classification on image of Landsat MSS band-7, April 12, 1984 (840412).
Band 4, 5 and 7 are assigned to Blue, Red and Green, respectively.

in Table 2 along with the corresponding of standard deviations. The spectral signature of these areas were plotted from the mean value of the four bands. Checking the graphs plotted out, we grouped them into 6 representative training areas whose plotted popular means are shown in Figure 15.

For the geomorphological terrain classification, two process were carried out in parallel. For a natural levee, a composite image consisting of band 2 and band 4 of both two images on 840412 and 850202 were used. After classifying it into three categories of a natural levee, a city area and a river, the nature levee was extracted as its mask pattern. Positions of the training areas are shown in Figure 14 and the spectral signatures are in table 3. For the other terrains, the data on 851203 is used to extract the Chao Phraya River and to classify a back marsh area into a marsh and a deep marsh.

The results of the classification are presented in Figure 16 and 17. In Figure 16, classified flooding are shown, but areas of corresponding to the Chao Phraya river and the mask of natural levees are deleted to an 'unclassified' area. In Figure 17, the geomorphological terrain, derived from the data on 851203, are shown after over lay with the mask.

The areal extent of each class was estimated from pixel counts and shown in Table 4.

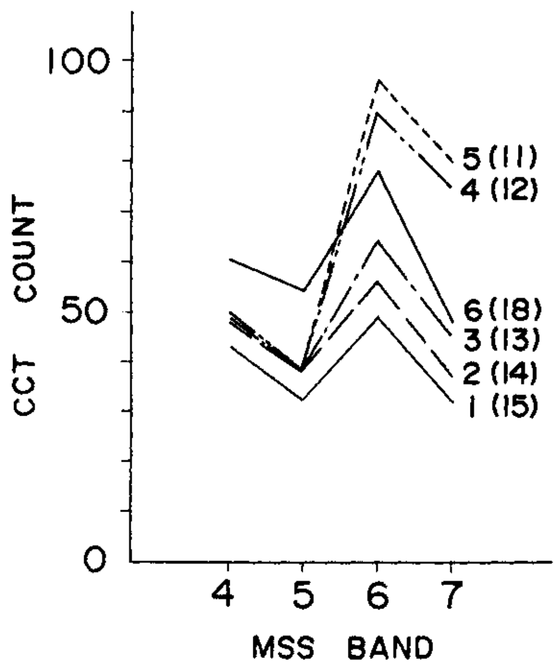


Figure 15 Spectral signature of the training areas for classifying flooding on image taken on October 21, 1984.
Numbers between parentheses correspond to the numbers of training area in Figure 13 and Table 2.

Table 3 Spectral Signature classification corresponding to Figure 11.

* * * CLASSIFICATION (RUN AT MAR/26/88 17:41:11) * * *

BASE IMAGE FILE (NAMEIN) =REMO/BUFF/THAI/CO-RES/C0202-0412
NUMBER OF PIXEL & LINE =960, 1408
TOTALBAND = 4

BAND COMPOSITION BAND 1 =BAND 5 OF 850202
BAND 2 =BAND 7 OF 850202
BAND 3 =BAND 5 OF 840412
BAND 4 =BAND 7 OF 840412

CLASSIFICATION METHOD =MAXIMUM LIKELIHOOD METHOD
USING CHANNEL =1, 2, 3, 4

FILE OF TRAINING AREA =REMO/BUFF/THAI/CO-RES/TRATBL

(I)NDIVIDUAL OR (G)ROUP =G =>TRAINING AREA SAREREARRANGED TO
3 CATEGORIES INDICATED BY THE TOP
CHARACTERS OF 'NAME OF AREA'

