CHAPTER 4

DEBRIS FLOW-FLOOD HAZARD ANALYSIS IN NAM KO YAI SUB-CATCHMENT

In this chapter, debris flow-flood hazard analysis in Nam Ko Yai sub-catchment is conducted from the significant and cost-effective information on flow-flood as previously mentioned in Chapter 3. Trends in landslide hazard analysis are briefly presented and the detailed statistical analysis of flow-flood susceptibility in Nam Ko Yai sub-catchment are proposed in detail as follows.

4.1 Trends in landslide hazard zonation

A large amount of researches on hazard zonation has been done in the last three decades through the world as a consequence of an urgent demand for slope instability hazard mapping. Overviews of the various slope instability hazard zonation techniques can be found in the works of, for examples, Hansen (1984), Varnes (1984), Hartlen and Viberg (1988). The general trends in landslide hazard zonation are given in Table 4-1. The distribution analyses and qualitative analyses are generally used for the very large areas with very low detail such as national hazard maps. The deterministic and frequency analyses are used generally for very small areas, such as areas of specific large engineering projects like dams, nuclear power plants, highway strips, open-pit mine slopes and spoils. Monitoring and laboratory analyses are indispensable for these analyses. There are many studies involving landslide hazard evaluation (Gokceoglu and Aksoy 1996; Larsen and Torres-Sanchez 1998; Turrini and Visintainer 1998; Guzzetti and others 1999; Lee 2000, Lee and Min, 2001). In particular, Guzzetti and others (1999) summarized many cases of landslide hazard evaluation studies.

4.2 Debris flow-flood susceptibility analysis

According to the landslide analysis method, there are three steps (Einstein, 1988) in landslide risk analysis, i.e. susceptibility, possibility, and risk, as specified in formulas 1, 2 and 3 below.

Susceptibility = f (landslide, landslide-related parameters) .... (1)

Possibility = f (susceptibility, impact parameters) .... (2)

Risk = f (possibility, damageable objects) .... (3)

Table 4-1 Trends in landslide hazard zonation (Van Westen, 1993).

Type of landslide hazard analysis	Main characteristics
A. Distribution analysis	Direct mapping of mass movement features resulting in a map, which gives information only for those sites where landslides have occurred in the past.
B. Qualitative analysis	Direct, or semi-direct, methods in which the geomorphological map is re-numbered to a hazard map, or in which several maps are combined into one using subjective decision rules, based on the experience of the earth scientist.
C. Statistical analysis	Indirect methods in which statistical analyses are used to obtain predictions of the mass movement hazard from a number of parameter maps.
D. Deterministic analysis	Indirect methods in which parameter maps are combined in slope stability calculations.
E. Landslide frequency analysis	Indirect methods in which earthquake and/or rainfall records or hydrological models are used for correlation with known landslide dates, to obtain threshold values with a certain frequency.

The susceptibility is a function of the probability of potential landslide occurrence and landslide-related factors. It does not depend on impact factors such as rainfall, earthquake, or human activity. The possibility depends on the impact parameters and the susceptibility. The risk depends on vulnerable objects such as people and property, and on the possibility. Of these three, only the first is further considered in details, and only flow-flood's that occurred as a result of heavy rain are discussed here.

For the flow-flood susceptibility analysis only in Nam Ko Yai sub-catchment of the study area was selected according to the scar-scouring locations (hereafter referred to as scar-scouring) from flow-flood occurrence were clearly detected whereas the alluvial fan of resulting depositional locations was not included in the analysis. Accurate detection of the scar-scouring that mainly occurred in Nam Ko Yai sub-catchment was very important. According to significant and cost-effective information on the flow-flood hazard assessment as discussed in Chapter 3, the medium scale (1:25,000-1:50,000) was chosen. Theoretically, statistical techniques were dominantly used in this scale.

In general, statistical techniques are the indirect methods in which statistical analyses are used to obtain predictions of the mass movement hazard from a number of parameter maps. The statistical or probabilistic approach is based on the observed relationship between each parameter and the past and present landslide distribution. The strong point of this functional approach is also directly dependent on the quality and quantity of the data collected. Drawbacks are derived from the fact that few parameters are relevant for landslide assessment and are mappable at a reasonable cost. The statistical approach, in turn, can be applied following different techniques which essentially differ on the statistical procedure used (univariant or multivariant), and on the type of mapping-unit selected. The conceptually (but not operationally) simplest technique is a conditional analysis which attempts to assess the probabilistic relationship between relevant environmental parameters and the occurrence of landslides in a given region.

In this part, the flow-flood susceptibility analysis was preliminary analyzed by using univariant probability analysis (Lee and Min, 2001) which is further explained below.

4.2.1 Susceptibility analysis using univariant probability method

Flow-flood susceptibility in this thesis was preliminary analyzed by univariant probability method to present the spatial relationship between the scar-scouring locations and each of available flow-flood influencing parameters (as theoretically mentioned by Van Westen (1994) in Chapter 2 and conducted in Chapter 3) in Nam Ko Yai sub-catchment, namely, slope, landform topography, geology, soil group unit, soil thickness, land cover, and stream proximity, respectively. The GIS was used to compile a vast amount of data efficiently, and a statistical program was used to maintain specificity and accuracy. A key assumption using this approach is that the potential (occurrence possibility) of flow-flood processes would be comparable to the actual frequency of flow-flood processes and relationships between each parameter are independent. The results of the statistic analysis were later verified in detail by using the field and laboratory evidence data in the Chapters 5 and 6.

For the univariant probability method to present the spatial relationship between the detected scar-scouring locations and each of the mentioned flow-flood influencing parameters in Nam Ko Yai sub-catchment, the spatial data were converted to a 10 x 10 m grid or cell (ARC/INFO GRID type), then further converted to ASCII data for a use with a general statistical program. For Nam Ko Yai sub-catchment, the total number of cells are 690,509 while the detected scar-scouring number of cells are 47,774. The correlation ratios were performed on the relationship between the detected scar-scouring locations and each parameter's range. The ratio between the number of the detected scar-scouring cell numbers (hereafter to be called b, for convenience) and the number of the non-detected scar-scouring cell numbers (hereafter to be called a, for convenience) was calculated as probability of flow-flood susceptibility in each parameter's range. The b/a ratio equal 1 defines an average value, greater than 1 means a high correlation, and less than 1 means a low correlation. A high correlation indicates a high probability of the flow-flood susceptibility in each flow-flood influencing parameter. Such relationships in Nam Ko Yai sub-catchment were briefly concluded in below.

4.2.1.1 Relationship between scar-scouring and slope

Theoretically, the slope angle is an essential component in slope stability analysis. As the slope angle critically increases, shear stress in soils or other unattached materials along a potential failure plane tend to increase as well. Gentler slope is expected to have a low frequency of scar-scouring locations because of generally lower shear stress associated with low gradient.

For slope as a parameter, the frequencies of recent scar-scouring number of cells for a given interval of slope angle were noted as shown in Figures 4-1, 4-2 and 4-3 and Table 4-4. The frequencies were determined by counting the scar-scouring number of cells for each 5 degree interval of slope angle, then ratios of pixel which scar-scouring were detected and pixel which scar-scoring are not detected (hereafter to be called b/a ratio, for convenience) were calculated. The b/a ratio indicated the susceptibility or probability of each interval of slope angle to flow-flood.

For area in slope below 5 °, the b/a ratio was 2.76, indicating a very high probability. From 5 to 10 °, the b/a ratio was 1.08, indicating a moderately probability also. From 10 to 30 °, the b/a ratio was in the range of 0.68-0.84, indicating a low probability. From 30 to 35 °, the b/a ratio was 1.06, indicating a moderate probability. From 35 to 40 ° and above 40 °, the b/a ratios were 1.43 and 1.54, respectively, indicating a high probability. It means that scar-scouring probability increases according to slope angle. If the slope angle is higher than 30 °, scar-scouring may occur.

It was generally noted in Nam Ko Yai sub-catchment that the steeper slope, the greater the flow-flood probability. But it was also noted that the flow-flood probability is commonly a high correlation in a gentle terrain with the slope below 5°. This was especially in the clear and opened area along Nam Ko Yai stream channel and its banks. So, this could be an effect of other parameters beyond the slope inclination alone.

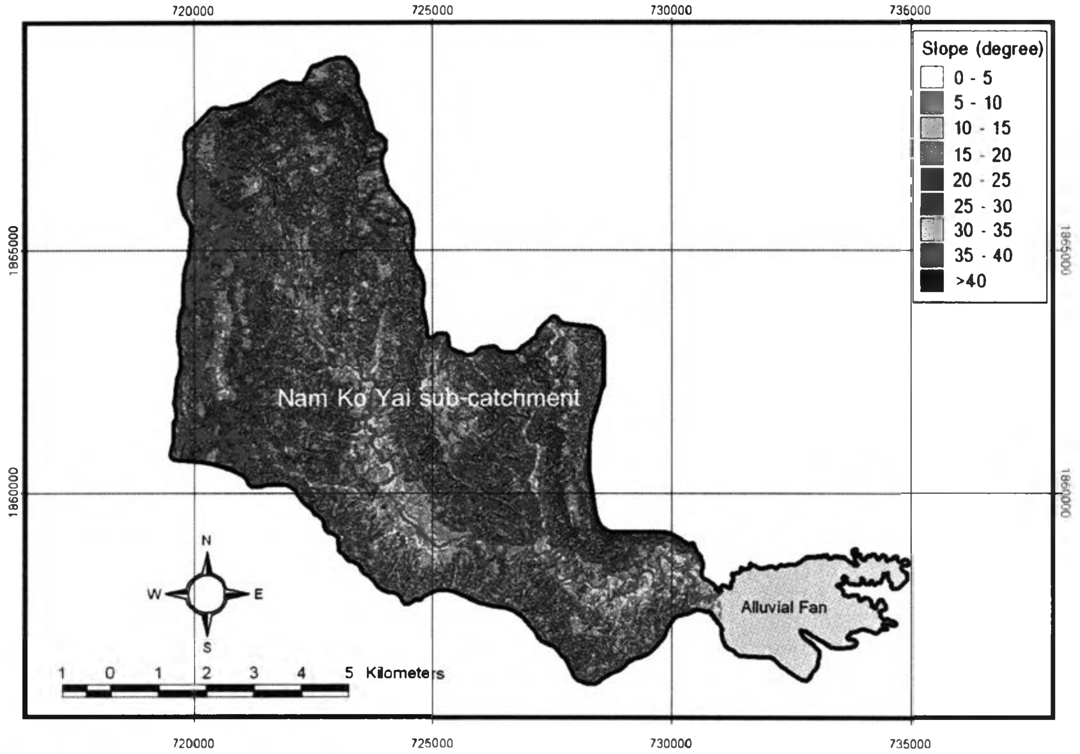


Figure 4-1 Slope map overlain with scars-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

