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ANALYSIS OF SUSPENDED SEDIMENT YIELD AND WATERSHED CHARACTERISTICS IN MAE KLONG RIVER BASIN

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Abstract

The relationship between Suspended sediment yield, rainfall pattern and watershed characteristics were analyzed in Mae Klong river basin as a first step to practice proper watershed management. Although Mae Klong river basin has abundant forest which is preserved in good conditions, its suspended sediment yield is not so low in comparison with other Thai basins. As a result of comparing Khwae Noi, Khwae Yai and Lam Phachi watersheds of the basin from the viewpoint of suspended sediment yield, rainfall pattern and watershed characteristics such as geology, topography, soil and land use, it is suggested that suspended sediment is easily produced in Lam Phachi watershed as compared with the other watersheds. Also the exponent of a equation in specific suspended sediment yield obtained by the study, could be a clue to consider where sources of suspended sediment are in a basin. In Mae Klong river basin, the exponent was found to be a positive value of 0.22. This could suggest that lowland of the basin has plenty of suspended sediment sources rather than upland because almost all agricultural land exist in lowland and increase with basin area. That is to say, agricultural activities in lowland affect increment of the source whereas natural forest covering almost all of upland area contributes towards decreasing sediment sources. As for watershed management in Mae Klong river basin is concerned, it is necessary to protect the remaining forest in upland for preventing increment of sediment sources and to conserve the soil of cultivated area in lowland for decreasing sediment sources.

Keywords: suspended sediment yield, watershed characteristics, rainfall pattern, soil erosion

1. INTRODUCTION

Watershed degradation results mostly from water erosion caused mainly by excessive exposure of bare soil due to poorly managed logging operations, indiscriminate forest cutting, widespread use of annual crops in farms, overgrazing, cutting of vegetation for fuelwood and inadequate management of run off. Therefore, it is important to control soil erosion in a watershed to achieve sustainable management. Furthermore, to practice proper watershed management, attention should be paid not only to on-site effect of erosion such as degradation of soil fertility accompanied by soil loss but also to its off-site effect such as reduction of river and reservoir capacities, linkage between both effects and watershed characteristics.

According to Jantwat (1985), annual erosion rate in each region of Thailand ranges from 12 to 2,045 ton/km^2/year in the North, 8 to 3,874 ton/km^2/year in the Northeast, 20 to 569 ton/km^2/year in the Central Plain, 27 to 355 ton/km^2/year in the East and 30 to 1,787 ton/km^2/year in the South. Thus the higher erosion rate occurs in the Northeastern and Northern regions where deforestation have rapidly progressed. Therefore, in these regions special attention has been paid to soil erosion and sedimentation issues. According to some plot investigation of soil erosion at Mae Klong Watershed Research Station of Royal Forest Department in Mae Klong river basin of the Western region, soil erosion rate is quite low (less than 0.2 ton/ha/year) in natural forest (Tangtham, 1991). Accordingly, in Mae Klong river basin, which is almost covered with forest preserved in good conditions, much attention to soil erosion and sedimentation has not been paid. However the soils on steep slopes in the basin are susceptible to erosion when natural cover is removed and the soil of cultivated area in agricultural land is also susceptible to erosion. Therefore, more attention has to be paid to erosion and sedimentation problems in the basin and proper watershed management has to be practiced.

The objective of this paper is to analyze suspended sediment yield, rainfall pattern, watershed characteristics and those relationship from the viewpoint of sediment source and sink in Mae Klong river basin as a first step to better understand the relationship among watershed characteristics, erosion or sedimentation ,on-site and off-site effects of erosion, and the interrelations for practicing proper watershed management.

2. STUDY AREA

Mae Klong river has a drainage area of 30,800 km^2. It has two major tributaries, namely Khawe Yai river where Srinagarind dam reservoir with a water surface area of 419 km^2 and Khawe Noi river where Khao Laem dam reservoir with a water surface area of 388 km^2 are located (Fig.1). Mountainous area of Mae Klong river basin is mainly underlain by Paleozoic and Mesozoic rocks such as limestone, sandstone, mudstone, shale and quartzite. Forest coverage ratio of this basin was 53 % in 1988 (Tangtham, 1997). This ratio was considerably high as compared with 28 % for all Thailand at the same time.

In this study, three tributaries were selected for the comparative analysis of the characteristics of rainfall, watershed and suspended sediment yield in the upstream as well as downstream areas of each tributary's basin. The tributaries are: (1) Khawe Yai river which has a drainage area of 11,750 km^2 above its confluence with Lam Taphoen stream, (2) Khawe Noi river which has a drainage area of 7,000 km^2 above its confluence with Huai Mae Kraban stream and (3) Lam Phachi river which has a drainage area of 793 km^2 above its confluence with Khawe Noi river (Fig.1).

3. METHODS AND DATA

To analyze characteristics of rainfall, watershed and suspended sediment yield, three basic sources of information were used. Firstly, topographical, geological and land use conditions were examined by using topographical maps (scale 1/500,000 published in 1984 by Defense Mapping Agency of the U.S.), geological maps (scale 1/250,000 published in 1976 by Department of Mineral Resources in Thailand), soil maps (scale 1/2,500,000 published in 1993 by Royal Thai Survey Department and land use maps (scale 1/2,500,000 published in 1972 by Department of Land Development). Secondly rainfall characteristics were examined by comparing isohyetal maps prepared using rainfall data mainly monitored form 1952 to 1991 at 25 rainfall stations by Royal Irrigation Department (Asian Institute of Technology, 1994). Thirdly, characteristics of suspended sediment yield were examined by comparing the relationship between basin area and suspended sediment yield, and suspended sediment rating curves were estimated by using water discharge data and suspended sediment load data monitored at many hydrological stations by Royal Irrigation Department (RID), Electricity Generating Authority of Thailand (EGAT) and Department of Energy Development and Promotion (DEDP).

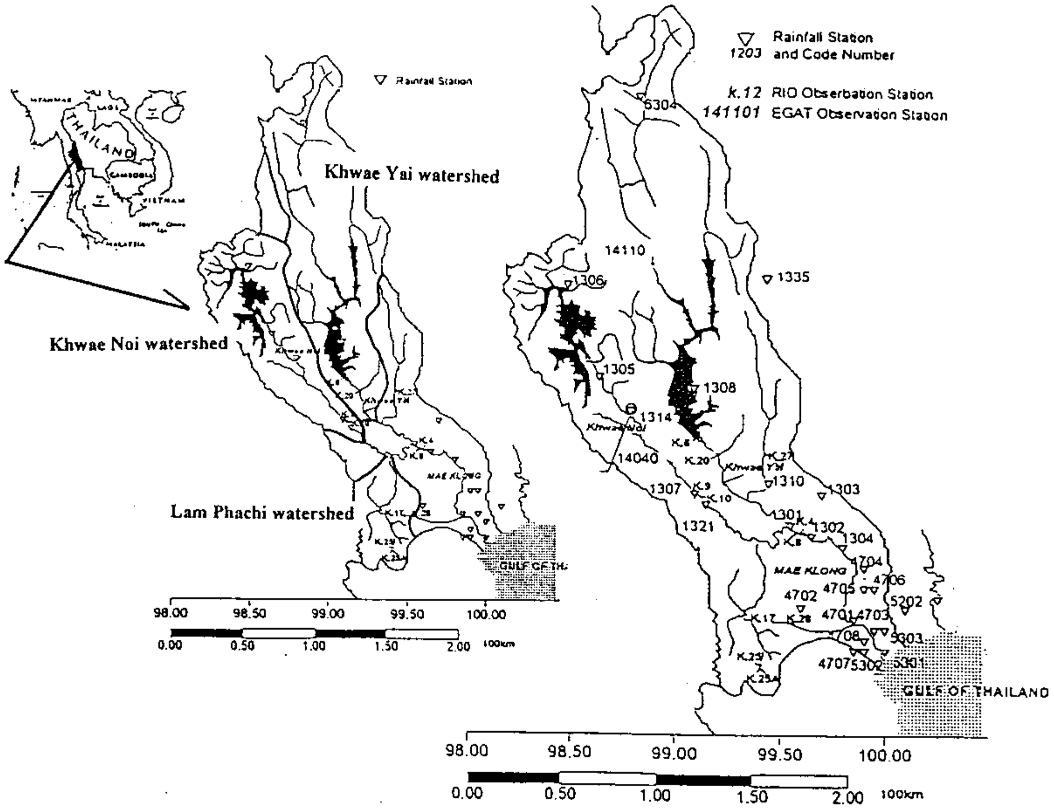


Fig. 1 Location map showing Khwae Noi, Khwae Yai and Lam Phachi watershed in Mae Klong river basin and hydrological observation stations.

