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Assessment of flood risk in Hat Yai Municipality, Southern Thailand, using GIS

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ABSTRACT

This article assesses the risk of flooding and identifies efficient measures to reduce flood risk in Hat Yai Municipality, southern Thailand using GIS and satellite imagery. The center of commercial trade and administration in southern Thailand, Hat Yai is located in the downstream area of the Khlong U-Taphao Basin. From 1982 to 2002, forest resources in the basin's upstream were decreased from 48,281 to 26,781 hectares, equivalent to a reduction of 44.5 %. This was largely attributable to the expansion of rubber cultivation. Further analysis revealed that 17,116 ha, 42.7 % of the forest resources in the basin's headwater source areas mainly had been replaced by rubber plantations. As a consequence of extensive deforestation, particularly in headwater source areas, the municipality has become vulnerable to natural disasters; primarily floods.

Hat Yai Municipality experienced two flood events of catastrophic magnitudes in 1988 and 2000. These destructive floods were detrimental to its vulnerable social and economic development due to the loss of life and destruction of property. Since the 2000 flood, considerable structural mitigation measures have been undertaken to prevent and alleviate future flooding of the municipality. Recent flooding on 10 December 2003, caused by a storm like that experienced in 2000, indicates that structural mitigation efforts undertaken so far are inadequate to withstand natural threats. Hat Yai Municipality will continue to be extremely vulnerable to future flood disasters. This shows the compelling need to increase the municipality's resilience against flooding through adoption in the coming year of non-structural disaster reduction schemes to supplement existing efforts. Risk assessment based on hazard and vulnerability analysis is needed to identify and implement adequate and successful non-structural alternatives.

Analyses showed that 99.0, 400.0, 1110.0, 346.0, and 100.0 ha of the municipality's total land areas were subjected respectively to very low, low, moderate, high, and very high flood hazards. Further analysis revealed that 39.6, 654.6, 152.7, 664.5, and 543.6 ha of the land areas respectively faced very low, low, moderate, high, and very high flood risks. Analyses also showed that all the residential, commercial, industrial, and the public utilities and facilities areas, equivalent to 1,188.0 ha (57.8 %) of the municipality's total land area, faced high and very high flood risks. Measures to reduce the risk of flooding in Hat Yai Municipality are discussed.

1. INTRODUCTION

Hat Yai Municipality, comprising 33 communities, covers an area of 20.1 km^2 and has a population of 157,876 people. The municipality, located in the downstream area of the Khong U-Taphao Basin, is the center of commercial trade and administration in southern Thailand. Its ideal geographical location also makes it a gateway to the major neighbouring countries of Malaysia and Singapore, and is thus a city with high tourism potential for domestic and foreign tourists who visit year-round. Due to its geographical characteristics and to unplanned urbanization and deforestation in upstream areas, Hat Yai Municipality has become extremely vulnerable to flood disasters. With its population density and as a commercial center, the municipality has characteristics that can magnify the impact of flooding to which it is prone. The unprecedented flooding of 21 to 24 November 2000, triggered by torrential rains, has been described as one of the worst natural disasters in the history of urban Thailand. It claimed 30 lives and severely damaged public utilities, critical facilities, and commercial and industrial establishments. Estimated total economic losses exceeded US $ 220 million. Indirect losses in terms of lost production and the cost of economic recovery make the estimation even higher. The losses caused by this adverse natural phenomenon have deprived the municipality of resources which could be used for social and economic development, thus impeding development. Future recurrences of flooding on the scale of the year 2000 disaster are anticipated because the municipality continues to engage in activities that increase the hazard potential, as well as economic and personal vulnerability to flood damage.

In recognizing the high likelihood of future flood disasters and the increased severity of flooding, Hat Yai Municipality has made considerable investment in flood mitigation schemes. Extensive works, including the construction of levees, drainage canals, water diversion channels and pumping stations, have been undertaken to prevent and alleviate flooding since the November 2000 catastrophe. In spite of these considerable structural mitigation activities,

KEY WORDS: flood disaster, risk assessment, risk reduction measures, Geographic Information Systems, satellite imagery

large areas of the municipality were submerged during the 10 December 2003 flood caused by rain storms of November 2000 magnitudes. The 2003 flooding indicated that the structural efforts undertaken so far are not adequate. Hat Yai Municipality therefore remains and will continue to be extremely vulnerable to future flooding.