NO	NAME OF AREA	--RECTANGLE AREA-- LOWER L. (JOX,JOY)		UPPER R. (JEX,JEY)		TOTAL PIXEL	BAND	----CCT COUNT---- MEAN	MAX	MIN	SIGMA
1	3LEVEE (BANG RA.)	393	861	399	867	49	1	78	90	63	1.07
							2	73	90	54	1.32
							3	72	96	63	1.03
							4	123	141	104	1.32
2	3LEVEE (PAROM)	837	626	840	633	32	1	53	63	41	1.25
							2	75	79	67	0.52
							3	72	85	57	1.19
							4	94	104	84	0.86
3	3LEVEE (UP NOI)	295	1224	299	1232	4	51	41	54	37	0.47
							2	81	92	43	1.33
							3	53	60	49	0.40
							4	100	108	86	0.82
4	1SINGBURI (city)	772	765	776	768	20	1	74	80	66	0.97
							2	56	67	48	1.25
							3	89	95	77	0.91
							4	75	87	67	1.05
5	2CHAO. RIVER 1	293	1298	297	1300	15	1	66	67	63	0.31
							2	20	30	16	0.74
							3	74	78	71	0.48
							4	30	34	27	0.54
6	2CHAO. RIVER 2	555	1151	555	1158	8	1	66	68	64	0.51
							2	37	59	19	5.44
							3	76	77	71	0.68
							4	27	28	24	0.58
7	2CHAO. RIVER 3	892	259	892	263	5	1	71	72	70	0.33
							2	15	18	13	0.85
							3	88	93	86	1.13
							4	37	40	35	0.83