Table 1 Monthly rainfall of Mae Klong river Basin

UNIT:mm

STATION CODE NO.	MONTHLY RAINFALL MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	TOTAL
13063	246.2	410.8	428.0	435.0	359.6	182.4	29.6	3.8	7.0	12.7	28.2	77.9	2221.2
13053	192.2	289.7	305.1	324.7	226.5	152.7	24.7	2.1	5.3	17.7	31.4	88.7	1660.8
13142	217.3	264.9	286.2	314.0	251.6	164.8	34.7	9.7	5.5	25.9	46.1	118.3	1739.0
63042	164.8	178.8	213.0	254.1	257.6	147.0	29.3	4.7	9.2	11.2	28.5	83.9	1382.1
13083	131.3	91.7	112.5	109.7	193.4	174.3	41.4	5.1	6.2	29.9	28.0	91.5	1015.0
13073	170.7	109.7	124.8	137.6	208.6	207.6	50.0	4.1	5.7	22.3	49.1	89.0	1179.2
13211	163.6	108.2	126.5	126.1	205.5	229.1	57.0	8.7	3.9	23.2	47.2	83.1	1182.1
13102	129.4	65.0	89.2	111.5	211.9	204.2	52.4	3.6	5.6	11.0	40.2	76.7	1000.7
13013	146.2	85.1	97.8	100.6	222.2	214.7	68.0	7.8	4.9	10.7	25.5	72.5	1056.0
47022	122.1	85.4	99.9	125.7	207.6	205.9	83.3	5.3	2.4	10.5	13.3	51.2	1012.6
13022	122.2	75.0	90.1	110.3	194.0	189.2	53.1	5.4	7.9	5.0	11.2	63.7	927.1
13032	121.6	56.0	81.4	95.3	220.7	173.5	40.6	8.0	4.1	8.0	23.2	41.3	873.7
13042	117.8	90.5	110.3	106.3	194.2	173.7	49.5	4.4	0.6	6.0	13.7	44.4	911.4
47012	131.2	107.0	109.0	136.0	201.1	206.0	68.8	5.9	3.6	5.0	5.3	29.8	1008.7
47072	144.7	115.4	127.2	144.4	208.2	245.5	106.5	9.8	5.3	5.2	11.0	32.1	1155.3
47042	137.6	99.0	126.6	135.2	204.9	210.1	58.8	6.1	5.7	8.5	10.5	41.0	1044.0
47052	144.9	129.0	129.6	135.1	198.7	182.2	60.9	7.1	2.8	5.9	13.4	42.2	1051.8
47082	109.8	99.4	106.2	122.4	174.7	199.2	56.3	3.7	1.1	4.1	5.8	16.8	899.5
53022	111.6	111.8	110.2	128.2	214.3	249.2	87.5	7.8	5.0	10.7	16.8	22.6	1075.7
47062	118.4	99.5	105.9	108.5	194.6	171.5	52.1	5.5	4.7	7.4	11.5	37.2	916.8
47032	136.9	115.3	141.2	135.1	246.5	242.3	90.0	8.2	4.6	8.5	14.2	29.0	1171.8
53032	130.4	119.8	114.1	134.7	215.7	246.2	87.1	5.1	1.3	9.2	17.4	27.6	1108.6
53012	116.9	101.1	106.0	143.2	213.0	234.1	91.9	5.8	5.2	8.9	13.2	27.6	1066.9
52022	131.4	123.2	134.0	142.4	254.0	201.2	70.5	15.1	6.5	9.0	11.8	32.7	1131.8
13352	133.5	103.1	116.9	130.6	211.5	205.1	64.5	6.5	4.6	10.5	19.6	49.3	1055.8

4. RESULTS AND DISCUSSION

4.1 Rainfall characteristics

Rainfall is one of the most important hydrological factors controlling flow regime, erosion, sedimentation and so on because it is input to a watershed. Therefore, isohyetal maps were prepared using rainfall data (Table 1) which were collected from 25 rainfall stations (Fig.1) to reveal rainfall characteristics of Khwae Yai, Khwae Noi and Lam Phachi watersheds. The isohyetal map of annual mean rainfall (Fig.2) shows that the annual rainfall for the lower part of Mae Klong river basin is roughly 1,000 mm, and it increases with latitude to about 2,100 mm in the upper part of the basin. Moreover the rainfall also increases spatially from the east to the west of the basin, ranging from 900 mm to 2,100 mm. The latter rainfall pattern is mainly caused by the south west monsoon from the Bay of Bengal and the central ridge which runs from the south to the north in the middle of the upper part of the basin and divides Khwae Yai and Khwae Noi watershed (Fig.4). This is because the south west monsoon with still high moist air produces much rainfall by reaching to the ridge, and after it traverses over the ridge it can not produce so much rainfall in the east as in the west owing to reduction of air moisture in the monsoon. The former pattern which rainfall increases with shifting from the lower part to the upper part of the basin also must be caused by the same reason.

As a result of comparing annual areal rainfall obtained by using the isohyetal method of investigated watersheds, Khwae Noi, Khwae Yai and Lam Phachi watersheds have 1,786 mm, 1,416 mm and 1,130 mm in annual areal rainfall respectively. Khwae Noi watershed has a higher value in annual areal rainfall than Khwae Yai watershed and Lam Phachi watershed has a lower value than Khwae Noi and Khwae Yai watersheds. The difference among the watersheds in annual areal rainfall results from rainfall pattern as mentioned above. Figs.3a and 3b show monthly isohyetal maps and monthly mean areal rainfall in Khwae Noi, Khwae Yai and Lam Phachi watersheds. In rainy season between May and October monthly areal rainfall ranges from 177 mm to 335 mm in Khwae Noi watershed, from 160 mm to 251 mm in Khwae Yai watershed and from 108 mm to 217 mm in Lam Phachi watershed, whereas in dry season between November and April it ranges from 5 mm to 36 mm in Khwae Noi watershed, from 5 mm to 40 mm in Khwae Yai watershed and from 4 mm to 86 mm in Lam Phachi watershed.

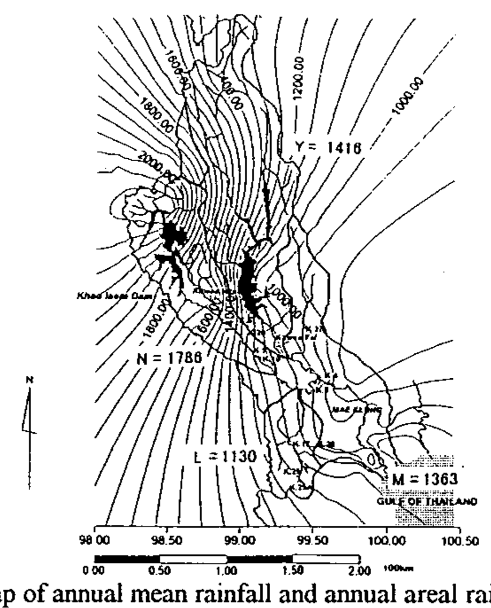


Fig. 2 Isohyetal map of annual mean rainfall and annual areal rainfall for each watershed. N: Khwae Noi watershed, Y: Khwae Yai watershed, L: Lam Phachi watershed, M: Mae Klong river basin, rainfall unit: mm.