It is important to recognize that there is a close relationship between water source areas in the upland watershed, transport areas in the foothill and terrace, and discharge areas in the lowlands of the Khlong U-Taphao Basin. These areas are inter-connected throughout the basin by the U-Taphao River and its tributaries, hence disturbances in upstream areas can prove detrimental downstream where Hat Yai Municipality is located (Tanavud et al., 2001a). For instance, deforestation of the mountainous upper watershed can increase the physical magnitude of the flood hazard and contribute to downstream flood damage (WHO, 2002). The hazard of flooding is known to be governed by the condition of upland ecosystems as well as those in the lowlands which increase the hazard or vulnerability. Measures that address flooding that poses a risk to the municipality downstream therefore need to be adopted in the context of the watershed basis. To identify and implement the most effective responses to flood hazards, risk assessment based on a hazard and vulnerability analysis needs to be made. Our study therefore aimed to assess the flood risk in Hat Yai Municipality in order that adequate, successful risk reduction schemes can be identified and measures taken to prevent future disasters.

2. MATERIALS

The data and their sources used to create a land-use map of the Klong U-Taphao Basin, and to assess flood risk in Hat Yai Municipality are reported below and in Table 1.

2.1 Klong U-Taphao Basin

1) Topographic maps for the areas studied on a 1 : 250,000 scale, produced by the Royal Thai Survey Department.
2) Land satellite images for the areas studied on a 1 : 250,000 as well as a 1 : 50,000 scale, produced by the Geo-Informatics and Space Technology Development Agency (GISDA).
3) Watershed classification map for the areas studied on a 1 : 50,000 scale, produced by the Office of Environmental Policy and Planning (OEPP).
4) Government department records on soil, land use, and watershed classes.

2.2 Hat Yai Municipality

1) Aerial photo of Hat Yai Municipality on a 1 : 4,000 scale, produced by the Royal Thai Survey Department.
2) Elevation map of Hat Yai Municipality on a 1 : 4,000 scale, produced by the Department of Public Works and Town and Country Planning.
3) Slope map of Hat Yai municipality on a 1 : 4,000 scale, produced by the Department of Public Works and Town and Country Planning.
4) Drainage map of Hat Yai Municipality on a 1 : 4,000 scale, produced by Hat Yai Municipality.
5) Government department records of population, rainfall, land use, and drainage systems.

2.3 Land-use changes in the Klong U-Taphao Basin.

In this study, Geographic Information Systems (GIS) were used to develop two digitized thematic maps that included basin boundaries, as well as 1982 and 2000 land-use maps. All GIS computations and coverage overlays were performed with PC ArcInfo software. Basin boundaries were digitized from the 1 : 50,000 topographic maps. Land-use coverage for 1982 and 2000 were generated in ArcInfo format by digitizing from land-use maps visually interpreted from the 1982 and 2000 Landsat TM images of the areas studied.

According to the Watershed Classification System, developed by the Office of Environmental Policy and Planning (OEPP), areas in watershed classes 1 and 2 are designated as headwater source areas. The data layer of these headwater areas was generated by digitizing from the 1 : 50,000 watershed classification maps. The resulting coverage, created by overlaying the 2000 land-use map and the headwater source areas map, using PC ArcInfo, generated a land use in headwater areas map.

Table 1. Data and their sources.

Areas	Data	Data type	Scale	Data sources
1. Khlong U-Taphao Basin	1. Boundary	Topographic map	1:50,000	Royal Thai Survey Department
	2. Land use	Landsat image	1:50,000	GISDA
	3. Watershed class	Watershed classification maps	1:50,000	Office of Environmental Policy and Planning
2. Hat Yai Municipality	1. Boundary	Boundary map	1:4,000	Hat Yai Municipality
	2. Daily rainfall	Rainfall records	-	Meteorological Department
	3. Elevation	Elevation map	1:4,000	Department of Public Works and Town & Country Planning
	4. Slope	Slope map	1:4,000	Department of Public Works and Town & Country Planning
	5. Drainage density	Drainage map	1:4,000	Hat Yai Municipality
	6. Road	Aerial photo	1:4,000	Royal Thai Survey Department
	7. Land use	Aerial photo	1:4,000	Royal Thai Survey Department
	8. Population density	Population data	-	Department of Provincial Administration
	9. Flood levels	Flood level data	-	Community residents

2.4 Flood catastrophes in Hat Yai Municipality in 1988 and 2000.

Data on flood water levels during the 1988 and 2000 flood catastrophes were obtained by a questionnaire survey. The survey was undertaken across the municipality, and twenty interviews were made per one square kilometer. A contour map showing variations in flood water levels at all locations across the municipality was generated from water level data obtained by use of the surface analysis function of ArcView 3.2 software.