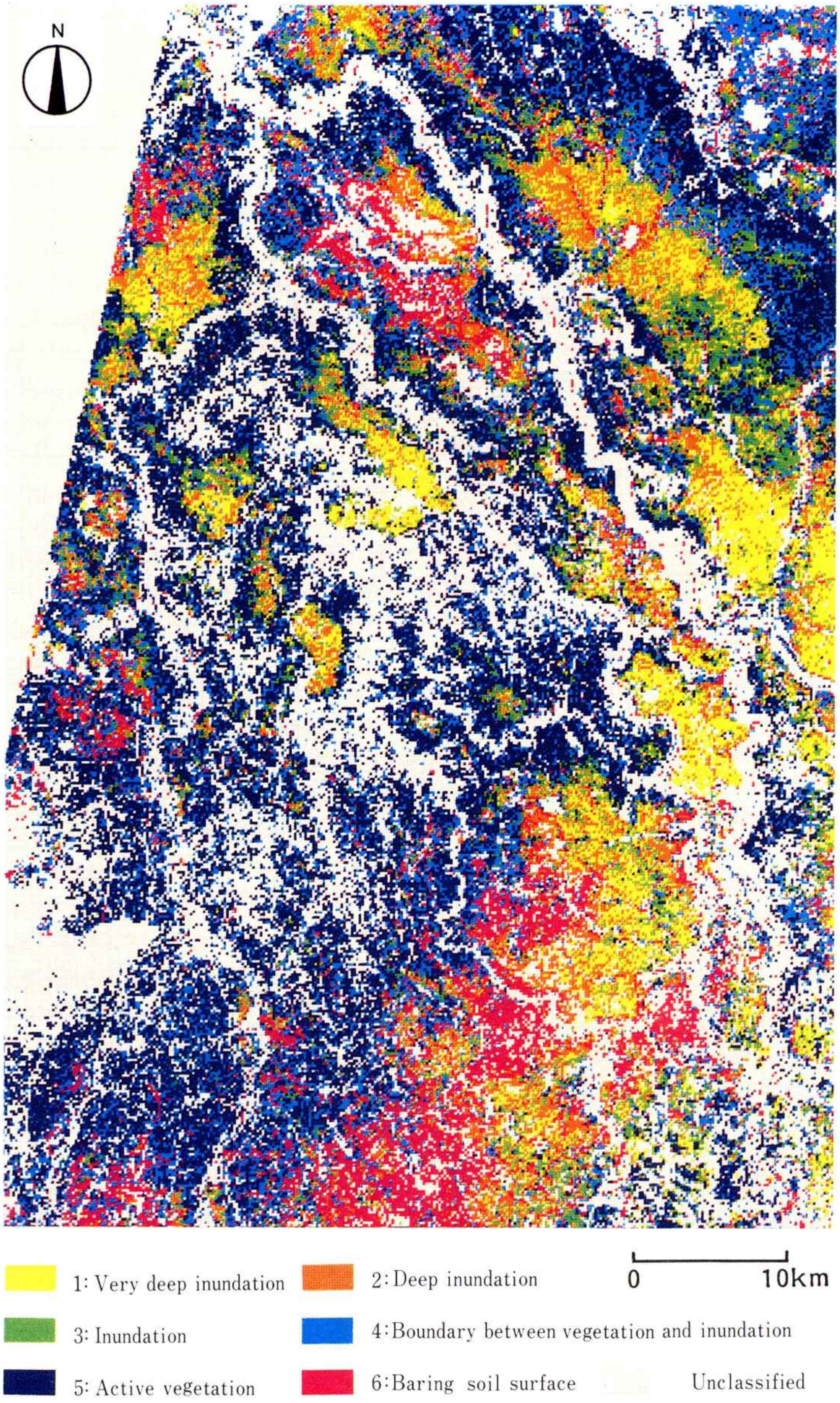


Figure 16 The result of geomorphological classification of data 841021 (October 21, 1984). Natural levees and rivers expressed in Figure 17 are intentionally categorized to a class 'UNCLASSIFIED'.