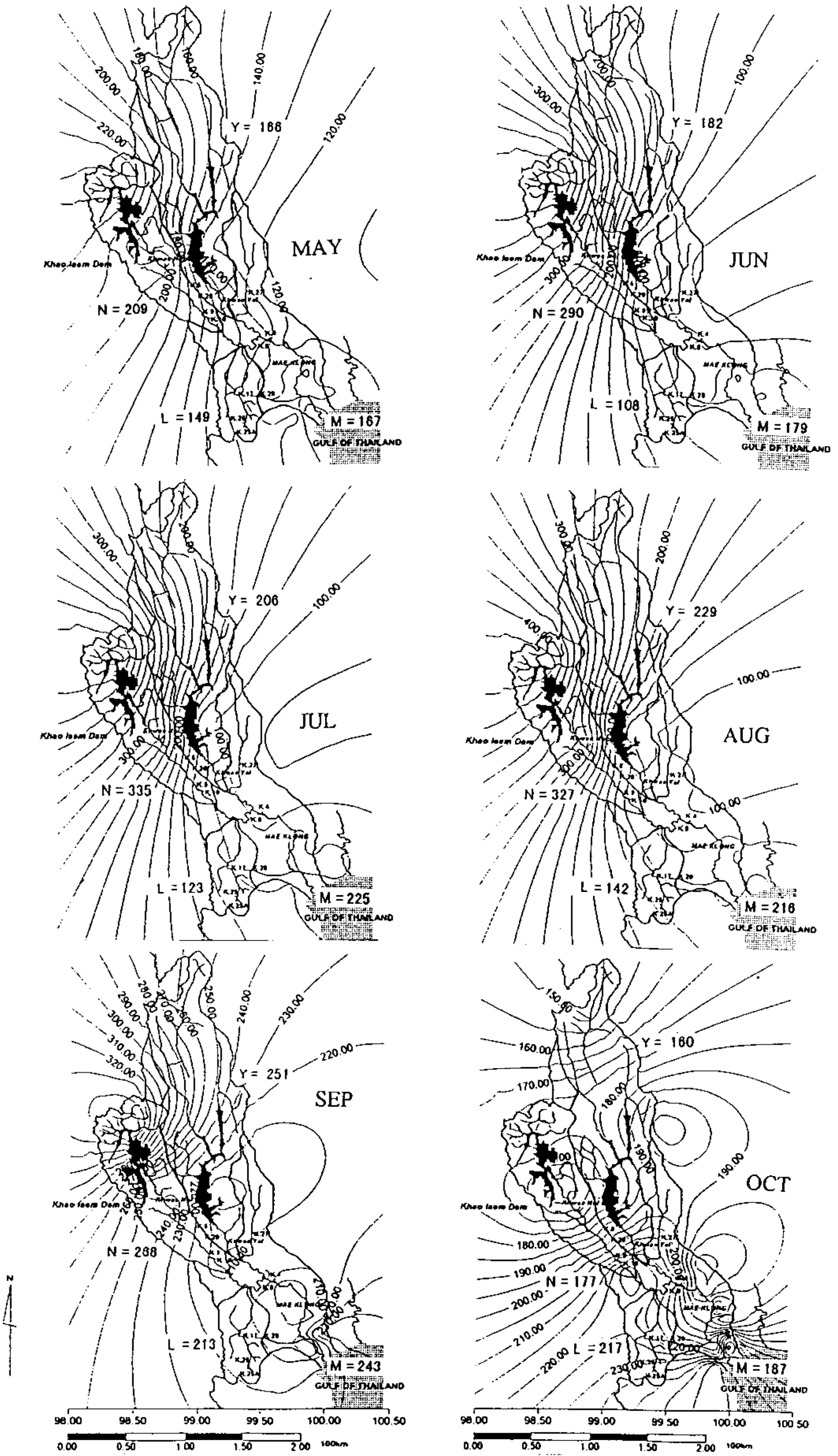


Fig. 3a Isohyetal maps of monthly mean rainfall and monthly areal rainfall for each watershed from May to October.
N: Khwae Noi watershed, Y: Khwae Yai watershed, L: Lam Phachi watershed, M: Mae Klong river basin, rainfall unit: mm.

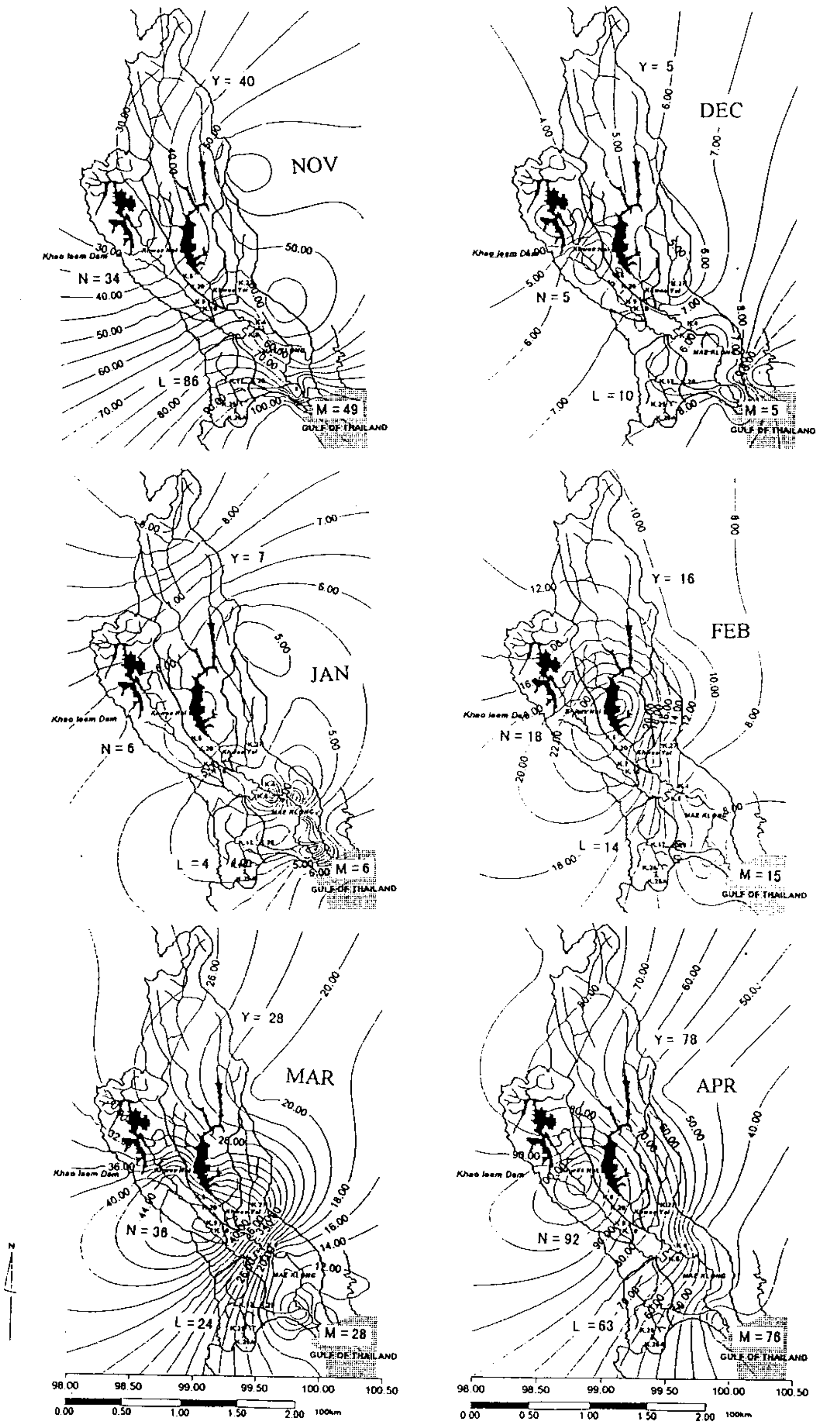


Fig. 3b Isohyetal map of monthly mean rainfall and monthly areal rainfall for each watershed from November to April.
N: Khwae Noi watershed, Y: Khwae Yai watershed, L: Lam Phachi watershed, M: Mae Klong river basin, rainfall unit: mm.

4.2 Watershed characteristics

Topography, geology, soil and land use play an important role in determining characteristics of watershed itself as a receptacle for rainfall. Thus topographical, geological, soil and land use conditions of the watersheds were analyzed.

4.2.1 Topographical conditions

First of all, a three dimensional map of the basin (Fig.4), to better understand topographical conditions visually, were prepared. For this purpose X grid lines and Y grid lines at the intervals of 3 minutes (approximately 5 km) were drawn based on longitude and latitude on the topographical map. Then the elevation on a grid node was read. Next the relative relief was obtained by comparing a grid node elevation with 8 node elevations around it. Figs.5 and 6 show features of elevation and relative relief in the basin respectively. As a result of comparing the feature of elevation and relative relief in Khwae Noi, Khwae Yai and Lam Phachi watersheds, Khwae Yai watershed is highest in both mean elevation and mean relative relief, whereas Lam Phachi watershed is lowest in both (Figs.5 and 6). As shown in Figs.5 and 6, Khwae Noi watershed is similar to Khwae Yai watershed in relative relief distribution, whereas Khwae Noi watershed is different from Khwae Yai watershed in elevation distribution. Furthermore, it should be noted that Lam Phachi watershed has a peak of high relative relief of roughly 600 m in distribution, in spite of the fact that its peak of elevation is only about 900 m. This suggests that the upland of Lam Phachi watershed is high in relief.