3. METHODS

The flood hazard and flood risk assessment was done as follows:

3.1 Database inputs.

1) Flood hazard assessment.

A disaster is comprised of three components; hazard, risk, and vulnerability. The hazard is the probability of the occurrence of a potentially damaging phenomenon within a given period of time and space. Data layers that were selected as input data for assessing flood hazard in Hat Yai Municipality using ArcInfo GIS included rainfall, elevation, slope, drainage density, road density and land-use type. Selection of these factors was based on quotation frequencies in flood-related publications as well as the authors' knowledge of past floods in the area being investigated (Tanavud et al., 2001b). Basin boundaries were digitized from the topographic maps using GIS ArcInfo. Because the magnitude of a storm event represented by rainfall duration-intensity is a contributing factor to the occurrence of landslides and flooding in southern Thailand (DeGraff, 1989; Rau, 1991), a seven-day period of rainfall prior to the 21-24 November 2000 flood was used to produce a rainfall isohyet map. Elevation and slope maps in the scale of 1 : 4,000 in digital format were provided by the Department of Public Works and Town and Country Planning. The drainage map was created in Arc/Info by digitizing from a paper map produced by Hat Yai Municipality. A land-use map that included roads and railways was created by digitizing from a map interpreted visually from the 1 : 4,000 aerial colour photo map of 2002. The resulting coverage created by the overlay of these maps generated the flood hazard map.

2) Flood risk assessment.

Risk refers to the threat to life or property that may result from the action of a hazard upon some structure, system, or population (French, 1991). There are three components in assessing risk of disasters (Tobin and Montz, 1997). The first is the hazard; the probability of the occurrence of potentially damaging phenomena within a specified time and given area. The second is the element or elements at risk. These mainly are regarded to be population, property, and economic activities in a given area. The third is vulnerability; the degree of loss for a given element or set of elements at risk. According to Shook (1997), risk can be presented as

Risk = (Elements at risk) (Hazard $\times$ Vulnerability)

Due to the scarcity of reliable information, the elements at risk in this study primarily were assessed based on population and land use in the municipality. Regarding vulnerability, the recent 10 December 2003 flooding in the municipality indicated that the structural mitigation measures undertaken so far are not adequate, therefore the vulnerabilities to flood loss of the people, property, and public utility and critical facilities is absolute, representing total loss.

A population density map was created in ArcInfo GIS by importing population data from the Department of Provincial Administration. A land-use map of Hat Yai Municipality was produced by digitizing from the land-use map interpreted visually from the 1 : 4,000 aerial colour photo map of 2002 produced by the Royal Thai Survey Department. A flood risk map then was created by overlaying the flood hazard map with the population density and then the land use maps.

3.2 Flood hazard and risk mapping.

1) Flood hazard map.

The flood hazard map in our study was created by the weighting and ranking technique of Pachauri and Pant (1992). This technique is a numerical system based on biophysical factors which are directly or indirectly correlated with the occurrence of floods. The factors were weighted according to their relative importance to each other and to their expected importance in causing floods. Further, each factor was partitioned into five subfactors, each of which was ascribed a ranking value. The higher ranking value the more susceptible the particular subfactor to the occurrence of floods.

Rainfall, elevation, slope, drainage density, road density and land use were chosen as the most influential factors for evaluating the flood hazard to the municipality. Selection of factors and subfactors for the generation of the flood hazard map was based on quotation frequencies in flood-related publications and on the authors' knowledge of past flooding in southern Thailand (Tanavud et al., 2001b). Of the factors selected, the highest weighting was given to rainfall, followed by elevation, slope, drainage density, road density, and land use. After the weighting procedures, each factor was partitioned into five subfactors, each of which was given a ranking value (Table 2). For each factor, the weighted hazard ranking was obtained by multiplying its weight by the ranking value for the corresponding subfactor. Pramojanee et al. (1997) and Tanavud et al. (2000) provide greater details on the weighting and ranking techniques. The total estimated hazard, obtained by adding the weighted flood rankings of all the factors, was classified in five categories; very low, low, moderate, high, and very high (Table 3).