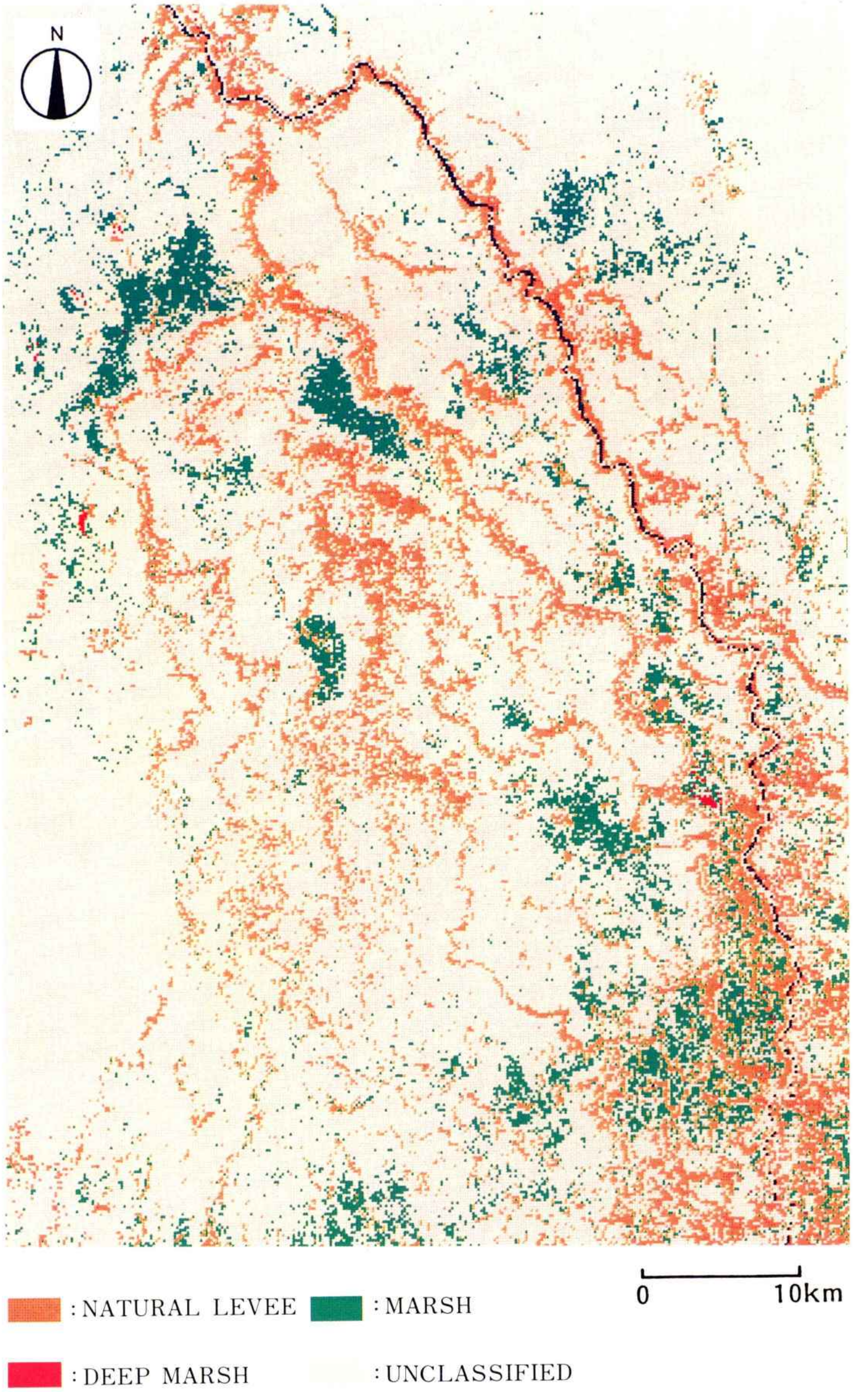


Figure 17　The result of geomorphological classification of data 851203 (December 3, 1985).

Table 4　The result of classification.

(a)

No. of level	Categories	Area (km^2)	Percentage (%)	Note
1	Very deep inundation	198.97	4.65	(1pixel=56.27m
2	Deep inundation	252.06	5.90	*56.33m)
3	Inundation	295.05	6.89	
4	Boundary between vegitaion and inundation	647.36	15.12	
5	Active vegitaion	1011.18	23.26	
6	Baring soil surface	353.73	8.26	
	Natural levee	685.93	16.02	
	Unclassified	836.38	19.54	
	Total	4280.66 ¯4281.00	99.99	

'No. of level' corresponds to 'Training area' of fig. 14.
: Flooding classification of image data acquired on October 21, 1984.

(b)

No. of level	Categories	Area (km^2)	Percentage (%)	Note
0	Unclassified area (terraceandfan)	345.60	8.07	(1pixel=56.27m *56.33m)
1	Unclassified area	2942.40	68.73	
2	Marsh	321.78	7.52	
3	Deep marsh	2.68	0.06	
4	Water surface of Chao Phraya River	16.12	0.38	
5	Natural levee	652.67	15.24	
	Total	4281.25 ¯4281.00	100.00	

: Geomorphological classification of image data acquired on December 3, 1985.

4.3 Result

By using multi-date of Landsat data to study flooding and geomorphological aspects, the results are as follow:

4.3.1 The geomorphological classification

According to the relationship between Landsat data taken in flooding season (841021) and dry season (840412), it can divide the geomorphology of study area into two main types:

1) Natural levee: It appears distinctly in dry season due to the vegetation that covers along the river channel while the other areas are almost clearing. In flooded season, the natural levees in the upper area can be also detected but the lowland always mix with paddy fields and other crops. Along the Chao Phraya River in flooded time, some part of this terrain will disappear by the inundation. Comparing with the geomorphological map it can be concluded that the Landsat data give a good result in providing the pattern and direction of natural levee specially in the upper part of study. But the lower part, it was more dispersion mixed with other terrains. The filtering techniques is necessary for smoothing the result in this area.