A drainage system analysis was carried out using a stream ordering method of Strahler (1952) to examine the characteristics of drainage density and frequency, to analyze fractal dimension on stream length (Gordon *et al*, 1992) and to examine the characteristics of stream meanders. The fractal dimension (f) is given by the equation (1).

$$f=1-b \qquad (1)$$

$$L=aX^b \qquad (2)$$

where b is a regression constant in the equation (2) obtained by the simple regression for a log-log plot of stream length (L) against step size (X) which means each different spacing for dividing a given stream repeatedly (Fig.7). If a stream is straight, the fractal dimension equals 1 because b equals 0. And it increases with meandering, thus the fractal dimension is a measure of the degree of meandering. Fig.8 shows a map of drainage system for each watershed. As shown in Table 2, Lam Phachi watershed has the highest drainage density and frequency among the three watersheds, whereas Khwae Noi and Khwae Yai watersheds have similar lower values than Lam Phachi watershed in drainage density and frequency. Usually a high density indicates that a drainage basin has a finely divided network of streams with short length and steep slopes.

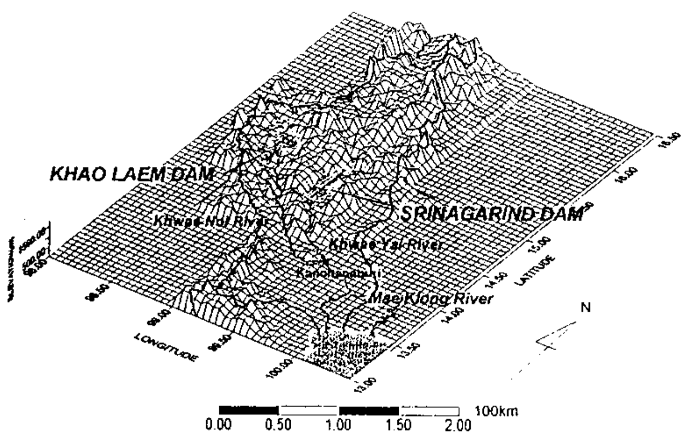
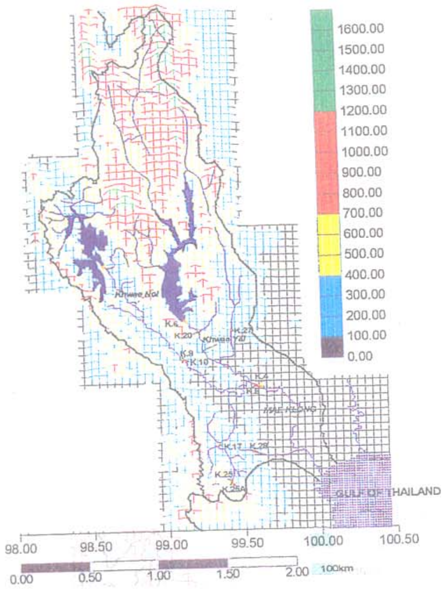
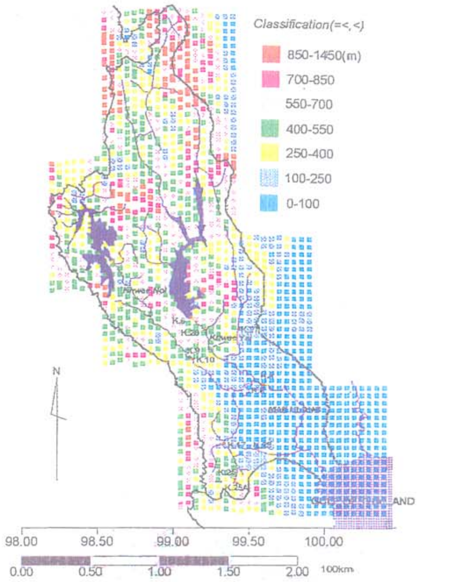
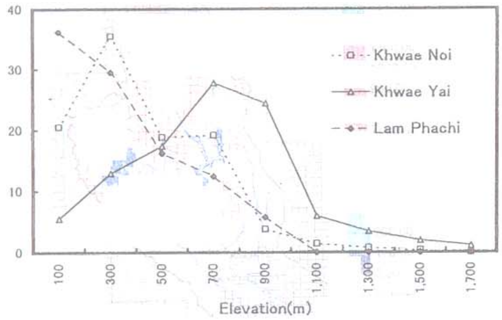
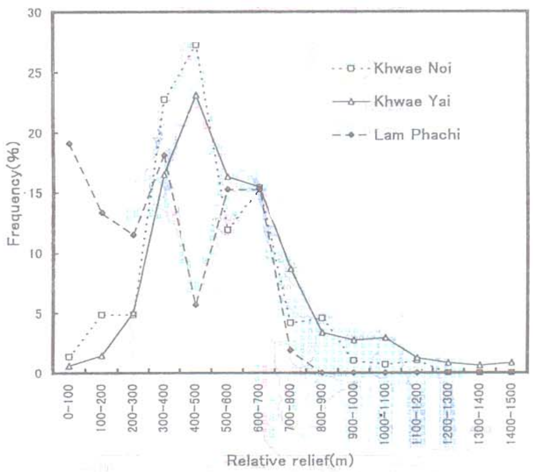


Fig. 4. Bird eye view of Mae Klong river basin.









Elevation (m)	Mae Klong %	Khwae Noi %	Khwae Yai %	Lam Phachi %
0-100	17.2	3.8	1.3	13.3
100-200	12.3	16.7	4.2	22.9
200-300	5.6	10.2	1.1	10.5
300-400	14.4	25.3	11.8	19.0
400-500	9.1	10.9	11.4	4.8
500-600	5.8	7.8	5.9	11.4
600-700	11.8	13.7	17.3	10.5
700-800	6.5	5.5	10.4	1.9
800-900	4.8	2.4	9.7	1.9
900-1000	6.7	1.4	14.6	3.8
1000-1100	1.9	0.7	4.0	0.0
1100-1200	0.9	0.7	1.9	0.0
1200-1300	0.9	0.0	2.3	0.0
1300-1400	0.6	0.7	1.1	0.0
1400-1500	0.3	0.3	0.4	0.0
1500-1600	0.6	0.0	1.5	0.0
1600-1700	0.3	0.0	0.8	0.0
1700-1800	0.1	0.0	0.2	0.0
Mean Elevation	(m)	(m)	(m)	(m)
	448	422	693	344

Fig. 5. Distribution of elevation in Mae Klong river basin.

Relative relief (m)	Mae Klong (%)	Khwae Noi (%)	Khwae Yai (%)	Lam Phachi (%)
0-100	15.7	1.4	0.6	19.1
100-200	6.7	4.9	1.5	13.3
200-300	7.7	4.9	5.1	11.5
300-400	16.0	22.7	16.5	18.1
400-500	17.4	27.3	23.1	5.7
500-600	11.4	11.9	16.3	15.2
600-700	12.5	15.4	15.5	15.2
700-800	5.2	4.2	8.7	1.9
800-900	2.5	4.6	3.4	0.0
900-1000	1.5	1.0	2.8	0.0
1000-1100	1.4	0.7	3.0	0.0
1100-1200	0.8	1.0	1.3	0.0
1200-1300	0.4	0	0.8	0.0
1300-1400	0.3	0	0.6	0.0
1400-1500	0.5	0	0.8	0.0
Mean relative relief	(m)	(m)	(m)	(m)
	425	486	562	342

Fig. 6. Distribution of relative relief in Mae Klong river basin.

As for the fractal dimension, Khwae Noi river has the highest value of 1.094, whereas Khwae Yai river has the lowest value of 1.073. Lam Phachi river has the intermediate value of 1.087. The values do not differ significantly. Consequently it may be considered that there is not much difference among the three watersheds in meandering.

Finally, It should be noted again that Lam Phachi watershed has the highest value in drainage density and frequency because these are closely related factors to sediment yield (Hadley and Schumm, 1961).

Table 2 Drainage frequency and density for each watershed

	Drainage Frequency				Drainage Density		
	Number				Length(km)		
Stream order	Khwae Noi	Khwae Yai	Lam Phachi	Stream order	Khwae Noi	Khwae Yai	Lam Phachi
1	75	160	66	1	784.4	1494.4	429.0
2	24	35	16	2	295.8	374.1	174.3
3	7	8	2	3	113.5	191.3	82.1
4	2	2	1	4	157.0	224.7	61.3
5	1	1		5	81.1	145.4	
Total	109	206	85	Total	1431.8	2429.9	746.7
F (Streams/km^2)	0.0156	0.0175	0.0324	D (km/km^2)	0.2045	0.2068	0.2850

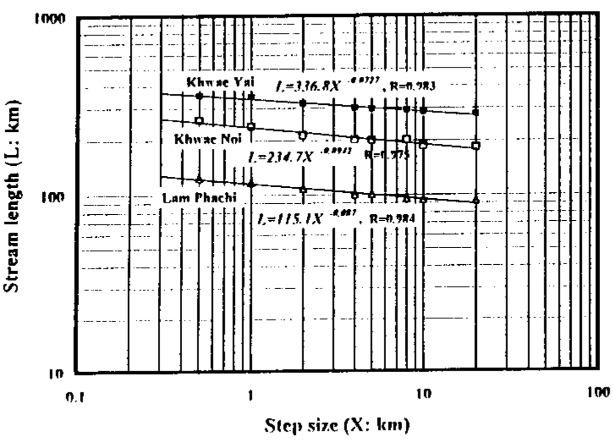


Fig. 7. Relationship between step size and stream length for each watershed.