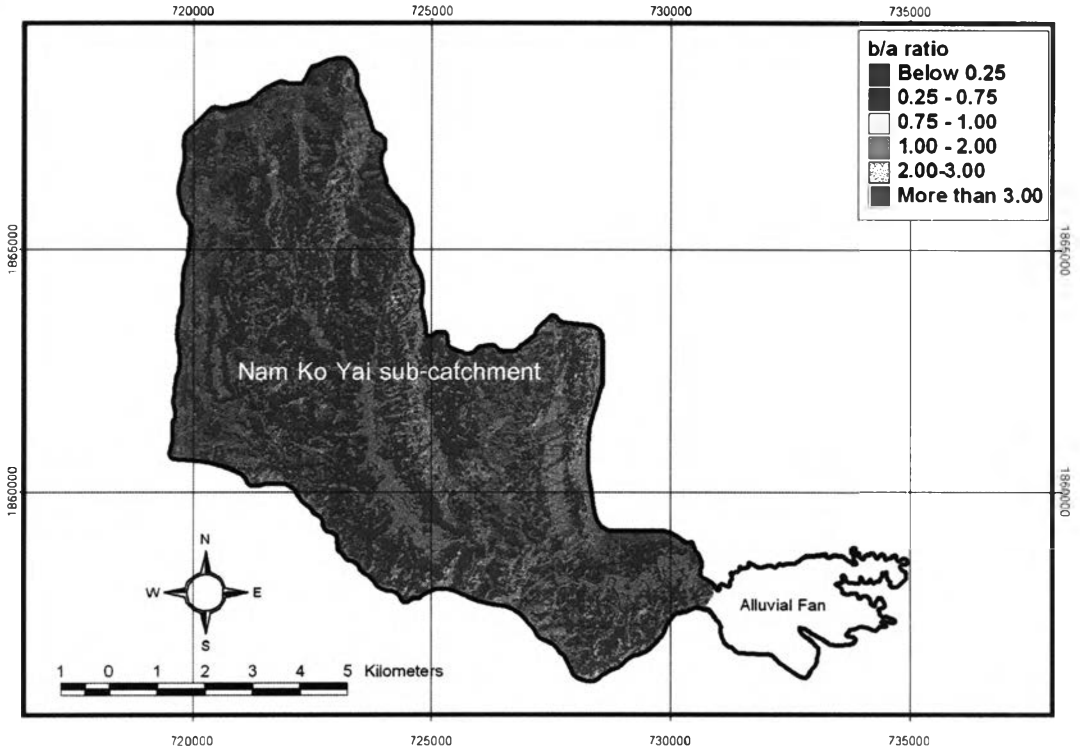
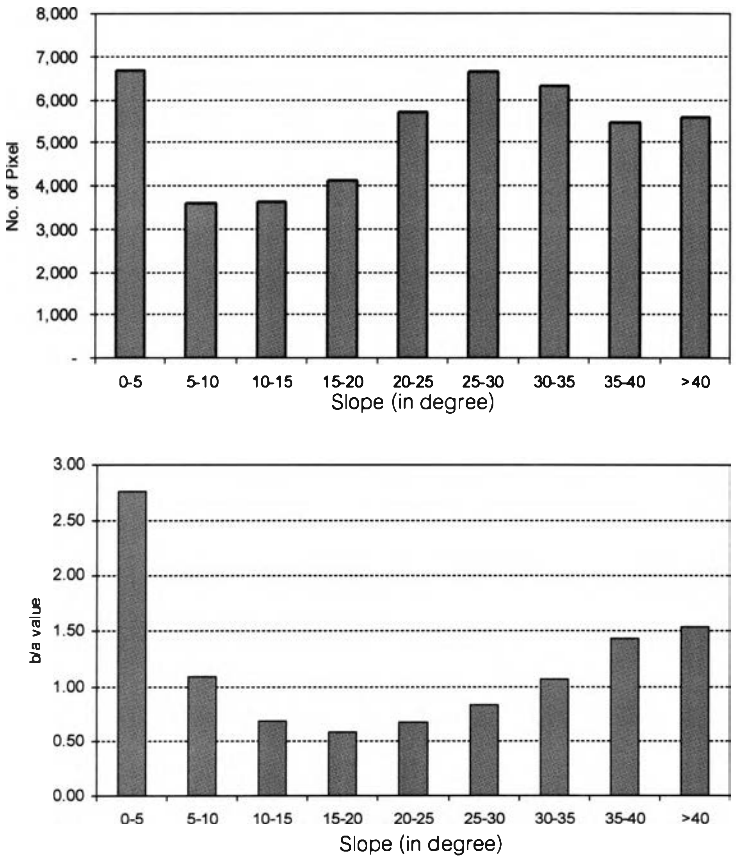


Figure 4-2 Map illustrating b/a ratio as probability of flow-flood susceptibility on slope in Nam Ko Yai sub-catchment.

Table 4-2 Relation of flow-flood and slope in Nam Ko Yai sub-catchment.

Slope range	Scar-scouring did not occur		Scar-scouring occurred		b/a
	Count	Ratio (%) a	Count	Ratio (%) b	
0-5 °	32,671	5.08	6,701	14.03	2.76
5-10°	44,684	6.95	3,596	7.53	1.08
10-15 °	71,342	11.10	3,629	7.60	0.68
15-20 °	94,386	14.69	4,133	8.65	0.59
20-25°	112,870	17.56	5,706	11.94	0.68
25-30 °	106,687	16.60	6,666	13.95	0.84
30-35 °	79,874	12.43	6,309	13.21	1.06
35-40 °	51,394	8.00	5,452	11.41	1.43
More than 40 °	48,827	7.60	5,582	11.68	1.54
Total	642,735	100.00	47,774	100.00	



a) Distribution of scar-scoring cell numbers on slope.

b) b/a ratio on slope.

Figure 4-3 Histogram distribution of a) scar-scoring number of cells on slope, and b) b/a ratio on slope in Nam Ko Yai sub-catchment.

4.2.1.2 Relationship between scar-scouring and landform topography

In the case of landform topography, the frequencies were determined by counting the scar-scoring number of cells for a giver topographic shape unit (namely, peak, ridge, saddle, flat, ravine, pit, convex hillside, concave hillside, slope hillside, inflection hillside and saddle hillside) and presented in Figures 4-4, 4-5 and 4-6 and Table 4-3.

It was noted that a very high probability was observed in flat landform that the b/a ratio was 5.05. A high probability was observed in saddle and pit landforms that the b/a ratios were 2.37 and 2.30, respectively. A moderate probability was generally observed in concave hillside, inflection hillside, slope hillside, ridge and ravine landforms that b/a ratios were in the range of 1.08-1.26. Whereas a low probability was only observed in convex hillside landform that the b/a ratio was 0.96.

It is concluded that the flow-flood probability was commonly a high correlation with the specific type of flat landform that especially was in the clear and opened area along Nam Ko Yai stream channel and its banks of the flat landform.

In the case of slope and landform topography as mentioned above, it is generally concluded that the flow-flood probability is commonly a high correlation with the area in slope below 5 ^{o} and flat landform in Nam Ko Yai sub-catchment. The slope and landform topography are summarized to be ones of the significant relevant parameters to the flow-flood occurrence that will be later used to calculate the debris flow-flood susceptibility.

4.2.1.3 Relationship between scar-scouring and aspect

In case of aspect or direction that a slope facet, the frequencies were determined by counting the scar-scouring cell number for a given slope aspect and presented in Figures 4-7, 4-8 and 4-9 and Table 4-4. Theoretically, the aspect is an essential component in slope stability analysis because some directions of slope facets

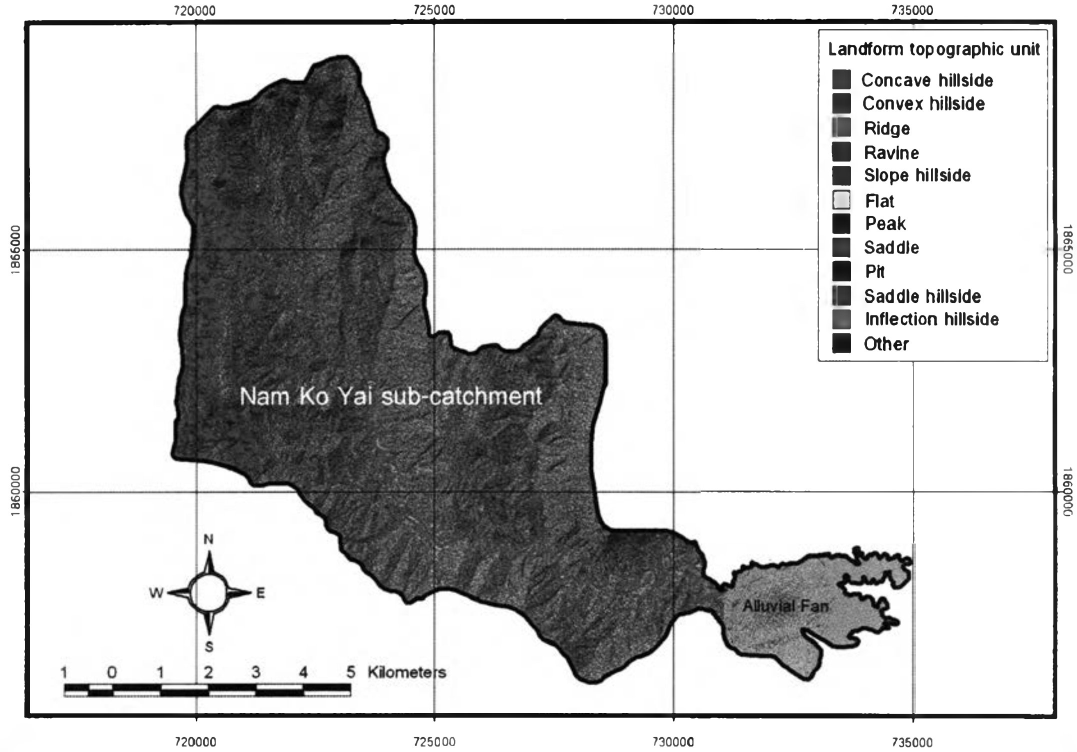


Figure 4-4 Landform topography overlain with scar-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

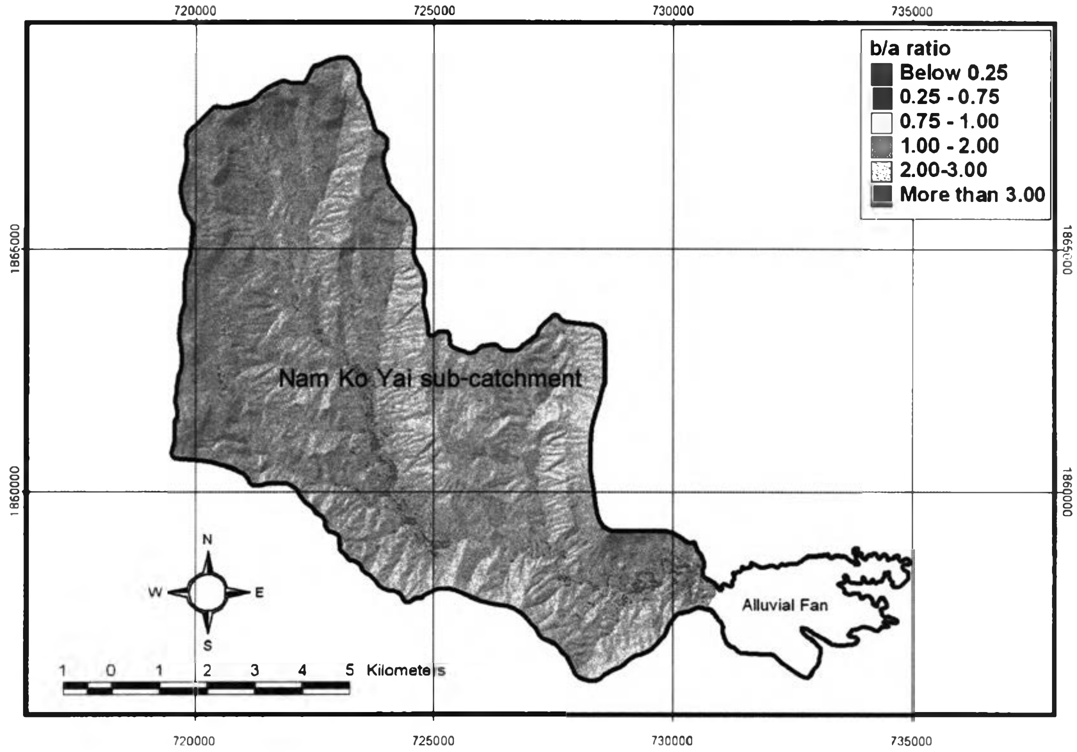


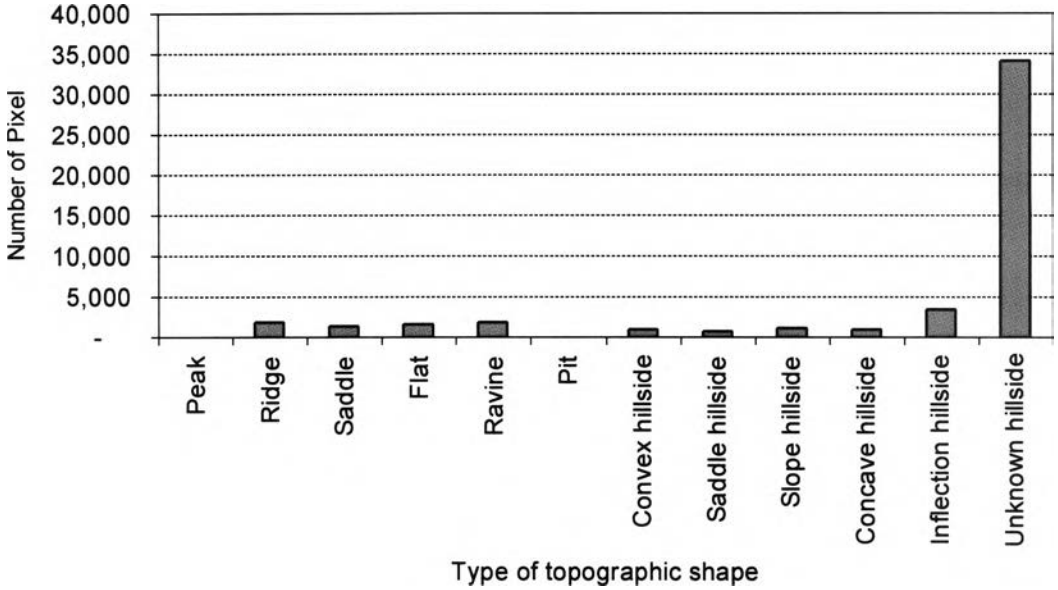
Figure 4-5 Map illustrating b/a ratio as probability of flow-flood susceptibility on landform topography in Nam Ko Yai sub-catchment.