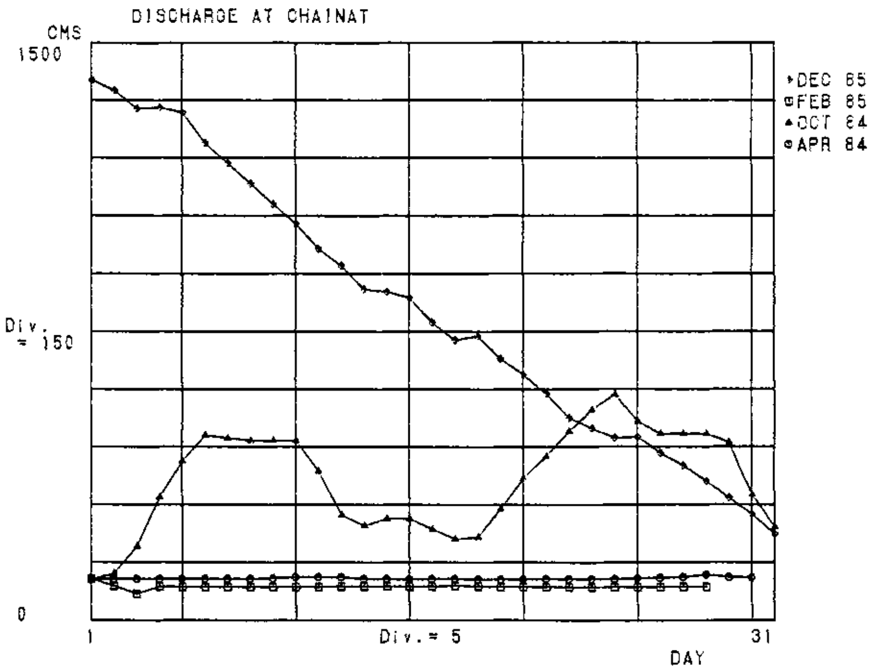
2) Marsh: The depth level of marsh can be divided with the combination of data among the flooded season, the data in harvesting time and the dry season. In flooded season, almost of the lowland and paddy field will be filled by water. The spectral signature of lower marsh was replaced by the water reflectance, so it cannot identify the depth of marsh. Two months later when the water level come down, some area have drained out for harvesting then the humid only shows in the lower land and deeper marsh. In February, the early dry season, the water was shown in deeper marsh and river channel, and disappear from the lowland. Due to the human activity, this occurrence is changed in April, the hottest month, when the water from irrigation canal has been supplied for second crops. The Landsat data acquired on 840412 was shown distinctly in this case where the deepest marsh was almost dried but the lowland in the lower part of study area appeared more moisture. As considering the rainfall, discharge and gage height recorded at that time, it is not indicated that the humid was come from precipitation. Figure 18 and 19 show the Hydrological data of the Central Plain during the image acquisition. By multi-temporal analysis of two images (841021 and 851203) the depth of marsh can be separated in 6 levels.

Level 1 : the paddy field.
Level 2 : the lowland located along the paddy field.
Level 3-4 : the lowland which gentle slope or border of the marsh.
Level 5 : the lowland which shallow inundation.
Level 6 : the lowest land which deep inundation.

The classification of Landsat image in dry season (850202 and 840412) can identify the marsh where the water was available all year. When superimposed the result of terrain classification together, the pattern of natural levee and the depth of marsh and back swamp are distinguished clearly. Any way to corrected the depth differential, more ground truth data of elevation of the area should be checked.

3) The stage of flooding

The Landsat data taken on 841021 has shown the inundation area in marsh and backswamp of the Chao Phraya river. The inundation was caused from the heavy rainfall and the large amount discharge of Ping, Wang, Yom and Nan which drained to the Chao Phraya river. On the gage height recorded at Chainat and Angthong during September 1984-February 1985 shown in Figure 18, the peak came up to 8.89 m. on