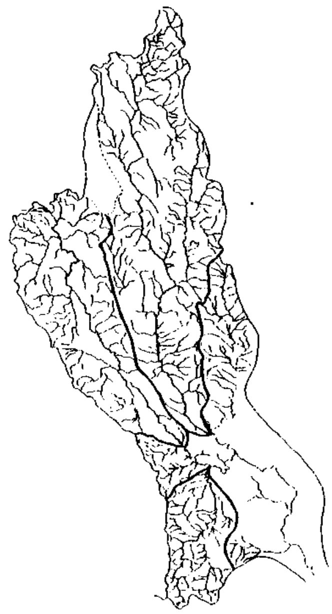


Fig. 8 Map showing drainage system for each watershed.

4.2.2 Geology, soil and land use conditions

Plane maps as well as three dimensional geological maps, soil maps and land use maps of the watersheds were prepared, and are shown in Figs.9, 10 and 11. Khwae Noi and the Khwae Yai watersheds are similar in geology mainly characterized by Limestone of Mesozoic era, whereas Lam Phachi watershed is characterized by Igneous rocks of Mesozoic era and Sedimentary rocks of Paleozoic era. Close attention has to be paid to this difference in geological conditions.

The distribution of soil groups in each watershed is not so much different. The majority of soils belong to the category of Slope Complex (Fig.10) which shows only that those soils are found on slopes. We can not know therefore the details of soil types distributed in upland areas of the watersheds.

Land use maps (Fig.11) show the situation of land use at the beginning of the 1970's. At that time forest coverage ratio of Khwae Noi , Khwae Yai and Lam Phachi watersheds were 76%, 83% and 57% respectively. According to Landsat imagery analysis in 1995, the forest coverage ratio of Khwae Noi and Khwae Yai watersheds are about 55%, and that of Lam Phachi watershed is about 25%. Particular attention should be paid to rapid decrease in forest in Lam Phachi watershed because of conversion into agricultural land. However, the forest coverage ratio of Mae Klong river basin decreased slightly from about 62% at the beginning of the 1970's (Fig.11) to 53% in 1988 as compared with the fact that the ratio of all Thailand decreased rapidly from about 45% to 28% in the same period. This suggests that the forest of Mae Klong river basin is kept in better conditions than other Thai basins. Actually in recent years the conservation zone which contains undisturbed forest areas has been widely established in the basin. According to Thangtham (1996), the area of WSC 1 of Watershed Classification Regulation promulgated since 1985, has reached to 39% for the total area of Mae Klong river basin. Here WSC 1 is defined as protected or conservation forest and headwater source where any activities are prohibited, and its area is usually located at high elevation with steep slopes (Tangtham and Somsopon, 1993). Finally, to clarify the details of present land use, particularity forest land, land classification analysis should be carried out using satellite imagery analysis and so on.

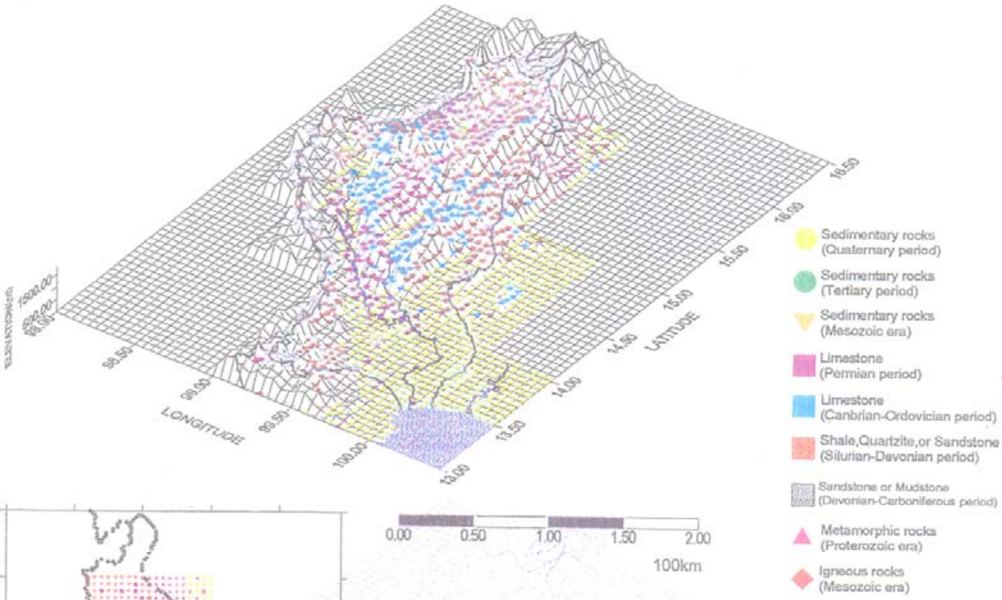
4.3 Characteristics of suspended sediment yield

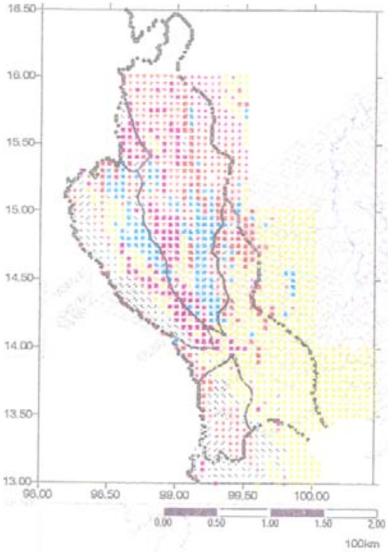
4.3.1 Relationship between basin area and annual suspended sediment yield in Thailand

Table 3 shows regression equations of basin area and annual suspended sediment yield of main basins in Thailand, which were calculated by RID in 1998. Fig.12 shows the relationship between basin area and specific suspended sediment yield obtained by dividing both sides of a regression equation (Table 3) by basin area. Furthermore, the relationship in 66 basins of Japan (Takahashi *et al.*, 1987) is also shown in Fig.12. Here the annual suspended sediment yield is estimated by assuming that sediment deposition in reservoirs contains the load of 70 per cent which was brought by suspended sediment transport and that its bulk density is 1,500 kg/m^3.

As compared with the specific suspended sediment yield of Japan which is approximately 600 ton/km^2/year, Thailand has a small value ranging from 10 to 200 ton/km^2/year. It should be noted that the specific suspended sediment yield of Mae Klong river basin is not so low as other Thai basins. It is rather high if the watershed area exceeds several hundred square kilometers.

The exponent of a equation in specific suspended sediment yield depends on the complex relationship between sources and sinks of suspended sediment in a basin, roughly speaking, if the exponent is negative, it could suggest that sources of suspended sediment decrease with basin area or sinks increase with basin area, whereas if positive it could suggest sources increase with basin area. In Mae Klong river basin the exponent is a positive value of 0.22. Thus it could be suggested that lowlands of the basin have plenty of suspended sediment sources rather than uplands because agricultural land existing almost in lowlands increases with basin area. In other words, agricultural activities in lowlands affect increment of sources while natural forest covering most of the upland area contributes towards decrease of sources.