Table 4-3 Relation of flow-flood and landform topography in Nam Ko Yai sub-catchment.

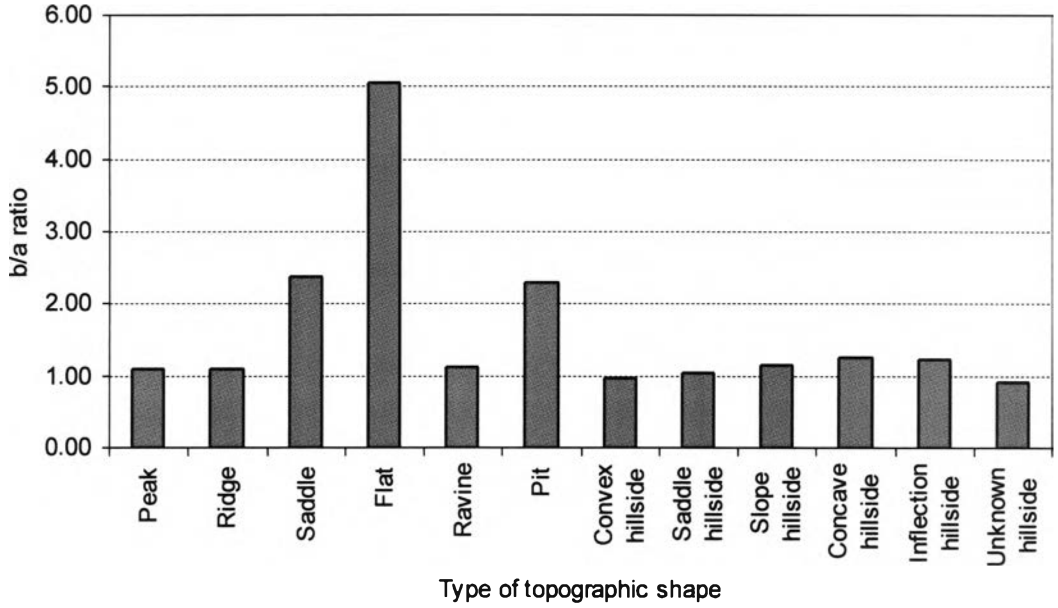
Topography shape	Scar-scouring did not occur		Scar-scouring occur		b/a
	Count	Ratio (%), a	Count	Ratio (%), b	
Peak	767	0.12	63	0.13	1.11
Ridge	23,608	3.67	1,902	3.98	1.08
Saddle	7,126	1.11	1,253	2.62	2.37
Flat	4,500	0.70	1,689	3.54	5.05
Ravine	20,690	3.22	1,731	3.62	1.13
Pit	473	0.07	81	0.17	2.30
Convex hillside	11,581	1.80	826	1.73	0.96
Saddle hillside	8,551	1.33	656	1.37	1.03
Slope hillside	14,091	2.19	1,192	2.50	1.14
Concave hillside	9,236	1.44	867	1.81	1.26
Inflection hillside	37,737	5.87	3,412	7.14	1.22
Unknown hillside	504,375	78.47	34,102	71.38	0.91
Total	642,735	100.00	47,774	100.00	

may be conformed to the attitudes of geological structures (bedding, faults or fracture planes) of potential failure planes. So shear stress in soils or other unattached materials along a potential failure plane in an aspect tends to increase as well.

A moderate probability was observed in east, southeast and south aspect directions that the b/a ratios were 1.82, 1.44 and 1.11, respectively. Whereas a low probability was generally observed in southwest, northeast, north, west and northwest aspect directions that the b/a ratio were 0.84, 0.73, 0.31, 0.30 and 0.22, respectively. So it is concluded that debris flow and debris flood occurrence probability value is lower dependent on the aspect.



a) scar-scoring cell numbers on landform topography



b) b/a ratio on landform topography

Figure 4-6 Histogram distribution of a) scar-scoring number of cells on landform topography, and b) b/a ratio on landform topography in Nam Ko Yai sub-catchment.

It is noted that a very high probability was only observed in flat aspect that the b/a ratio was 4.84. So the flow-flood probability is commonly a high correlation only with the flat area in Nam Ko Yai sub-catchment that especially was in the clear and opened area along Nam Ko Yai stream channel and its banks as previous mentioned in the relationship between scar-scouring and landform topography. It is also concluded that the aspect is not one of the significant relevant parameters to the flow-flood occurrence and will not be later used to calculate the debris flow-flood susceptibility.

4.2.1.4 Relationship between scar-scouring and geology

Considering the geology of Nam Ko Yai sub-catchment, the frequencies of recent scar-scouring cell number for a given rock unit were analyzed as shown in Figures 4-10, 4-11 and 4-12 and Table 4-5. The probability was noted in the rock units in the sub-catchment from the lower to the upper. For area underlain by Lom Kao Formation (Lk), the b/a ratio was 0.08, indicating a very low probability. For area underlain by Lom Sak Formation (Ls), the b/a ratio was 0.44, indicating a very low probability. For area in Phu Kradung (Pk) the b/a ratio was 2.07, indicating a very high probability. For area in Phra Wihan Formation (Pw), the b/a ratio was 2.77, indicating a very high probability. For area in Phu Phan Formation (Pp), the b/a ratio was 0.17, indicating a very low probability. For area in fluvial deposits (Qa1), the b/a ratio was 2.98, indicating a very high probability.

It was noted in the areas of fluvial deposits (Qa1) consisting of mainly stream deposits, composing of river sands and gravels, silts, clays and gray soils in the middle of the sub-catchment; Phra Wihan Formation (Pw) comprising of gray sandstone, tuffaceous siltstone, and red shale; and Phu Kradung Formation (Pk) conposing of red siltstone, conglomeratic sandstone, tuffaceous sandstone and siltstone in western and northern steep-cliff areas, indicating the very high probabilities for the flow-flood occurrence in the most units. The general lithology of low-resistant beds of fluvial deposits (Qa1) and Phu Kradung Formation (Pk), together with other parameters, perhaps play an important role on the flow-flood creation as well.

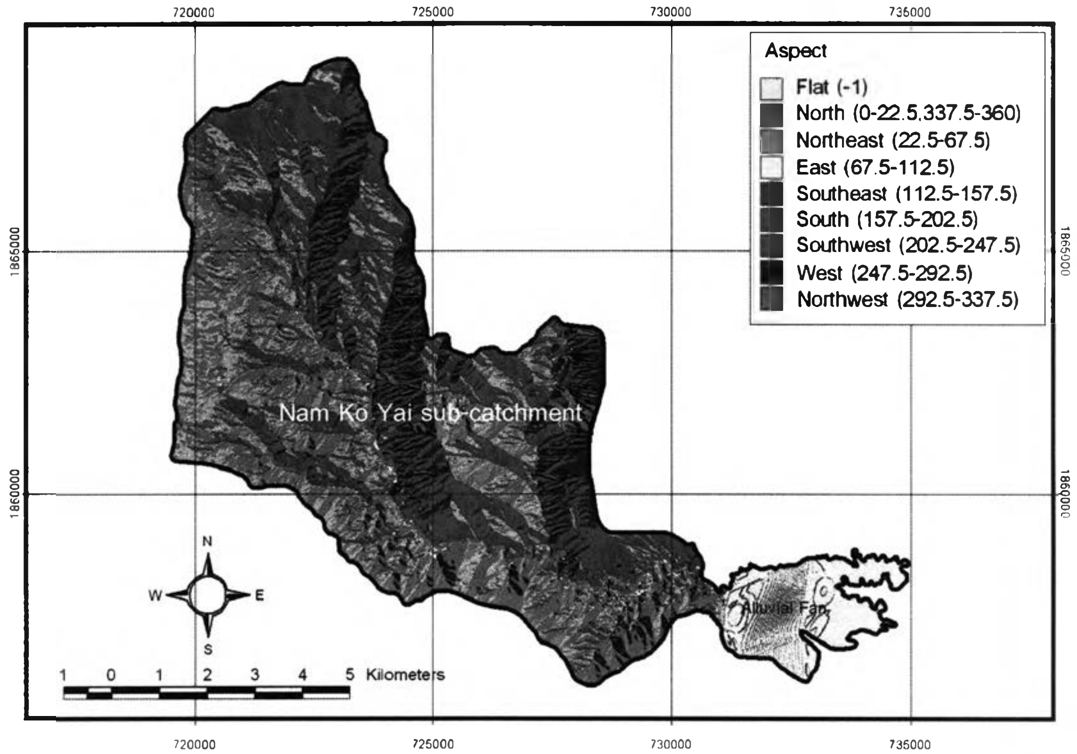


Figure 4-7 Aspect overlain with scar-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

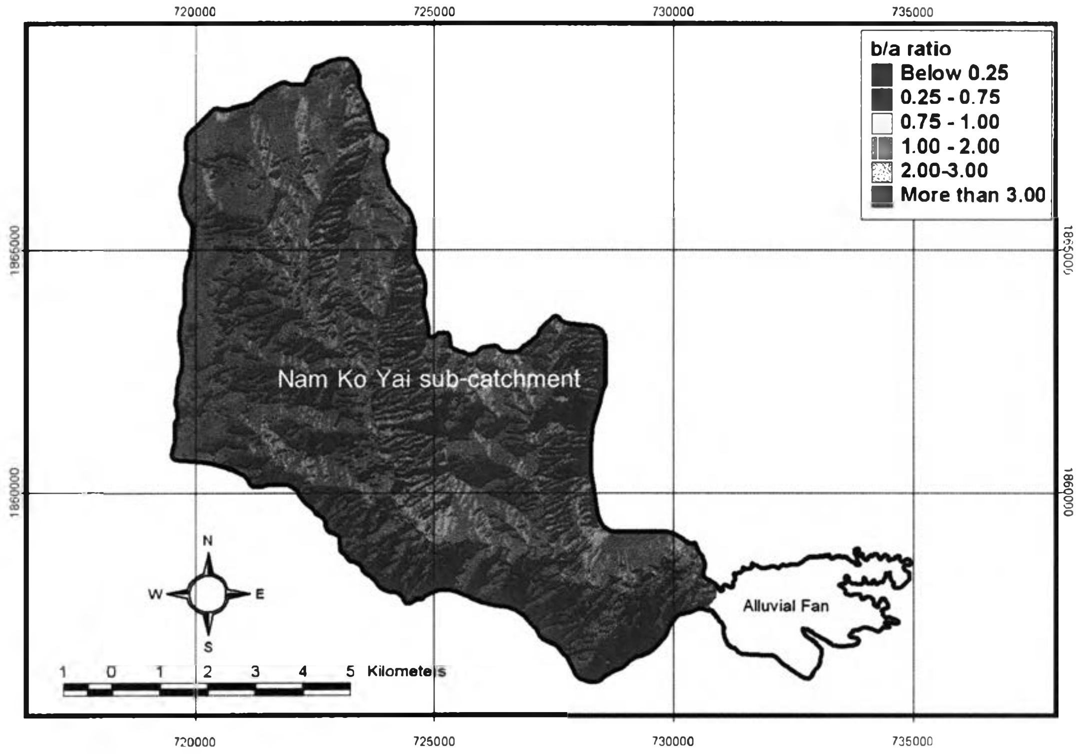
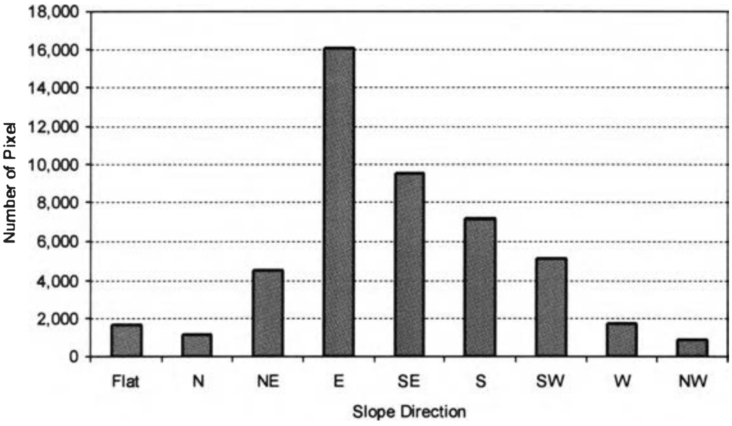


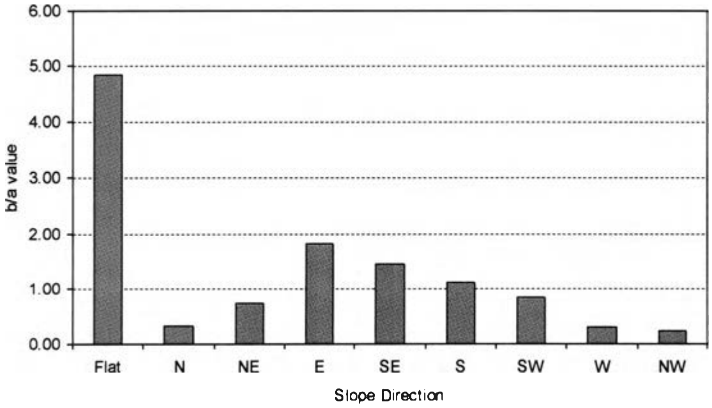
Figure 4-8 Map illustrating b/a ratio as probability of flow-flood susceptibility on aspect in Nam Ko Yai sub-catchment.