2) Flood risk map.

A flood risk map was created by use of the same weighting and ranking technique used for mapping flood hazard areas. Hazard, population, and land-use types were selected as the most influential factors in evaluating flood risk. For land-use types, because residential, commercial, and industrial areas generally are more valuable than institutional areas (government agencies' offices, hospitals, banks, schools and universities), public utilities and critical facilities areas (power, water, roads and railways) and agricultural land, higher weighting values were given to residential, commercial, and industrial areas, followed in descending order by institutional areas, public utility and critical facility areas, and agricultural land (Table 4). The total estimated risk, obtained by adding the weighted risk rankings of all factors, also was classified in five categories; very low, low, moderate, high, and very high risk (Table 5). Tanavud et al. (2001b) provides additional details on the flood hazard and risk mapping methods.

Table 2. Weighted flood hazard rankings for Hat Yai Municipality.

Factors	Weighting	Subfactors	Ranking
1. Rainfall over a seven-day period (mm).	6		
		1.1 < 806 mm	1
		1.2 806 - 821 mm	2
		1.3 822 - 837 mm	3
		1.4 838-852 mm	4
		1.5 > 852 mm	5
2. Elevation (m).	5		
		2.1 > 10	1
		2.2 8 - 10	2
		2.3 6 - 7	3
		2.4 4 - 5	4
		2.5 < 4	5
3. Slope (%).	4		
		3.1 > 4.0 %	1
		3.2 3.0 – 4.0 %	2
		3.3 2.0 – 2.9 %	3
		3.4 1.0– 1.9 %	4
		3.5 < 1.0 %	5
4. Drainage density (% each community)	3		
		4.1 > 22.0	1
		4.2 20.1-22.0	2
		4.3 18.1-20.0	3
		4.4 16.0-18.0	4
		4.5 <16.0	5
5. Road density (% each community)	2		
		5.1 < 10.0	1
		5.2 10.0 – 12.0	2
		5.3 12.1 – 15.0	3
		5.4 15.1 – 17.0	4
		5.5 > 17.0	5
6. Land use type (related to water absorption and drainage capacities)	1		
		6.1 Water bodies	1
		6.2 Rice fields, bush and shrubs, swamp	2
		6.3 Perennials, fruit trees	3
		6.4 Open land	4
		6.5 Urban and built-up areas	5

Table 3. Maximum and minimum values of the total estimated hazard for each flood hazard category.

Flood hazard category	**Total estimated hazard values**
Very low	< 46
Low	47 – 60
Moderate	61 – 73
High	74 – 87
Very high	> 87

Table 4. Weighted flood risk rankings for Hat Yai Municipality.

Factors	**Weighting**	**Subfactors**	**Ranking**
1. Flood hazard	1		
		1.1 very low	1
		1.2 low	2
		1.3 moderate	3
		1.4 high	4
		1.5 very high	5
2. population density (no. per sq. km)	1		
		2.1 < 4,586	1
		2.2 4,586 – 13,341	2
		2.3 13,342 – 22,103	3
		2.4 22,104 – 30,864	4
		2.5 > 30,864	5
3. Land use types	1		
		3.1 swamp, marsh, and bush and shrubs	1
		3.2 agricultural land	2
		3.3 public utility and critical facility areas	3
		3.4 institutional areas	4
		3.5 residential, commercial, and industrial areas	5

Table 5. Maximum and minimum values of the total estimated risk for each flood risk category.

Flood risk category	Total estimated risk values
Very low	< 5
Low	5 - 7
Moderate	8 - 10
High	11 - 13
Very high	> 13

Table 6. Land use changes in the Klong U-Taphao Basin, 1982 to 2002.

Land use category	Areas (ha)	
	1982	**2002**
Forest	48,281	26,781
Rubber	150,218	172,130
Rice	18,203	14,018
Fruit trees	758	2,031
Mixed orchards	4,428	713
Mangroves	467	111
Aquaculture	115	727
Urban and built-up areas	5,745	12,954
Miscellaneous uses	6,860	5,610
Total	**235,075**	**235,075**

Table 7. Land use in headwater source areas of the Klong U-Taphao Basin.

Land use category	Areas of headwater sources	
	Hectares	Percent
Forest	22,968	57.3
Rubber	17,031	42.5
Rice	-	-
Fruit trees	-	-
Mixed orchards	-	-
Mangroves	-	-
Aquaculture	-	-
Urban and built-up land	19	0.05
Miscellaneous uses	62	0.15
Total	**40,080**	**100.00**

Table 8. Changes in land use in the Klong U-Taphao Basin, 1982 to 2002.