Geology	Mae Klong	Khwae Noi	Khwae Yai	Lam Phachi
Sedimentary rocks of Quaternary period	24.1	11.6	3.3	20.0
Sedimentary rocks of Tertiay period	1.5	3.9	1.4	0
Sedimentary rocks of Mesozoic era	10.4	7.8	19.6	2.8
Limestone of Mesozoic era	24.9	32.4	40.6	1.0
Igneous rocks of Mesozoic era	13.9	11.7	17.5	31.4
Sedimentary rocks of Paleozoic era	22.7	32.8	12.5	44.8
Metamorphic rocks of Proterozoic era	2.5	0.0	5.1	0

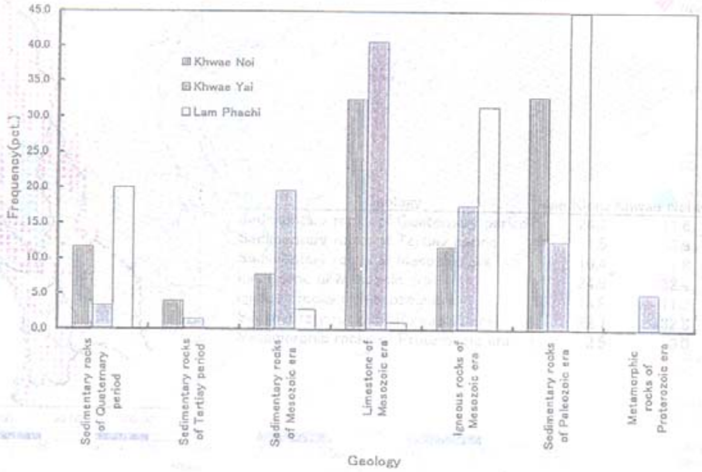
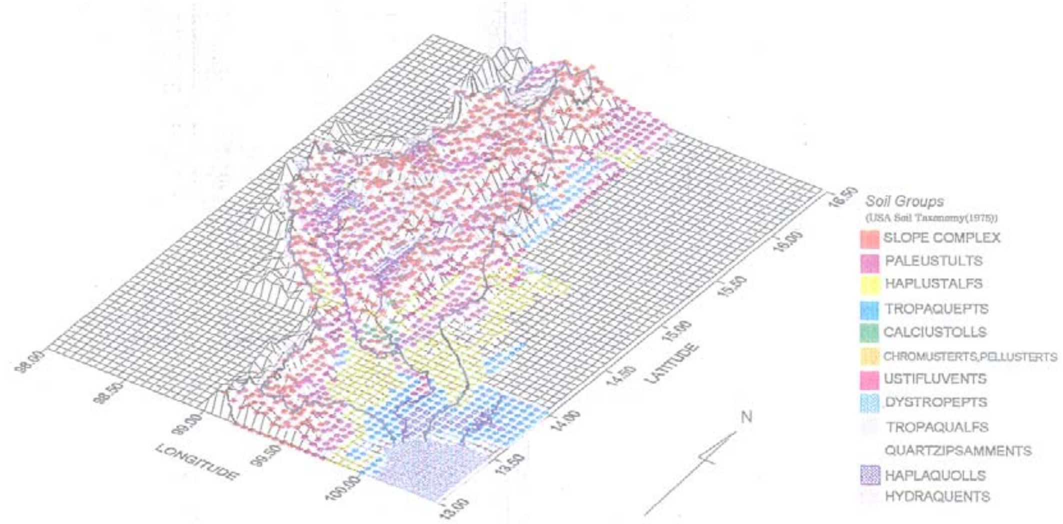
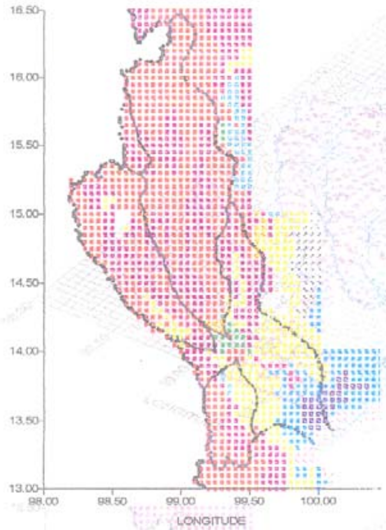


Fig. 9 Maps, diagram and table showing geological conditions for each watershed.





SOIL GROUPS	Mae Klong (%)	Khwae Noi (%)	Khwae Yai (%)	Lam Phach (%)
SLOPE COMPLEX	48.1	56.3	69.3	46.7
PALEUSTULTS	28.5	36.3	28.3	23.8
HAPLUSTALFS	14.2	7.4	0.7	25.7
TROPAQUEPTS	3.8	0	0	0
CALCIUSTOLLS	1.3	0	1.3	0
CHROMUSTERTS, PELLUSTERT	0.7	0	0.4	0
USTIFLUVENTS	0.8	0	0	0
DYSTROPEPTS	0.4	0	0	3.8
TROPAQUALFS	0	0	0	0
QUARTZIPSAMMENTS	0.3	0	0	0
HAPLAQUOLLS	1.5	0	0	0
HYDRAQUENTS	0.4	0	0	0
	100	100	100	100

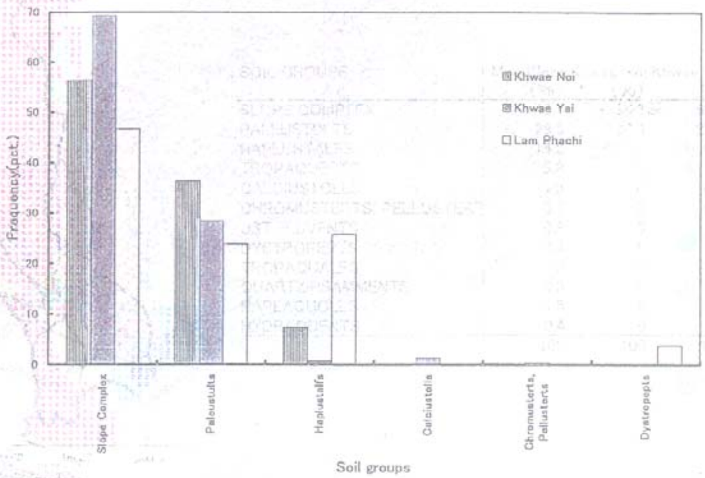
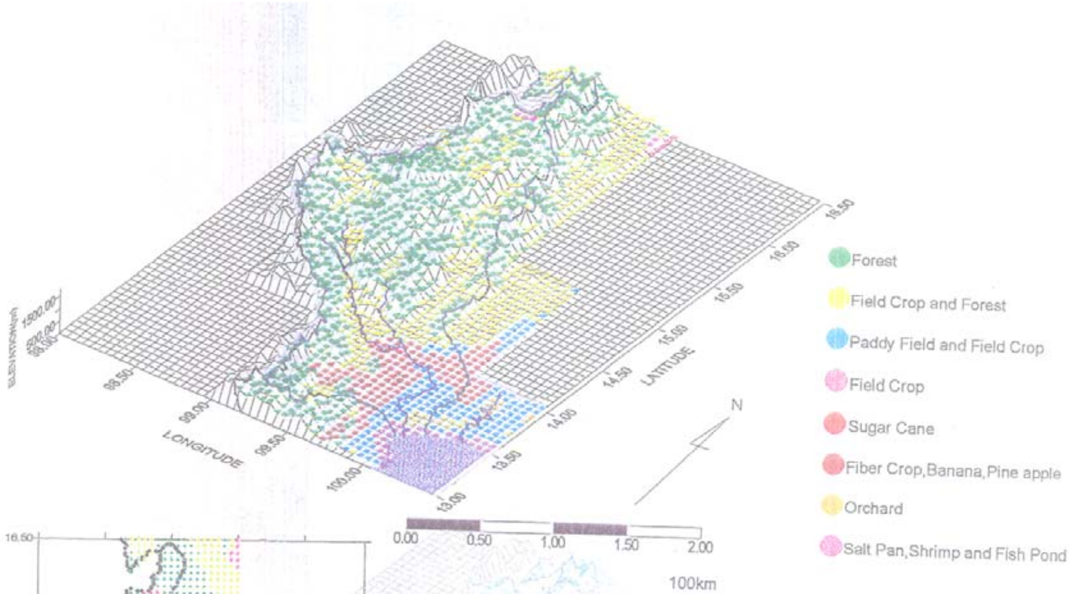
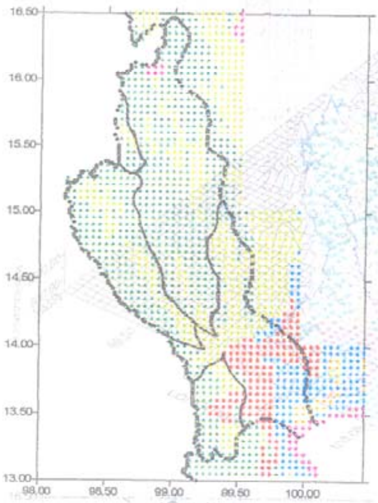


Fig. 10 Maps, diagram and table showing soil conditions for each watershed.