Table 4-4 Relation of flow-flood and aspect in Nam Ko Yai sub-catchment.

Aspect direction	Scar-scouring did not occur		Scar-scouring occur		b/a
	Count	Ratio (%) a	Count	Ratio (%) b	
Flat	4,553	0.71	1,639	3.43	4.84
North	51,632	8.03	1,187	2.48	0.31
Northeast	82,971	12.91	4,497	9.41	0.73
East	118,602	18.45	16,073	33.64	1.82
Southeast	88,871	13.83	9,535	19.96	1.44
South	86,917	13.52	7,200	15.07	1.11
Southwest	81,453	12.67	5,103	10.68	0.84
West	74,957	11.66	1,678	3.51	0.30
Northwest	52,779	8.21	862	1.80	0.22
Total	642,735	100.00	47,774	100.00	



a) scar-scoring cell numbers on aspect.



b) b/a ratio on aspect.

Figure 4-9 Histogram distribution of a) scar-scoring number of cells on aspect, and b) b/a ratio on aspect in Nam Ko Yai sub-catchment.

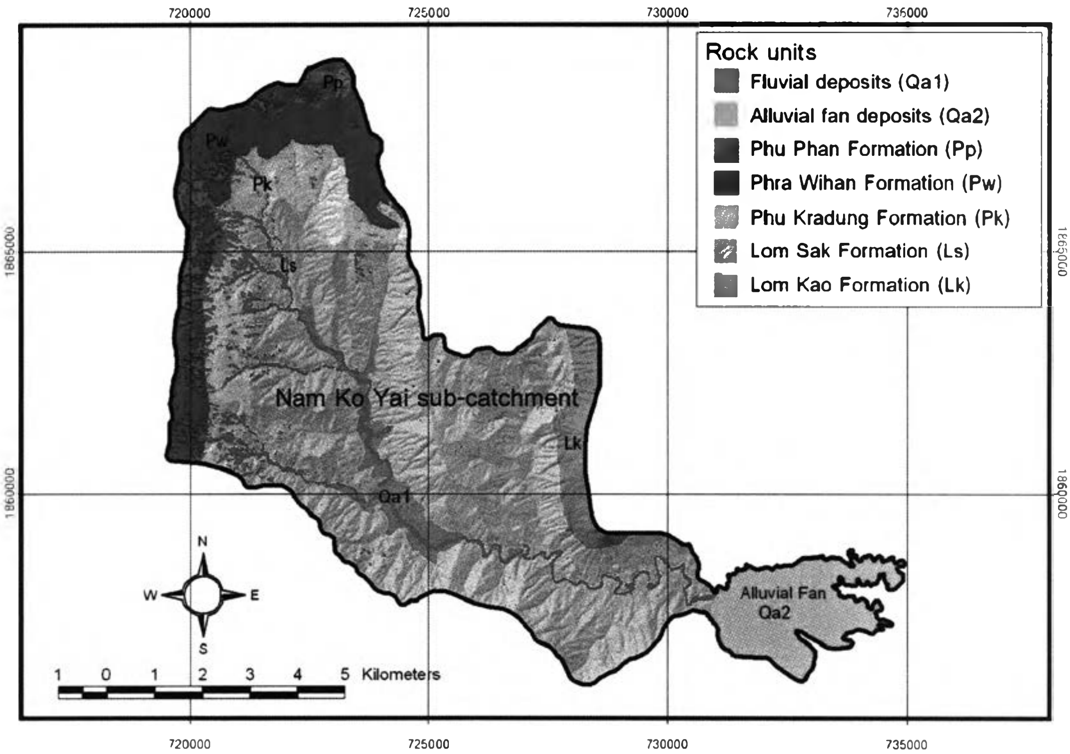


Figure 4-10 Geologic map overlain with scar-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

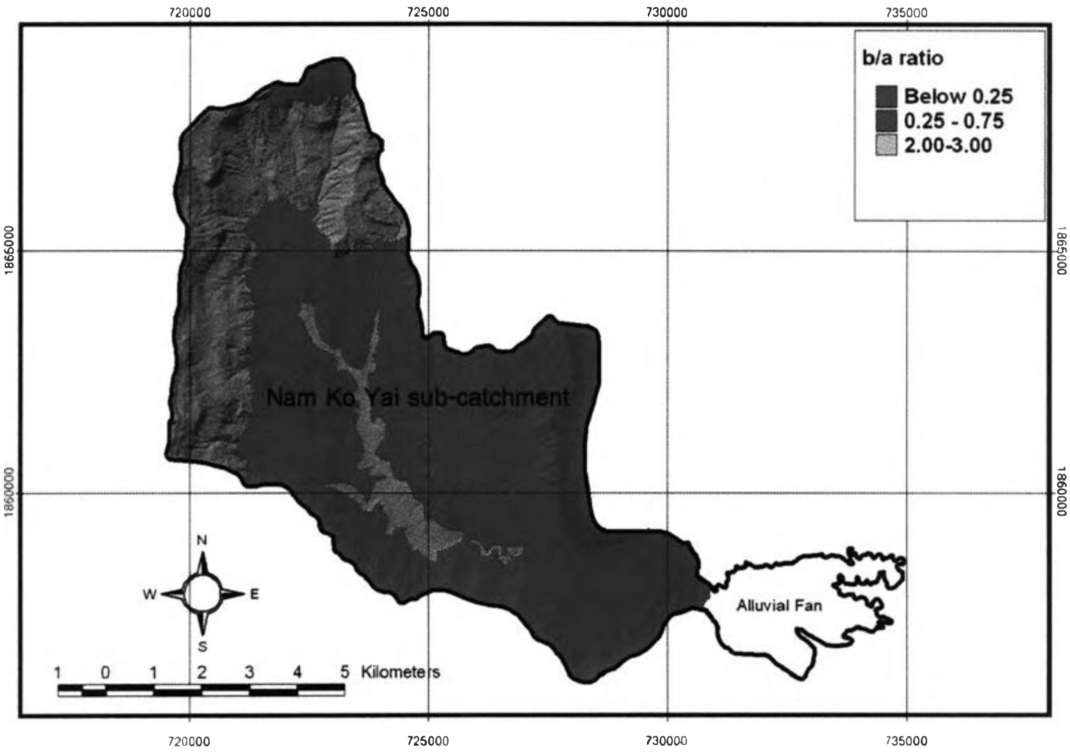


Figure 4-11 Map illustrating b/a ratio as probability of flow-flood susceptibility on geology in Nam Ko Yai sub-catchment.

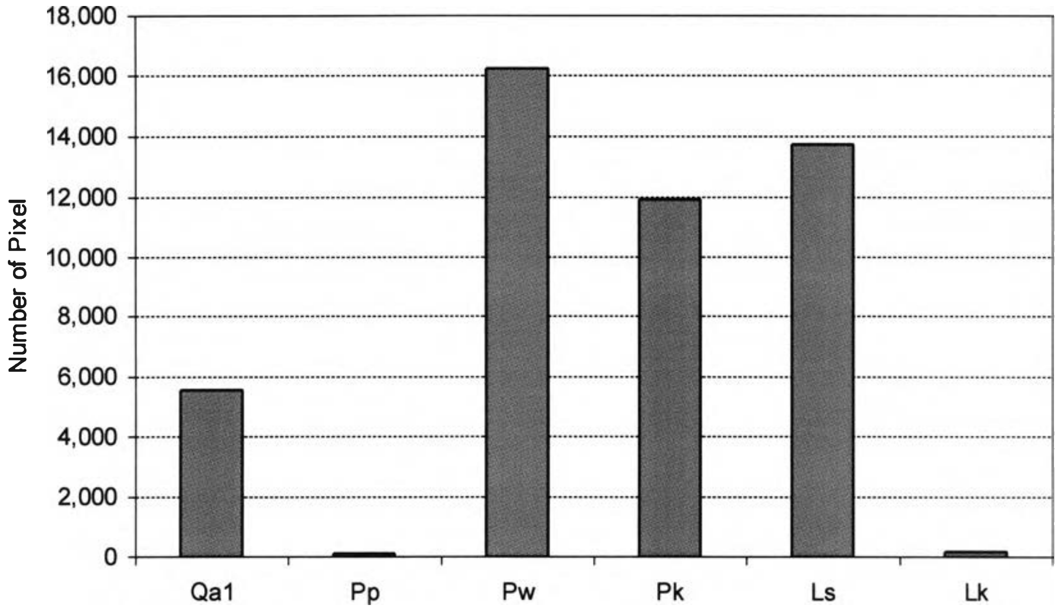
Table 4-5 Relation of flow-flood and geology in Nam Ko Yai sub-catchment.

Rock unit	scar-scouring did not occur		scar-scouring occur		b/a
	Count	Ratio (%) a	Count	Ratio (%) b	
Qa1	25,285	3.93	5,594	11.71	2.98
Pp	10,530	1.64	130	0.27	0.17
Pw	78,827	12.26	16,217	33.95	2.77
Pk	77,320	12.03	11,923	24.96	2.07
Ls	421,652	65.60	13,729	28.74	0.44
Lk	29,121	4.53	181	0.38	0.08
Total	642,735	100.00	47,774	100.00	

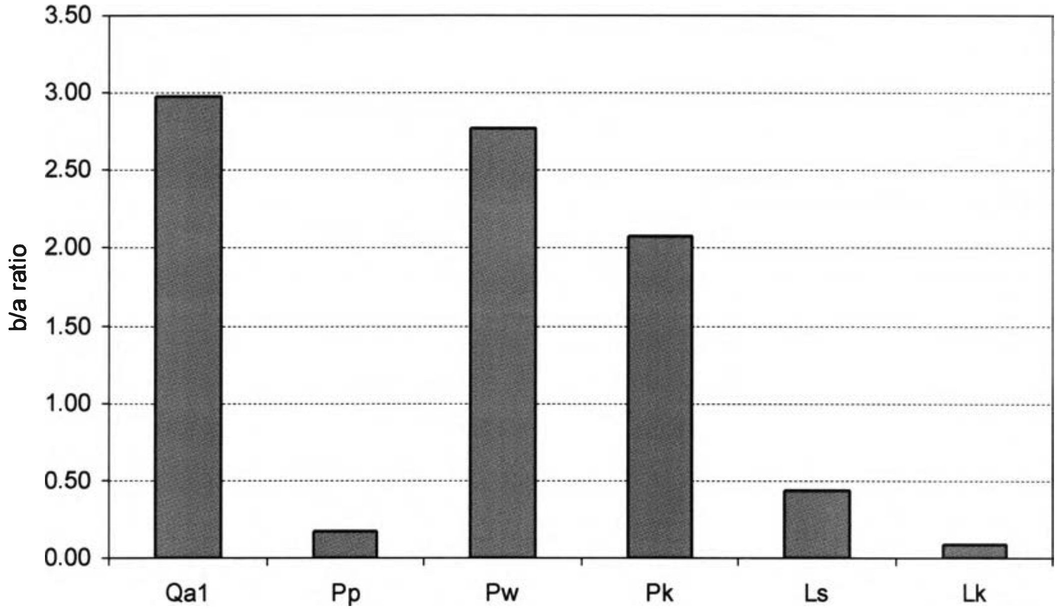
It is noted that the geology is concluded to be ones of the significant relevant parameters in the sub-catchment to the flow-flood occurrence that will be later used to calculate the debris flow-flood susceptibility.