Land use in 1982	Land use in 2002										
	Rice	Forest	Urban / built-up areas	Miscellaneous	Aquaculture	Rubber	Water bodies	Orchards	Perennial crops	Mangroves	**Total (ha)**
1. Rice fileds	11,074	4	1,434	447	306	4,855	34	5	41	3	**18,203**
2. Forests	105	24,765	182	316	-	22,631	22	-	259	-	**48,281**
3. Urban /built-up areas	197	5	3,775	188	-	1,418	-	163	-	-	**5,745**
4. Miscellaneous	517	31	1,825	2,272	100	1,264	13	-	308	29	**6,356**
5. Aquaculture	-	-	1	-	155	-	-	-	-	7	**163**
6. Rubber	1,450	1,975	4,414	981	-	138,930	780	449	1,238	-	**150,218**
7. Water bodies	7	0.9	-	9	-	107	329	-	4	-	**458**
8. Orchards	531	0.4	1,229	39	11	2,513	9	96	-	-	**4,427**
9. Perennial crop	58	-	87	21	-	411	-	-	182	-	**758**
10. Mangroves	80	-	8	102	204	-	-	-	-	72	**466**
Total (ha)	**14,018**	**26,781**	**12,954**	**4,375**	**775**	**172,130**	**1,187**	**713**	**2,031**	**111**	**235,075**

Note : Numbers at the intersection of rows and columns with the same land-use designation represent hectares that did not change from 1982 to 2002. Reading to the right or left of this number are the hectares converted to other uses in 2002. Reading up and down from this number are the hectares converted from other uses in 1982.

4. RESULTS AND DISCUSSION

4.1 Land use changes

In 1982, in the Klong U-Taphao Basin, forests covered an estimated 48,281 ha, equivalent to 20.5 % of the basin's total land area (Table 6). Over a period of 20 years, from 1982 to 2002, these forests were depleted by a total of 21,500 ha, equivalent to an annual loss of 1,075 ha (Figures 1 and 2). As a result, by 2002, forests accounted for only 11.4 % of the basin (Table 6). During that same period, the proportion of rubber plantation areas expanded dramatically from 150,218 to 172,130 ha, an annual increase of 1,096 ha (Table 6). In southern Thailand, such encroachment and conversion of natural forests to other uses has been attributed to the expansion of agricultural land, illegal logging, and lack of public awareness of the flood protection values of forests (UNDP, 1994).

The municipality's land-use map, when overlaid with the headwater source areas map, provided new insight into the status of land use in headwater areas. These types of environmentally critical areas had been designated by the Watershed Classification System as "protected forest", but of the 42,084 ha of headwater areas, 17,116 ha, 42.7 percent, had already been converted to other uses (Table 7). Indeed by 2002 or 42.5 % of the headwater areas had been converted to rubber plantation.

Overlaying the land-use map of 1982 with that of 2002 revealed that a 21,912 ha increase in rubber cultivation areas came from the conversion of 22,631 ha of forest area, 4,855 ha of rice fields and 2,513 ha of mixed orchards (Table 8). The dramatic