	Mae Klong (%)	Khwae Noi (%)	Khwae Yai (%)	Lam Phachi (%)
Forest	61.7	75.9	82.8	57.1
Field Crop and Forest	22.4	24.1	15.9	23.8
Paddy Field and Field Crop	4.5	0	0	0
Field Crop	0.6	0	1.3	0
Suger Cane	9.5	0	0	19.1
Fiber Crop, Banana, Pine apple	0.0	0	0	0
Orchard	0.7	0	0	0
Salt Pan, Shrimp and Fish Pond	0.6	0	0	0
	100	100	100	100

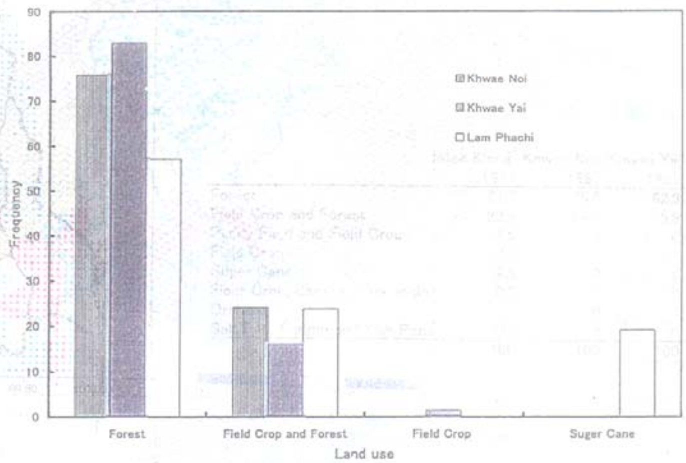


Fig. 11 Maps, diagram and table showing land use conditions for each watershed.

Table 3 Equations showing relationship between basin area and annual suspended sediment yield for main basins in Thailand

Basin name	Total Statoins	Basin area (km^2)	Equation S : ann. susp. sedi. yield A : basin area	R
Japanese basin	66	16-782	$S=882A^{0.943}$	0.633
Mae Klong	22	67-26,441	$S=21.61A^{1.223}$	0.949
Salawin	31	24-8,360	$S=14.81A^{1.296}$	0.942
MeKong	44	12-419,000	$S=20.20A^{1.196}$	0.968
Kok	22	51-10,300	$S=32.6A^{1.142}$	0.979
Chi	31	158-47,391	$S=56.24A^{0.989}$	0.904
Mun	35	61-117,000	$S=79.72A^{0.823}$	0.833
Ping	61	2-42,704	$S=12.96A^{1.219}$	0.971
Nan	15	90-25,294	$S=17.57A^{1.239}$	0.951
Pasak	8	67-14,522	$S=2132A^{0.575}$	0.804
Prachin Buri	11	45-7,502	$S=60.83A^{0.974}$	0.950
Bang Pa Kong	5	128-8,360	$S=4955A^{0.216}$	0.651
East Coast-Gulf	8	45-671	$S=707.2A^{0.678}$	0.599
Phetchaburi	4	264-2,207	$S=2.203A^{1.389}$	0.925
West Coast-Gulf	5	93-2,370	$S=7391A^{0.215}$	0.308
Peninsula East Coast	24	11-1,638	$S=30.97A^{1.146}$	0.823
Tapi	14	36-4,415	$S=173.6A^{0.914}$	0.898
Thale Sap Song Khla	8	14-1,562	$S=181.6A^{0.760}$	0.960
Peninsula West Coast	18	16-1,801	$S=57.37A^{1.081}$	0.863

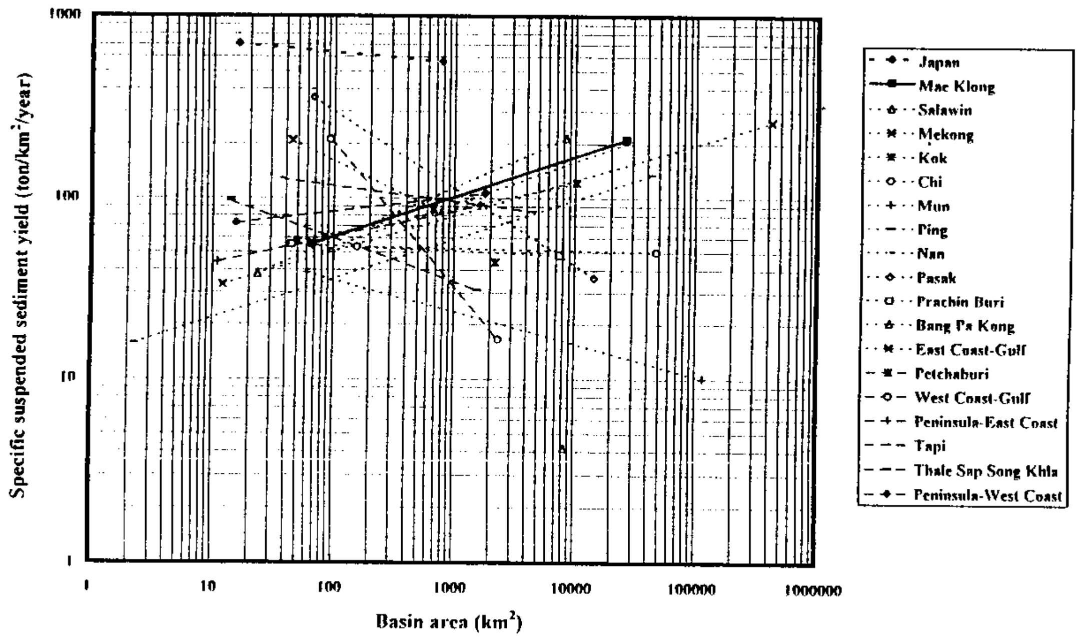


Fig. 12 Relationship between basin area and specific suspended sediment yield for main basins in Thailand.

4.3.2 Suspended sediment yield in Khwae Noi, Khwae Yai and Lam Phachi watershed

Table 4 shows a list of sediment measurement stations, basin area and annual mean suspended sediment yield in Mae Klong river basin. As a result of the regression analysis using mean annual suspended sediment and basin area data for each watershed, the following equations were obtained:

$S/A=36.8A^{0.24}$, R=0.930 for Khwae Noi watershed (308 km^2<A< 7,008 km^2)

$S/A=37.6A^{0.13}$, R=0.939 for Khwae Yai watershed (66.7 km^2<A< 14,037 km^2

$S/A=11.0\,A^{0.31}$, R=0.987 for Lam Phachi watershed (250 km^2<A< 1,355 km^2)

$S/A=21.61A^{0.22}$, R=0.949 for Mae Klong river basin (66.7 km^2< A < 26,441 km^2)

Where S/A is specific suspended sediment yield (ton/km^2/year), S is annual mean suspended sediment yield (ton/year), A is basin area (km^2) and R is correlation coefficient. As shown in Fig. 13, from the viewpoint of relationship between basin area and specific suspended sediment yield, Khwae Noi watershed has the highest value and Lam Phachi watershed has the lowest value in specific suspended sediment yield, while the exponent of the equation for Lam Phachi watershed has the highest positive value and for Khwae Yai watershed has the lowest positive value. This corresponds to the ratio of low land which is less than 200 mm (Fig.5) to the ratio of agricultural land (Fig.11) and also inversely corresponds to the ratio of forest land (Fig.11). The correspondence suggests that Lam Phachi watershed has plenty of suspended sediment sources than the other two watersheds because of agricultural activities in lowland areas. Lam Phachi watershed, however, is not so high in specific suspended sediment yield as the other two watersheds. Since the suspended sediment yield is calculated by using the suspended sediment rating curve, it considerably depends on water discharge as will be mentioned later. Therefore, less annual rainfall in Lam Phachi watershed (Fig.2) results into less annual suspended sediment yield though Lam Phachi watershed is considerably higher than the other watersheds in suspended sediment discharge against the same water discharge (Fig.14).