4.2.1.5 Relationship between scar-scouring and soil group unit

In the case of soil group unit in the study area, the frequencies of recent scar-scouring cell number for a given soil group unit were analyzed and presented in Figures 4-13, 4-14 and 4-15 and Table 4-6. For area under soil group unit 29 (that covering a very small area in the sub-catchment), b/a ratio was 3.76, indicating a very high probability. For area under soil group unit 31, b/a ratio was 1.10, indicating a moderate probability. For area under soil group unit 47, ratio was 0.95, indicating a low probability. For area under soil group unit 55, ratio was 1.93, indicating a moderate probability.



a) scar-scoring cell numbers on geology.



b) b/a ratio on geology.

Figure 4-12 Histogram distribution of a) scar-scoring number of cells on geology, and b) b/a ratio on geology in Nam Ko Yai sub-catchment.

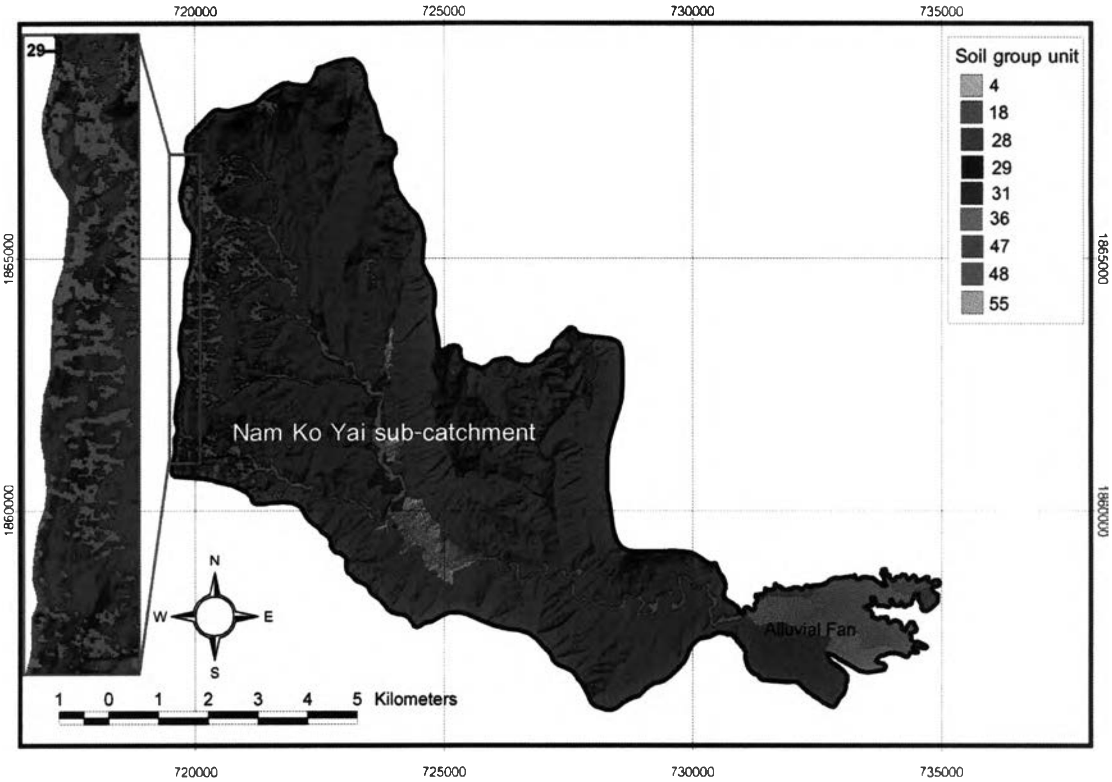


Figure 4-13 Soil group unit map overlain with scar-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

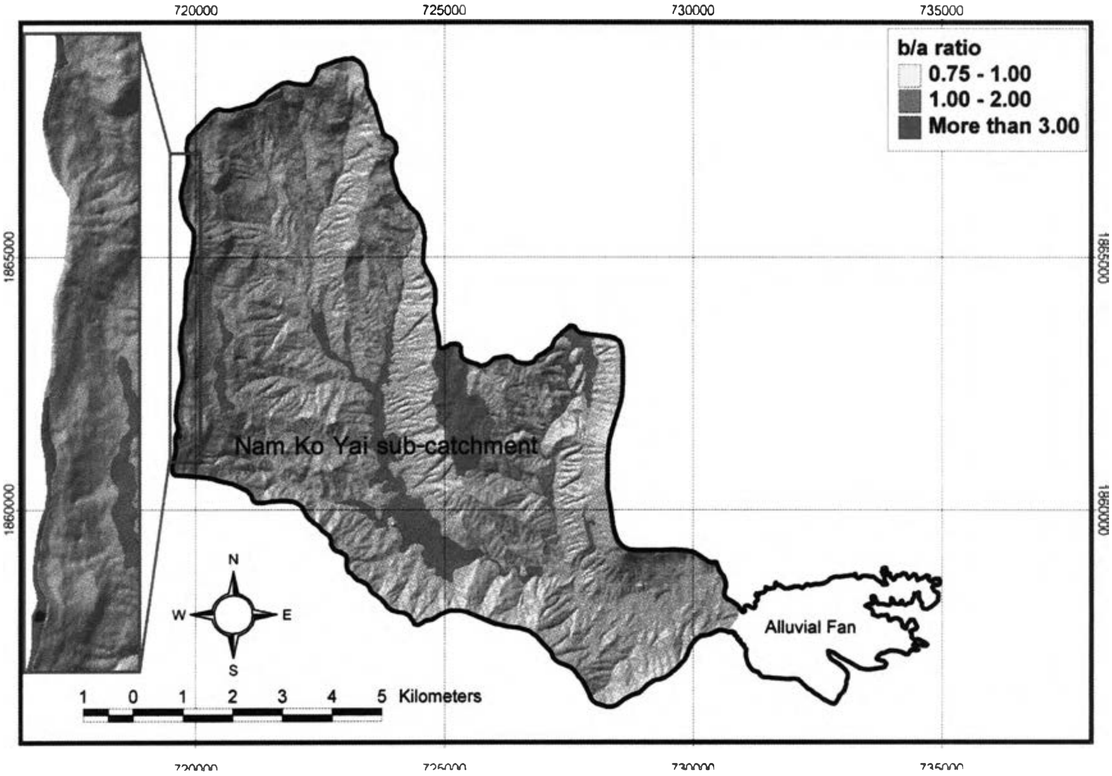
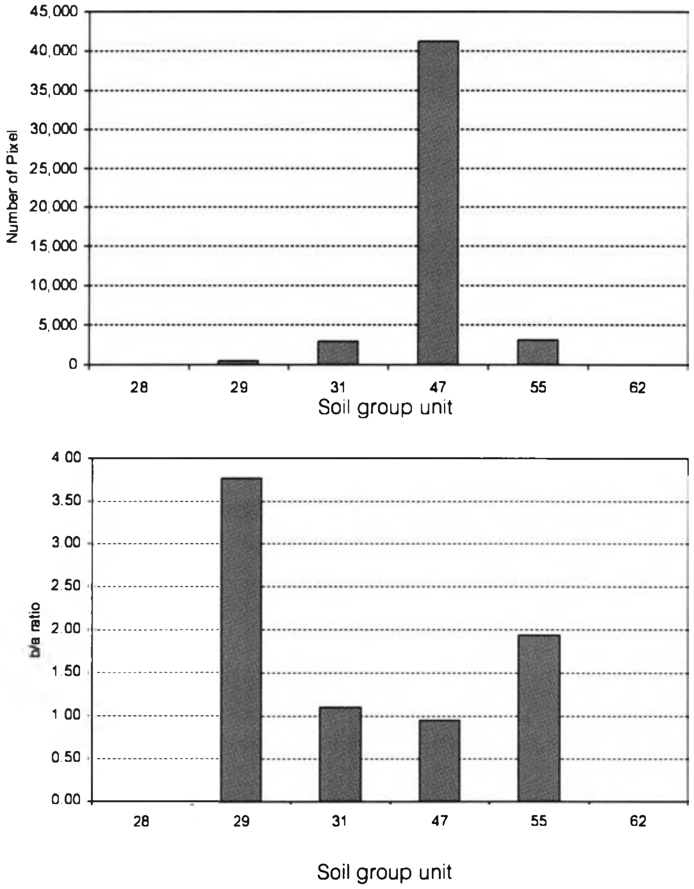


Figure 4-14 Map illustrating b/a ratio as probability of flow-flood susceptibility on soil group unit in Nam Ko Yai sub-catchment.

Table 4-6 Relation of flow-flood and soil group unit in Nam Ko Yai sub-catchment.

Soil major group	scar-scouring did not occur		scar-scouring occur		b/a
	Count	Ratio (%) a	Count	Ratio (%) b	
28	64	0.01	0	0.00	0.00
29	1,857	0.29	519	1.09	3.76
31	35,755	5.56	2,926	6.12	1.10
47	583,306	90.75	41,215	86.27	0.95
55	21,679	3.37	3,114	6.52	1.93
62	74	0.01	0	0.00	0.00
Total	642,735	100.00	47,774	100.00	



a) scar-scoring cell numbers on soil group unit.

b) b/a ratio on soil group unit.

Figure 4-15 Histogram distribution of a) scar-scoring number of cells on soil group unit, and b) b/a ratio on soil group unit in Nam Ko Yai sub-catchment.

It is remarked in the areas of soil group unit 55 and soil group unit 31 in the middle of the sub-catchment, the ratios were 1.93 and 1.10, respectively, generally indicating a moderate probability for the flow-flood occurrence in the most units. So debris flow and debris flood occurrence probability value is lower dependent on the soil group units.

It is remarked that the soil group unit is not one of the significant relevant parameters to the flow-flood occurrence and will not be later used to calculate the debris flow-flood susceptibility.

4.2.1.6 Relationship between scar-scouring and soil thickness

A relationship between the frequencies of scar-scouring cell number and topsoil thickness was attempted with the thickness of less than 50 cm, between 50 and 100 cm, and more than 100 cm (Figures 4-16, 4-17 and 4-18 and Table 4-7). For area which soil thickness was below 50 cm, b/a ratio was 0.95, indicating a low probability. But for the soil thickness between 50-100 cm and more than 100 cm, b/a ratios were 1.93 and 1.23 ,respectively, indicating a moderate probability. It is found that such relationship is confusing as the frequency was doubtfully high in a small area of 50-100 cm soil-thickness and some further explanation is needed. Perhaps the scar-scouring occurrence was significantly related to the underlying basement rocks or other parameters than just the topsoil thickness alone.

It is also concluded that the soil thickness is not one of the significant relevant parameters to the flow-flood occurrence and will not be later used to calculate the debris flow-flood susceptibility.

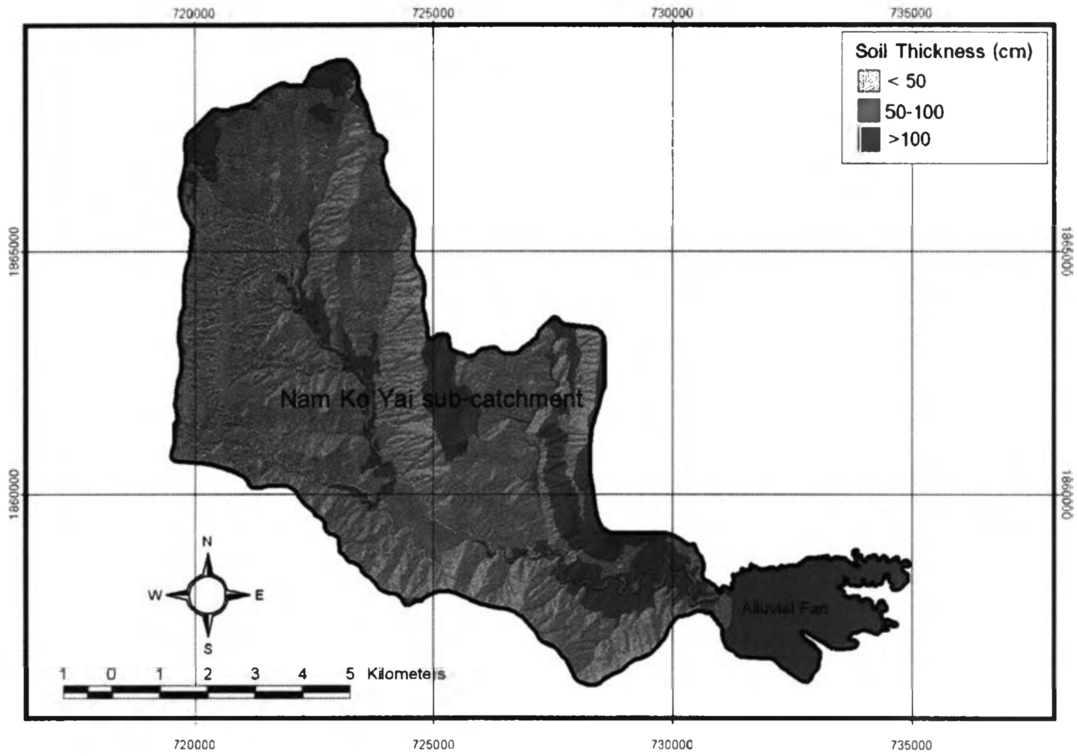


Figure 4-16 Soil thickness map overlain with scar-scouring and depositional locations (grouped in red color) in the study area.