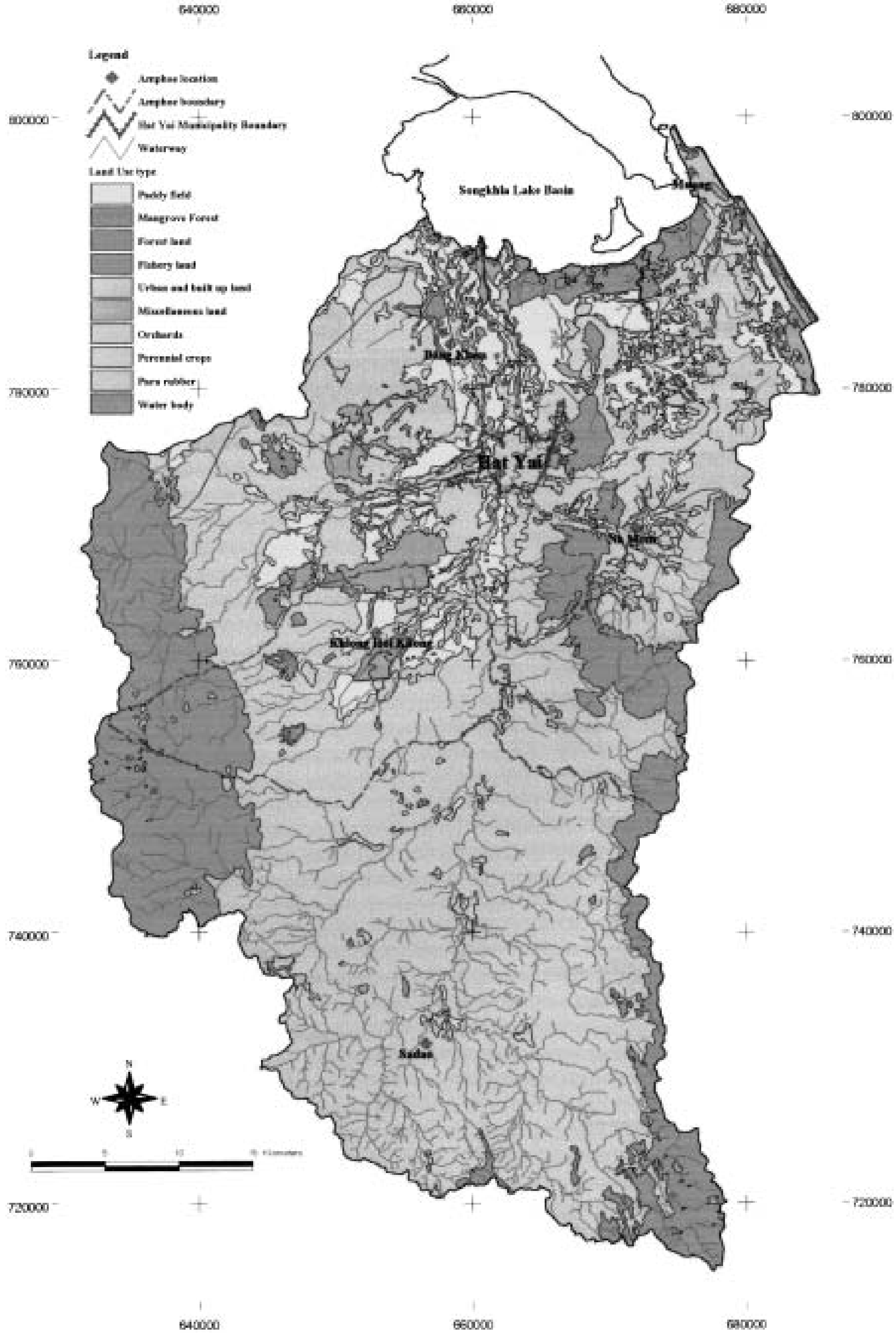

Fig. 1 Land use map of Khlong U-Taphao Basin in 1982.