Table 4 List of sediment stations, basin area and annual mean suspended sediment yield

Watershed name	River name	Station Code	Location (Amphoe)	Period	Basin area (km^2)	Annual mean susp. sedi. yield (ton)	(*)
Khwae Noi	Khawe Noi	140801	Thong Pha Phum	1969.71-74	2,570	1,101,550	4
	Nam Mae Run	140802	Sangkhla Buri	1980	308	37,145	4
	Khawe Noi	141101	Sai Yok	1973-1994	6,512	1,867,074	2
	Khawe Noi	K.9	Sai Yok	1963-1973	6,902	4,016,098	1
	Khawe Noi	K.10	Sai Yok	1965-1991	7,008	808,004	1
Khwae Yai	Khawe Yai	140603	Si Sawat	1966-1971	5,530	389,772	4
	Huai Khlong Ngu	140604	Si Sawat	1968-1972	351	73,806	4
	Huai Wang Kiang	140903	Thong Pha Phum	1982	67	4,487	4
	Khawe Yai	140403	Thong Pha Phum	1979-86,88-91	4,960	615,578	2
	Khawe Yai	140201	Si Sawat	1973-1978	5,644	912,795	2
	Khawe Yai	140601	Si Sawat	1969-1975	10,500	1,870,306	2
	Khawe Yai	140703	Muang	1973-1974	11,352	1,759,922	2
	Khawe Yai	140702	Muang	1973-1976	14,037	2,580,189	2
	Khawe Yai	K.6	Si Sawat	1952-1972	10,001	1,792,826	1
	Khawe Yai	K.20	Si Sawat	1967-1975	11,184	1,330,359	1
	Lam Taphoen	K.27	Bo Phioi	1978-1985	1,921	31,920	1
Lam Phachi	Lam Phachi	K.17	Suan Phung	1978-1986	1,355	127,693	1
	Huai Tha Khoei	K.25	Suan Phung	1991-1993	482	44,223	1
	Huai Tha Khoei	K.25A	Suan Phung	1994-1995	250	13,367	1

Remark (*) 1=Dtata from Royal Irrigation Department (RID)
2=DData from Electricity Generating Authority of Thailand (EGAT)
4=Data from Department of Energy Development and Promotion (DEDP)

Fig.14 shows suspended sediment rating curves showing suspended sediment discharge against water discharge. Equations representing Khwae Noi and Khwae Yai watersheds are obtained by using data from 1978 to 1991 of K10 station in Khwae Noi watershed and from 1988 to 1991 of 140403 station at Nam Chon in Khwae Yai watershed. Two equations representing Lam Phachi watershed are obtained by using data between 1994 and 1995 at K25A station and between 1980 and 1986 at K17 station respectively. As shown in Fig. 14, suspended sediment rating curves of Khwae Yai watershed exists within the range of scattering in the rating curves of Khwae Noi watershed, which suggests that Khwae Noi watershed is not so different from Khwae Yai watershed in suspended sediment production. Whereas Lam Phachi watershed is significantly different from Khwae Noi and Khwae Yai watersheds in that it has considerably higher suspended sediment discharge than the other watersheds against the same water discharge. This suggests that the suspended sediment is produced easily in Lam Phachi watershed as compared with the other watersheds because it has many sediment sources in lowland areas due to production activities of agricultural land. This result is well in agreement with the interpretation of the exponent in the equation of specific suspended sediment yield as mentioned before. Therefore, the exponent of the equation could be a clue to consider where sources of suspended sediment are in a basin. However, it should be verified by the analysis based on more data and examples in the future.

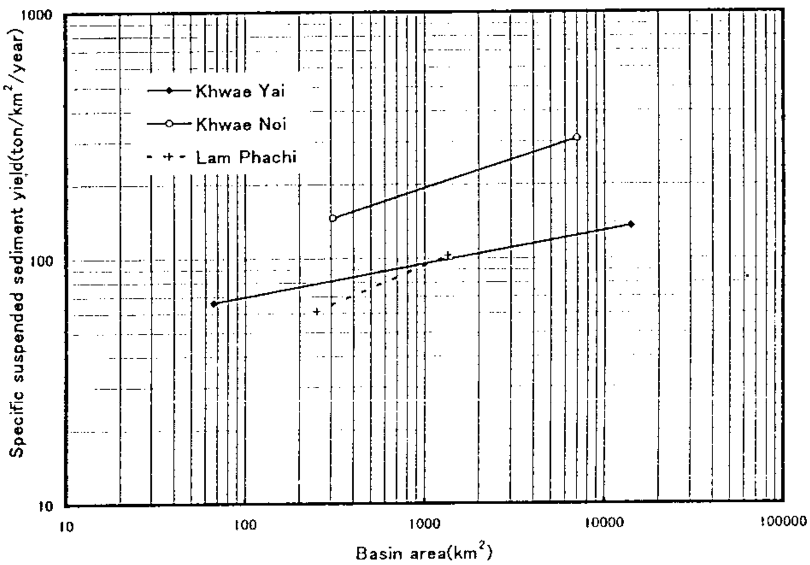


Fig. 13 Relationship between basin area and specific suspended sediment yield for Khwae Noi, Khwae Yai and Lam Phachi watersheds.

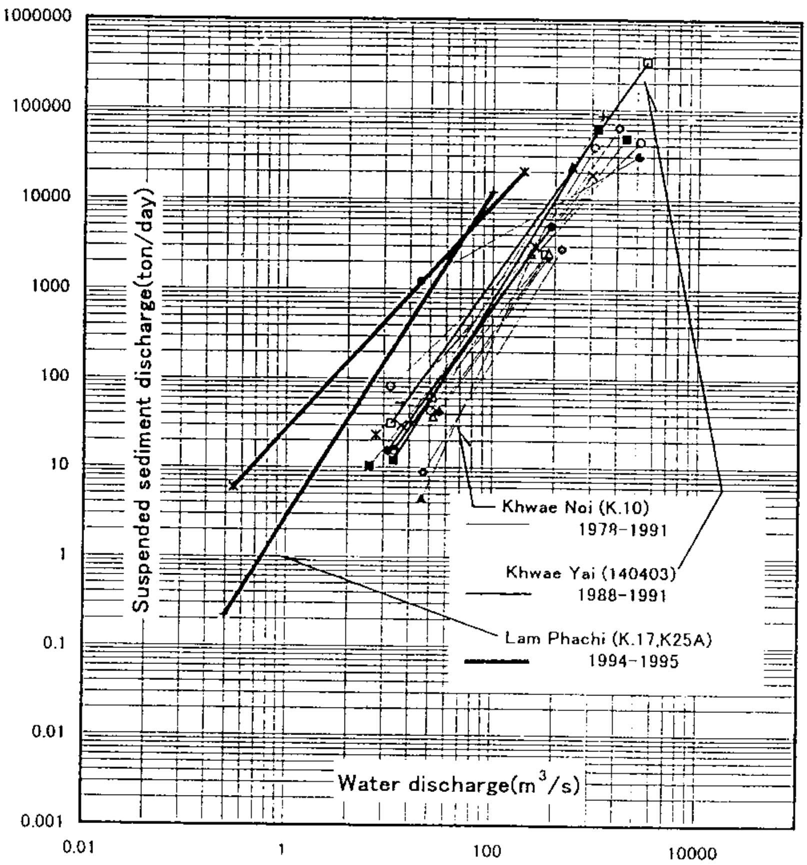


Fig. 14 Suspended sediment rating curves for Khwae Noi, Khwae Yai and Lam Phachi watersheds.

5. CONCLUSIONS

Mae Klong river basin is abundant in forest kept in good conditions as compared with other basins in Thailand as it had the forest coverage ratio of 53% in 1988, while the figure for whole Thailand was 28% in same year. As a result of the analysis on the relationship between basin area and annual suspended sediment yield, however Mae Klong river basin is not so low in suspended sediment yield as other Thai basins, it is rather high considering its larger watershed area.

Lam Phachi watershed is different from Khwai Noi and Khwae Yai watersheds in rainfall, geology, relative relief, drainage density, agricultural land ratio and forest land ratio. That is to say, annual rainfall is not so high, relative relief and drainage density related to steep slope is high, agricultural land ratio is high but forest land ratio is low. In this way most factors controlling watershed conditions with the exception of rainfall suggest that suspended sediment production occurs easily in Lam Phachi watershed as compared with the other watersheds.

The exponent of the equation in specific suspended sediment yield corresponds to relative relief, low land ratio and agricultural land ratio, and corresponds inversely to forest land ratio. According to analysis of suspended rating curves, suspended sediment production occurs easily in Lam Phachi watershed which has the highest value of the exponent as compared with the other watersheds. Taking into account characteristics of Lam Phachi watershed, the exponent of the equation could be a clue to consider where sources of suspended sediment are in a basin though it should be confirmed by the analysis based on more data and examples in the future. Roughly speaking, if the exponent's value is negative, it could suggest that the source of suspended sediment decreases with basin area or the sink increases with basin area, whereas if the value is positive it could suggest the source increases with basin area. Mae Klong river basin has a positive exponent value of 0.22, which suggests that lowland areas where much agricultural land is located, has plenty of suspended sediment sources than upland areas which are almost covered with forest.

Finally, if we consider the results of this study from the viewpoint of soil erosion control, in Mae Klong river basin it is necessary to protect the remaining forest in upland areas for preventing the increase of sediment sources and to conserve the soil of cultivated land in lowland areas for decreasing sediment sources, though currently, erosion and sedimentation problems are not serious in the basin. To address the issues of protection or conservation in the basin, we must fully understand on-site and off-site effects of erosion and their interrelation as well as relationship among the effects, rainfall, watershed characteristics and particularity activities in agricultural land and forest land. However, these could be topics for future studies.

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