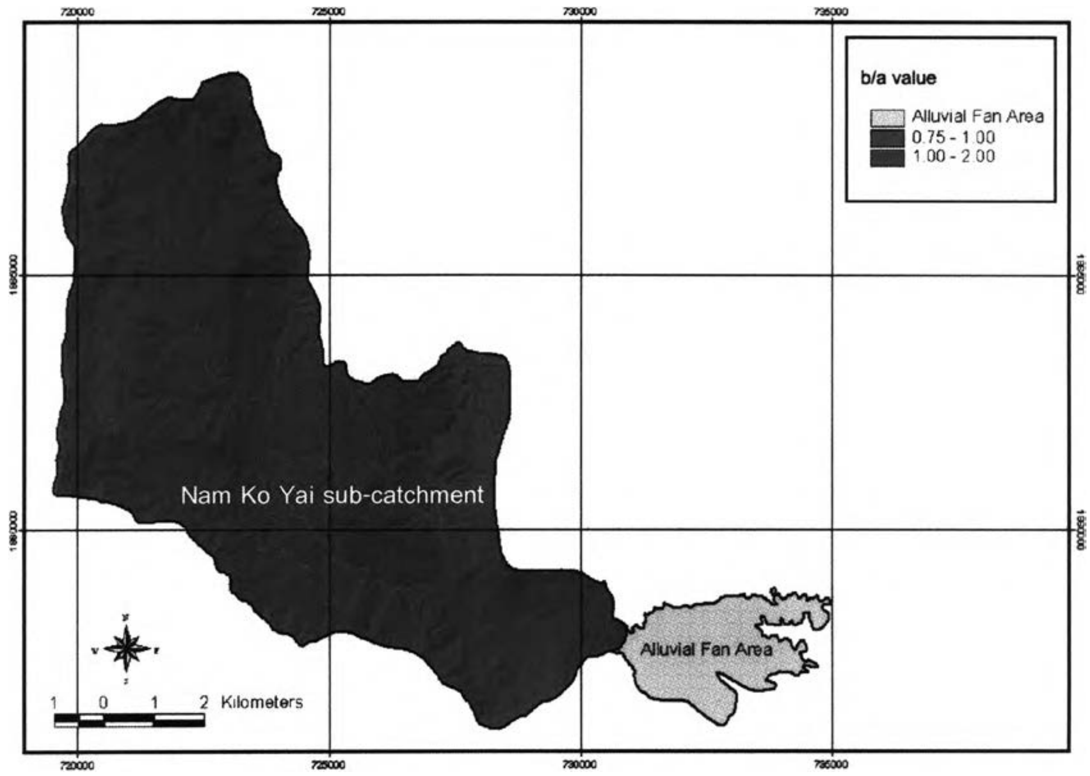
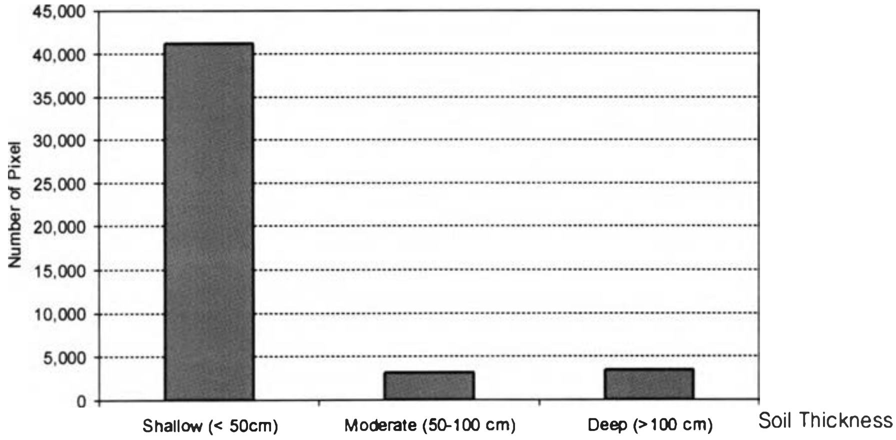


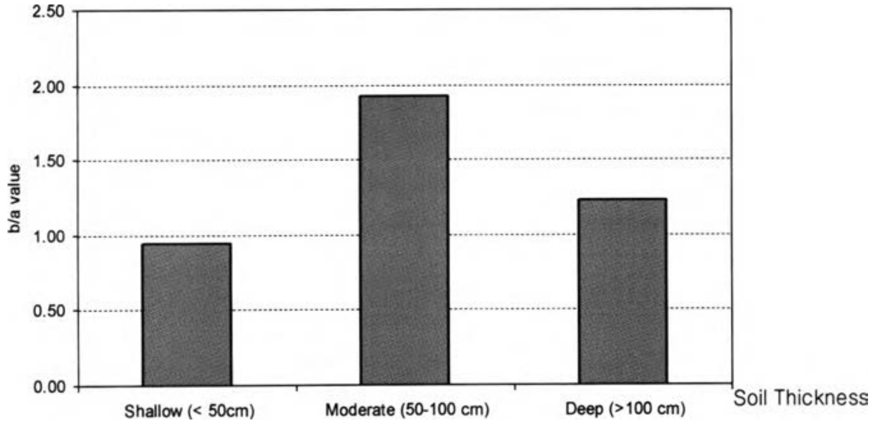
Figure 4-17 Map illustrating b/a ratio as probability of flow-flood susceptibility on soil thickness in Nam Ko Yai sub-catchment.

Table 4-7 Relation of flow-flood and soil thickness in Nam Ko Yai sub-catchment.

Soil Thickness range	scar-scouring did not occur		scar-scouring occur		b/a
	Count	Ratio (%) a	Count	Ratio (%) b	
Shallow (< 50cm)	583,306	90.76	41,215	86.27	0.95
Moderate (50-100 cm)	21,743	3.38	3,114	6.52	1.93
Deep (>100 cm)	37,612	5.85	3,445	7.21	1.23
Total	642,661	100.00	47,774	100.00	



a) scar-scoring cell numbers on soil thickness.



b) b/a ratio on soil thickness.

Figure 4-18 Histogram distribution of a) scar-scoring number of cells on soil thickness, and b) b/a ratio on soil thickness in Nam Ko Yai sub-catchment.

4.2.1.7 Relationship between scar-scouring and land cover

The frequencies of scar-scouring cell number for a given type of land-cover were also determined (as shown in Figures 4-19, 4-20 and 4-21 and Table 4-8). It was noted that an extremely high probability was observed in the water body area that the b/a ratio was 10.63. A high probability was observed in orchard, paddy field and forest areas that the b/a ratios were 2.69, 2.65 and 1.99, respectively. A moderate probability was generally observed in field crop area that b/a ratio was 1.17. Whereas a very low probability was generally observed in inundated land that b/a ratio was 0.45.

The results in fact reveal an extremely high probability value on the banks just adjacent to the stream course and high in the orchard, paddy field, and forest areas further away, but lower in the cultivate flat areas. This is contrary to a general belief previously mentioned that cultivated lands played a major role in this event. The explanation could be that the flow-flood occurred close to the main stream where there was high energy for erosion and transportation of sediments, and in the orchard, paddy field and forest areas where water could be accumulated and retained to introduce a further more effective process of erosion and transportation.

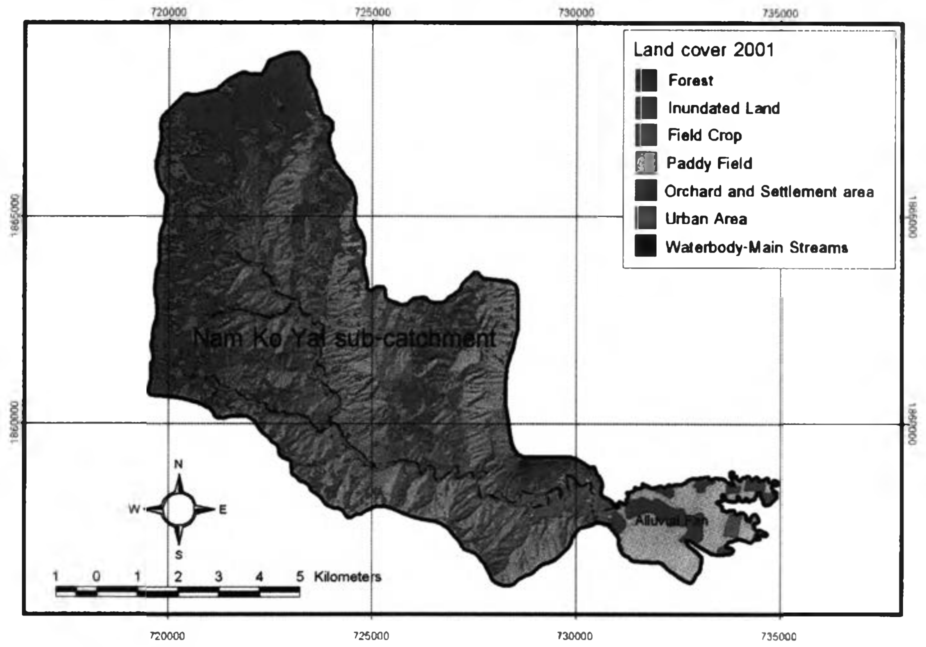


Figure 4-19 Land cover map overlain with scar-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

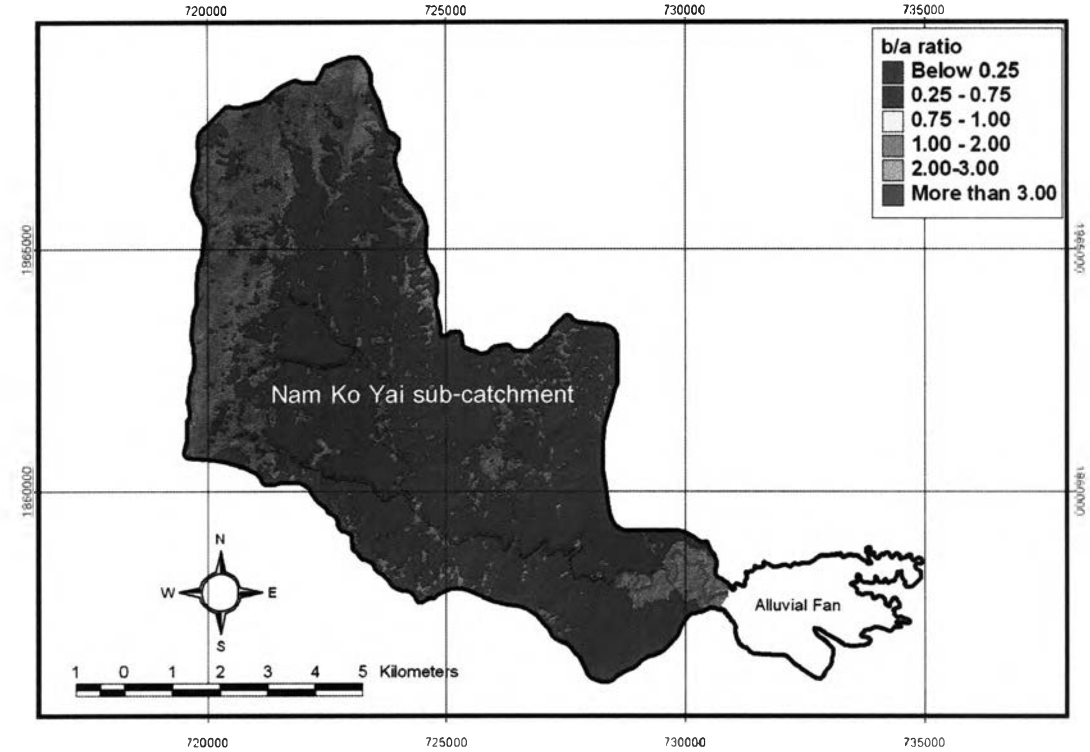
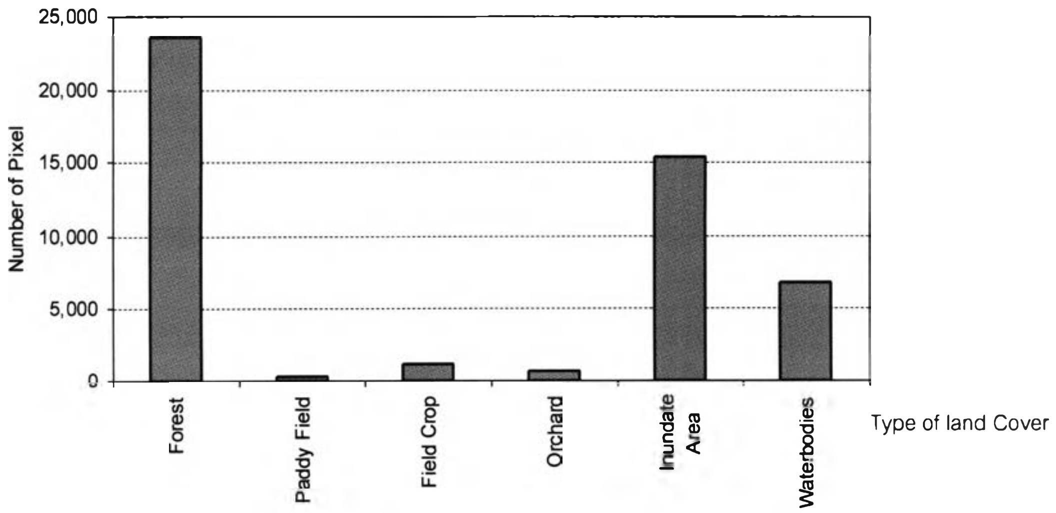