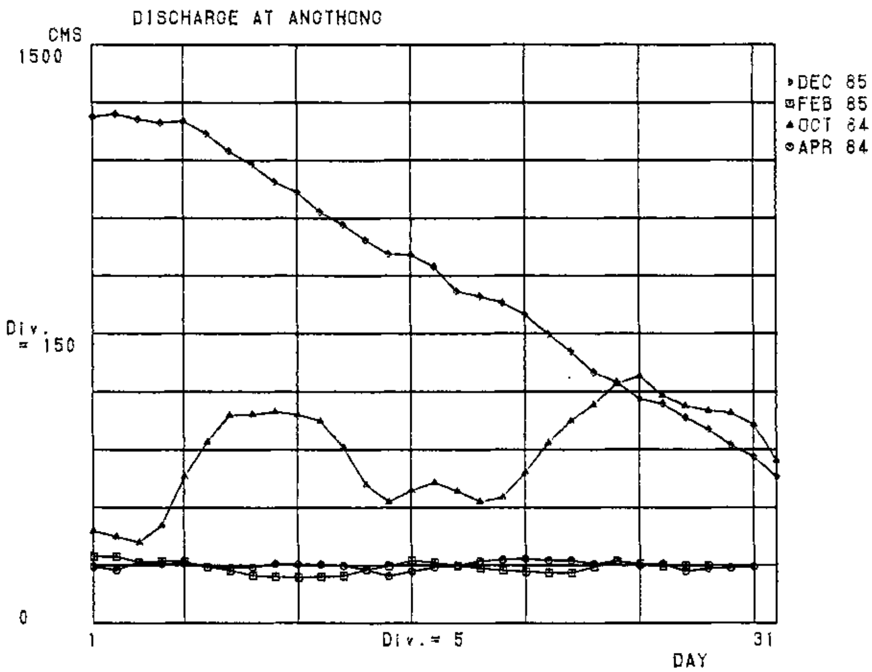
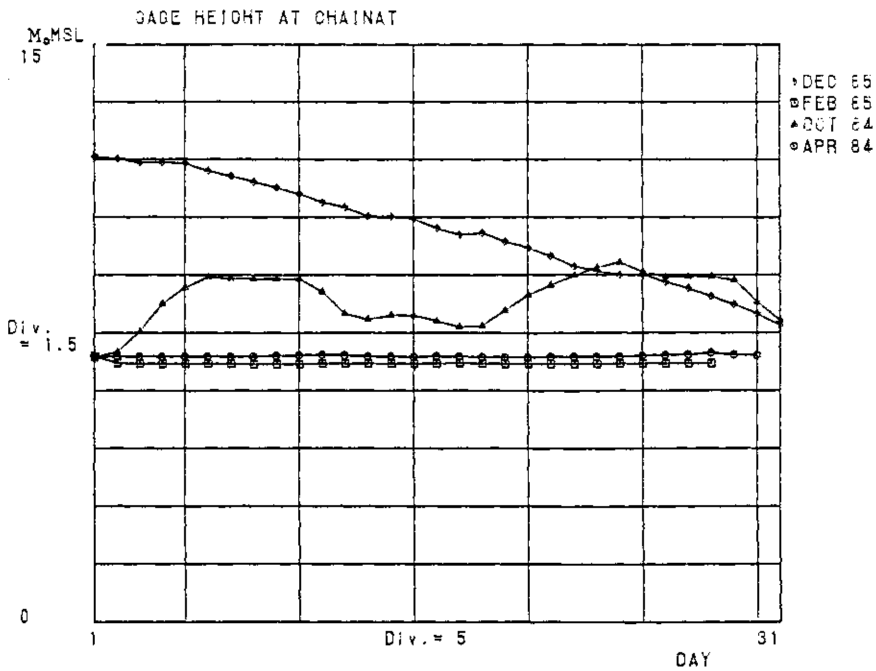


Figure 18　Monthly Discharge of the Chao Phraya recorded at Chainat and Angthong Province