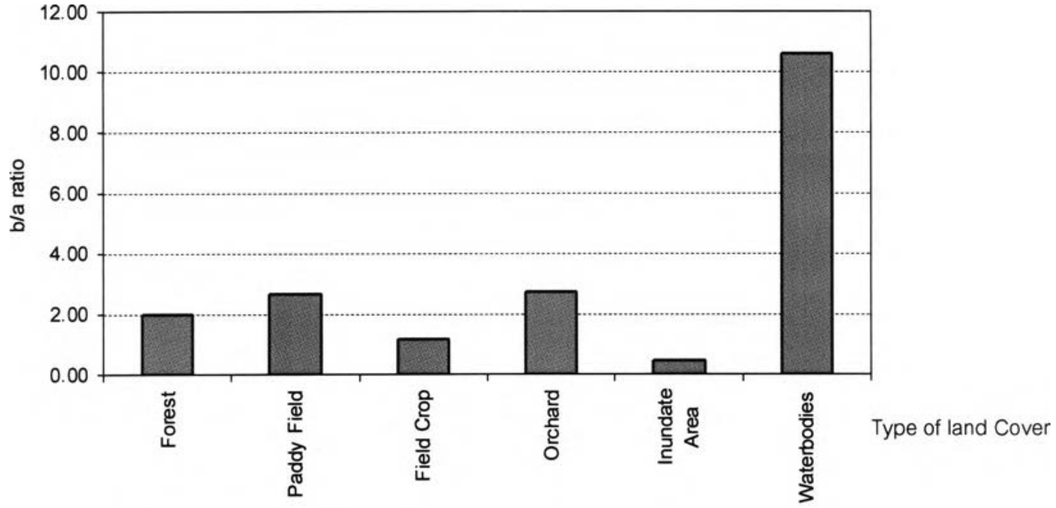
Figure 4-20 Map illustrating b/a ratio as probability of flow-flood susceptibility on land cover in Nam Ko Yai sub-catchment.

Table 4-8 Relation of flow-flood and land cover in Nam Ko Yai sub-catchment.

Land cover type	scar-scouring did not occur		scar-scouring occur		b/a
	Count	Ratio (%), a	Count	Ratio (%), b	
Forest	159,388	24.80	23,572	49.34	1.99
Paddy Field	1,578	0.25	311	0.65	2.65
Field Crop	13,361	2.08	1,165	2.44	1.17
Orchard	3,465	0.54	694	1.45	2.69
Inundated Area	456,432	71.01	15,309	32.04	0.45
Water bodies	8,511	1.32	6,723	14.07	10.63
Total	642,735	100.00	47,774	100.00	



a) scar-scoring cell numbers on land cover.



b) b/a ratio on land cover.

Figure 4-21 Histogram distribution of a) scar-scoring number of cells on land cover, and b) b/a ratio on land cover in Nam Ko Yai sub-catchment.

It is noted that the land cover is concluded to be ones of the significant relevant parameters in the sub-catchment to the flow-flood occurrence that will be later used to calculate the debris flow-flood susceptibility.

4.2.1.8 Relationship between scar-scouring and buffering distance to drainage-line

In the relationship between scar-scouring and buffering distance to drainage-line, the frequencies were determined by counting scar-scouring cell number for the different range of buffering distance to drainage-line (Figures 4-22, 4-23 and 4-24 and Table 4-9). It is noted that low probabilities were commonly observed in the area which stream proximity was in the ranges of less than 20 m, between 20-30 m, between 30-40 m, between 40-50 m and between 50-60 m, that the b/a ratios were 0.91, 0.89, 0.90, 0.90, and 0.86, respectively. Whereas a moderate probability was generally observed the area which buffering distance to drainage-line was more than 60 m that b/a ratio was 1.18.

The results reveal that flow-flood is generally insignificant relationship with the most of buffering distance to drainage-line range. So stream proximity will not be later used to calculate the debris flow-flood susceptibility.

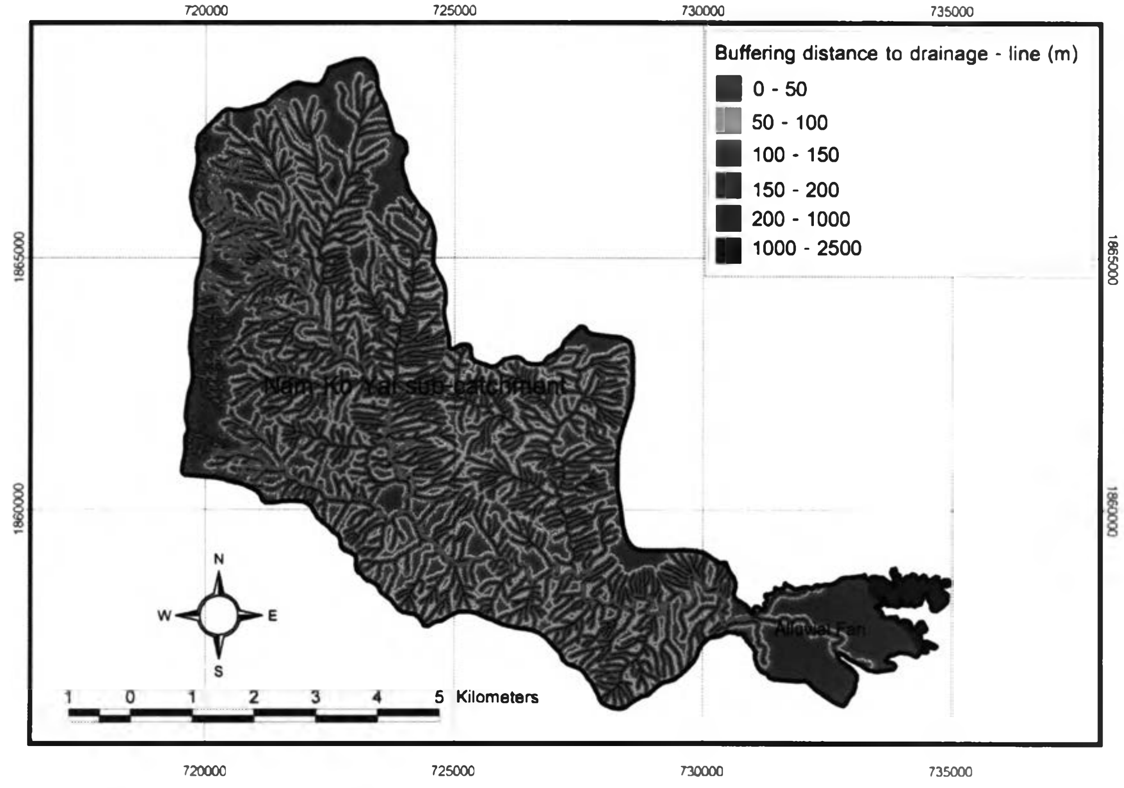


Figure 4-22 Buffering distance to drainage-line map overlain with scar-scouring locations (grouped in red color) in Nam Ko Yai sub-catchment.

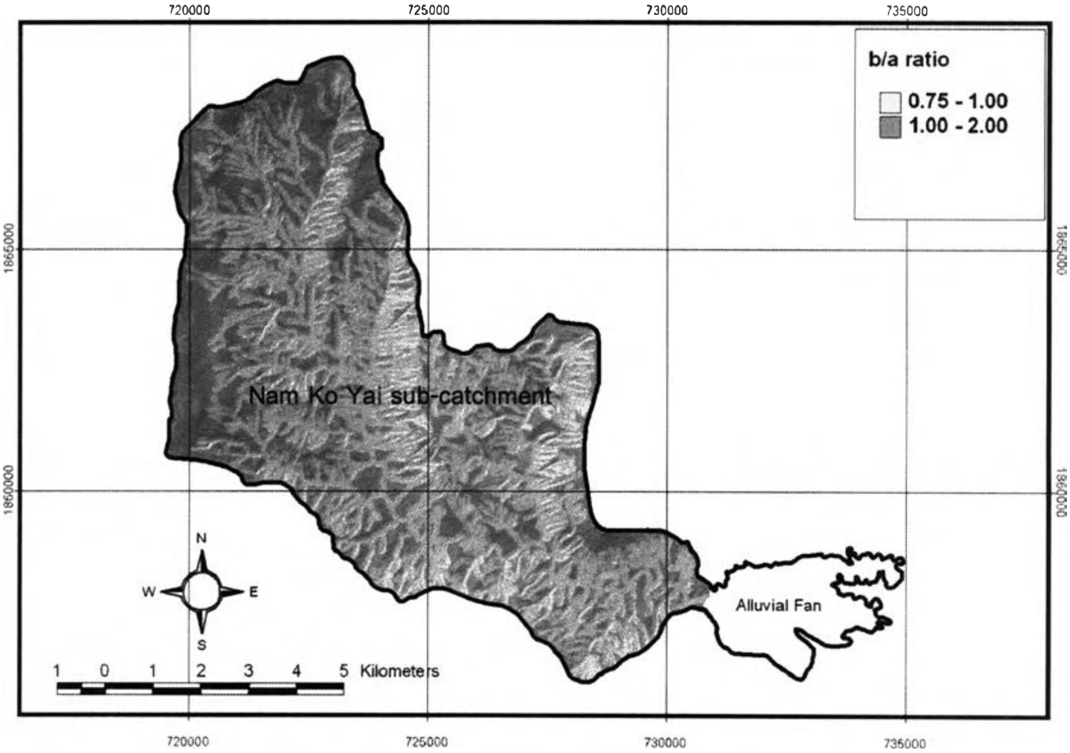
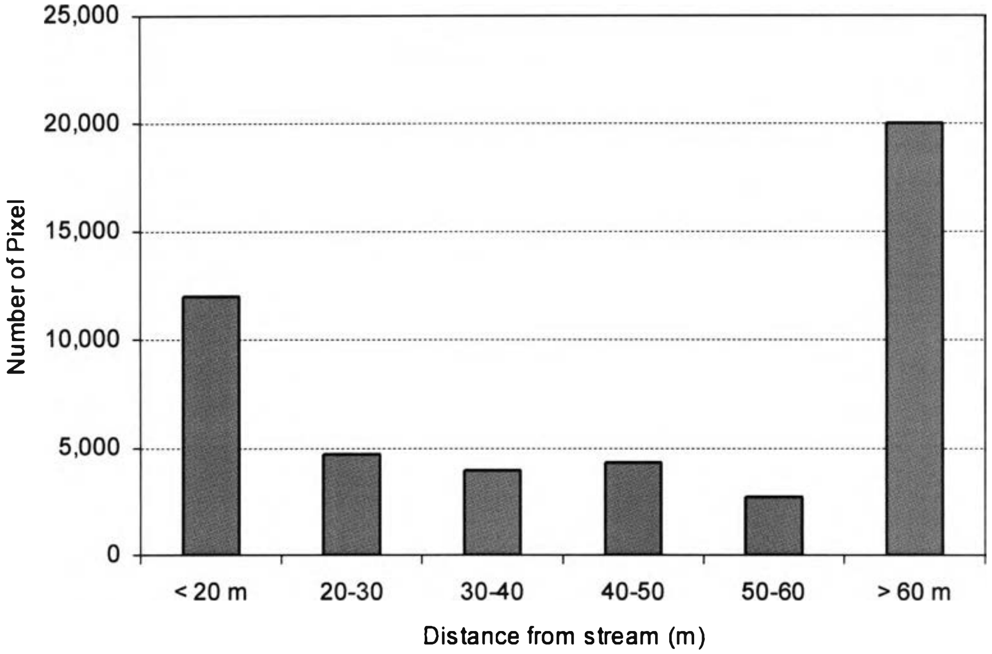