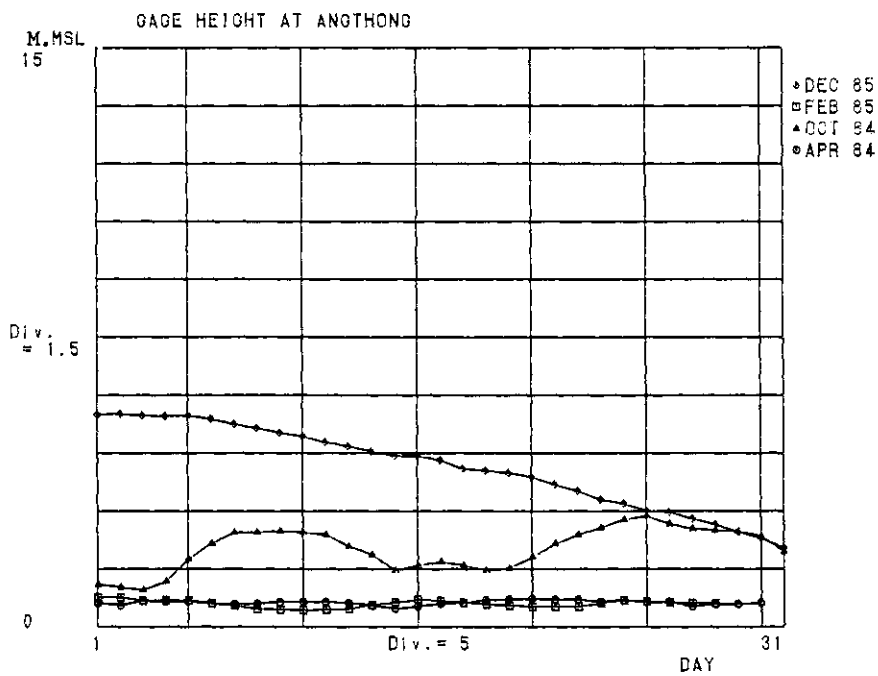


Figure 19　Gage height of the Chao Phraya River recorded at Chainat and Angthong Province

October 10, 1984; 11 days before the image acquired and decrease to normal level on October 17, 1984 and after that it became high again because of reaching of water from the northern watershed.

5. Conclusion

To study flooding and geomorphological aspects by satellite data, it can be concluded that the geomorphology terrain can be classified by using multi-date imagery. The temporal change between rainy season and dry season can be distinguished the different elevation of marsh and swamp but the ground truth data should be checked for grouping the same class. The natural levee also appeared clearly along the river channel and the former channel while the terrace, high terrace and monadnock can not identified. The construction of road and irrigation canal has an activity on flooding prevention in the paddy field and providing water in the dry season. This cause difficulty in analysis the differential level of marsh and swamp. Another difficult faced was the pattern of vegetation in the Central plain which rotated all year. The data of harvest time will be useful for separating the level of terrain but will cause a problem in classify the natural levee. Due to the high resolution of Landsat data in Thematic Mapper system and Spot data, the other types of geomorphology as the terraces, small marsh and alluvial fan could be identify in more detail.

Japanese and Thai researchers' reciprocal visits activated this co-operated study. Those visits were executed for the period of 22 days in 1986 and 32 days in 1988. The field research in Thailand was carried out for the former period and the digital analysis at the National Research Center for Disaster Prevention (NRCDP) was for the latter. This report is the improved one that was submitted to the Science and Technology Agency of Japan as Thai visitors research report in Japan.

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タイ中央平原における洪水と地形の特徴

ランプン・シムキン，ラサミー・スワンウェラカントルン，大倉　博

要　旨

タイ中央平原の洪水氾濫と地形学的特徴の調査に衛星画像を利用した。研究対象域はタイ中央平原の北部，北緯14°30' - 15°13'，東経100°00' - 100°30'の範囲である。始めに対象域の地形，水文，気候の特徴を述べた。次に，異なる時期に受信・取得された当該地域のランドサットＭＳＳ（Multispectral Scanner）の4画像をデジタル解析した。この結果，多時期の衛星画像を用いて，地形分類が分類できることが分かった。自然堤防は，研究対象域の南部では他の地形要素と混じりあって抽出されるが，北部では明瞭に分離・抽出された。雨期と乾期の画像の季節変化から，後背湿地や沼沢地の地盤高の差異を見分けることが出来るが，差異を定量化するためにはグランドトルースと照らし合わせた調査が必要である。