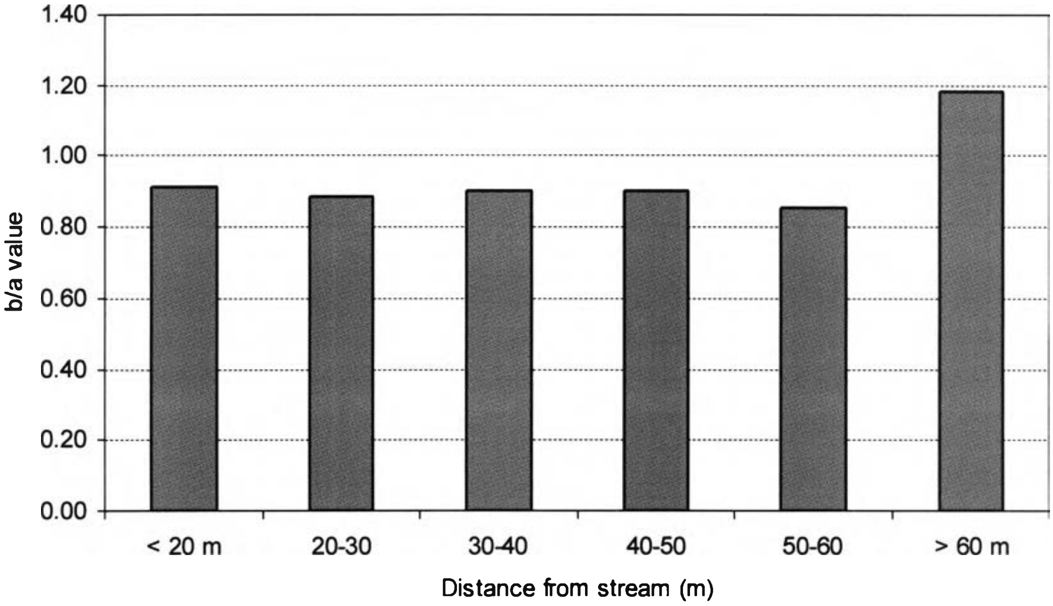
Figure 4-23 Map illustrating b/a ratio as probability of flow-flood susceptibility on buffering distance to drainage-line in Nam Ko Yai sub-catchment.

Table 4-9 Relation of flow-flood and buffering distance to drainage-line in Nam Ko Yai sub-catchment

Stream proximity (m)	scar-scouring did not occur		scar-scouring occur		b/a
	Count	Ratio (%) a	Count	Ratio (%) b	
Less than 20	177,040	27.54	12,024	25.17	0.91
Between 20-30	72,122	11.22	4,749	9.94	0.89
Between 30-40	58,304	9.07	3,918	8.20	0.90
Between 40-50	65,057	10.12	4,347	9.10	0.90
Between 50-60	42,683	6.64	2,713	5.68	0.86
More than 60	227,529	35.40	20,023	41.91	1.18
Total	642,735	100.00	47,774	100.00	



a) scar-scoring cell numbers on buffering distance to drainage-line



b) b/a ratio on buffering distance to drainage-line

Figure 4-24 Histogram distribution of a) scar-scoring number of cells on buffering distance to drainage-line, and b) b/a ratio on buffering distance to drainage-line in Nam Ko Yai sub-catchment.

4.2.2 Calculation of debris flow-flood susceptibility

Using the probability method, the spatial relationships between flow-flood occurrence locations and the significant flow-flood influencing parameters as previous mentioned were derived. It is previously concluded that debris flow and debris flood occurrence probability value is generally much higher dependent on the significant influencing parameters, namely, slope, landform topography, geology, and land cover. Later, these significant influencing parameters were converted to a 10 x 10 m grid for use in the statistical package. In Nam Ko Yai sub-catchment, the total number of cells were 690,509 while the detected scar-scouring number of cells were 47,774. Using GIS software, a grid of 1,292 rows and 1,544 columns, with a point spacing of 10 m was overlain with each geographic coverage for Nam Ko Yai sub-catchment.

The correlation ratios were calculated from relation analysis between the flow-flood and the significant relevant parameters. Therefore the ratio of each parameter's type or range was assigned as the relationship between the flow-flood and each significant parameter's type or range, that is, b/a ratio (ratio between the number of cells where the flow-flood occurred (b) to the number of cells where the flow-flood not occurred (a)) as shown in Tables 4-2, 4-3, 4-5 and 4-8. The flow-flood susceptibility index (FFSI) was calculated by summation of the significant influencing parameter's b/a ratio value weighted to 1 as shown in equation 4-1 below.

$$\mathrm{FFSI} = \sum \mathrm{Fr} \qquad \text{...(Equation 4-1)}$$

Where: Fr = b/a ratio of each parameter's type or range

The relationship analysis is for the b/a ratio of the area where the flow-flood occurred to the total area. So the value of 1 means an average value. If the value is greater than 1, it means a higher correlation, and lower than 1, lower correlation. The flow-flood susceptibility map was made using the FFSI value index for interpretation, and

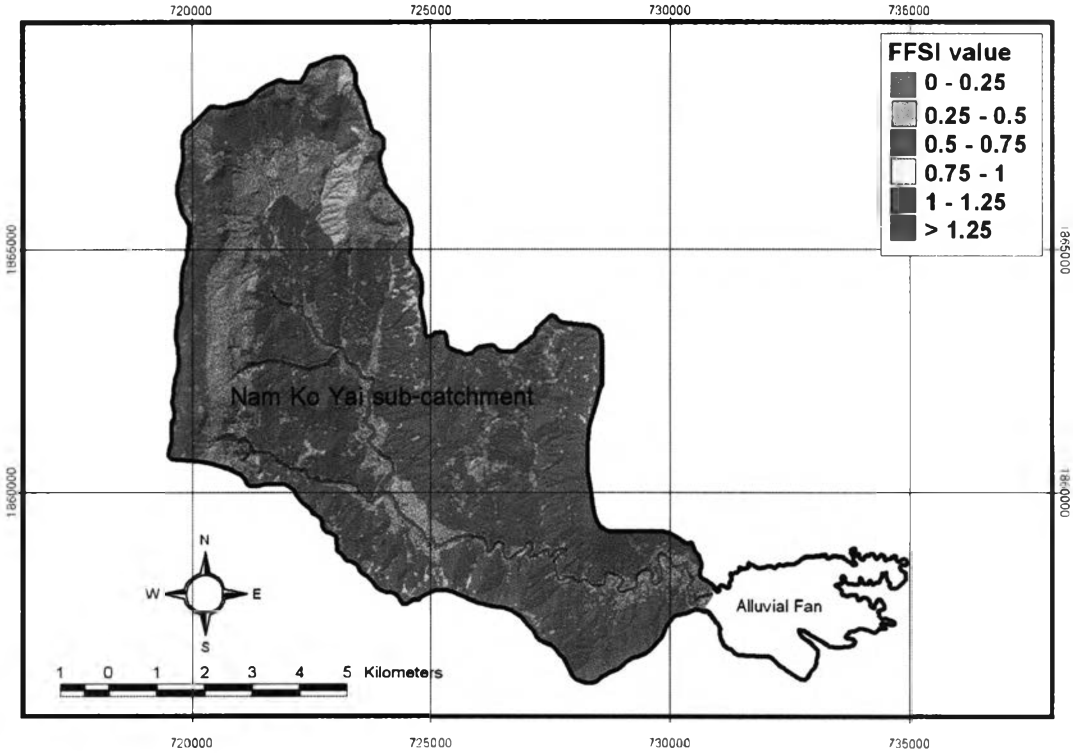


Figure 4-25 Flow-flood susceptibility index (FFSI) of Nam Ko Yai sub-catchment.

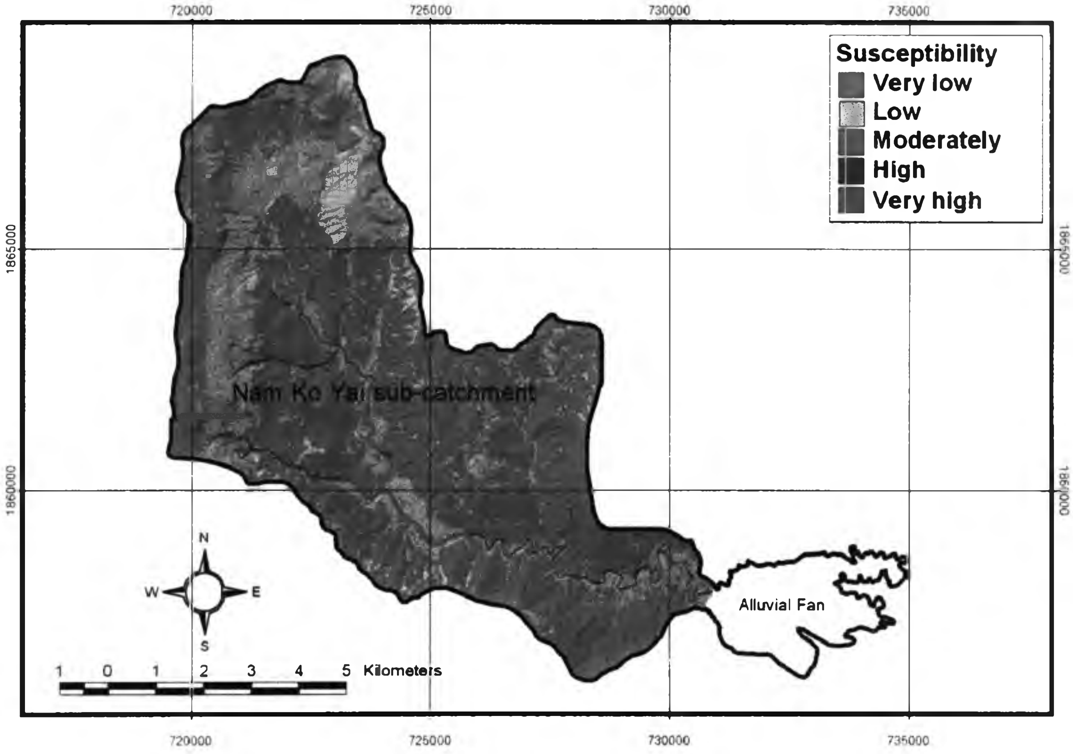


Figure 4-26 Flow-flood susceptibility map illustrating five classes of very high, high, moderate, low, and very low susceptibility in Nam Ko Yai sub-catchment.

was presented in Figure 4-25. The index was further classified by equal areas and grouped into five classes of flow-flood susceptibility map as shown in Figure 4-26. It was remarked that classes of very high-, high-, moderate-, low-, and very low susceptibility, had FFSI value more than 1.25, between 1.00 and 1.25, between 0.50 and 1.00, between 0.25 and 0.50, and less than 0.25, respectively. For Nam Ko Yai sub-catchment of about 69.05 square kilometers, the very high-, low-, moderate-, low-, and very low susceptibility zone cover an area of 0.74, 0.81, 16.73, 18.62 and 32.13 square kilometers, respectively. It is noted that the low- and very low susceptibility zone cover more than 73 % of the total area of Nam Ko Yai sub-catchment.

From the flow-flood susceptibility map of the sub-catchment area as shown in Figure 4-26, it was noted that the very high to very low susceptibility was occurred here. The middle part of Nam Ko Yai stream channel and its adjacent banks had a very high to high flow-flood susceptibility whereas the lower downstream part of the stream had a high flow-flood susceptibility. It was also remarked that the western and northern steep-cliff areas had a low to moderate flow-flood susceptibility whereas the main other parts else of the sub-catchment have in general very low flow-flood susceptibility. The flow-flood susceptibility result was further verified and confirmed by the field investigation of the new evidences and parameters affecting debris flow-flood processes in the following chapter.