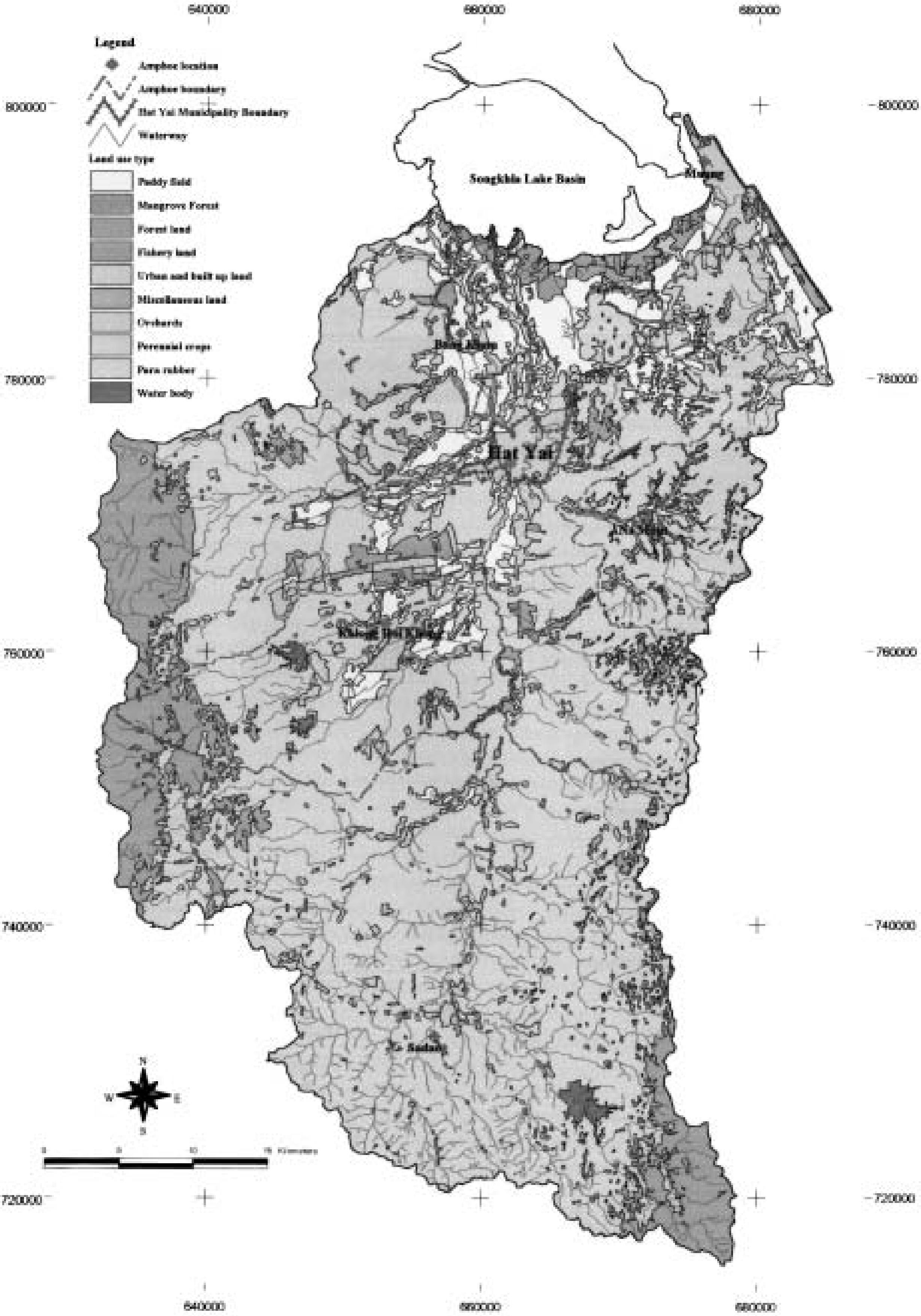

Fig. 2 Land use map of Khlong U-Taphao Basin in 2002.

increase in the price of rubber during this period and the subsidies provided by the Thai Government's Office of Rubber Replanting Aid Fund have been instrumental in promoting land conversion to rubber plantation (Usher, 1994). Complete land-use change, including land converted to other uses and land formerly in other uses, is shown in detail in Table 8.

4.2 Consequences of land-use changes.

Ecological transition in the basin's uplands, particularly in headwater source areas, from natural forest to rubber plantations disturbed the finely tuned equilibrium of the natural ecosystems to such a degree that environmental stability was compromised (Donovan, 1989). This change limited the basin's ability to absorb the impact of a flood and lowered the resilience of the natural ecosystem to hazard impact (United Nations, 2002). Consequently, Hat Yai Municipality has become extremely vulnerable to natural disasters, primarily floods (ESCAP, 1989). Such calamitous events inhibit vulnerable social and economic development through the loss of life and destruction of property, as in Hat Yai Municipality in November 1988 (Rau, 1991) and in November 2000 (Bangkok Post, 2000).

4.3 Flood events in Hat Yai municipality in 1988 and 2000.

Hat Yai Municipality experienced floods of catastrophic magnitude in 1988 and 2000. The flood water levels of those floods are shown in Table 9. In 1988, it was estimated that 114 ha (5.6 %) of the municipality's total land area were inundated at depths of 2 to more than 3 meters (Figure 3). As shown in Figure 4, in 2000, the area facing the same flood water depth had increased to 452 ha (22.0 %) of the municipality, an increase of 348 ha (334.6 %) (Table 9). It should be noted that areas inundated to depths greater than 3 meters increased from 6 ha (0.3 %) of the municipality's total land area in 1988 to 16 ha (0.8 %) in 2000. This indicates that the severity of flooding in Hat Yai had increased greatly over the 12 year period from 1988 to 2000. Recurrence of flooding on the scale of or greater than the November 2000 disaster are anticipated because residents are continuing activities that increase flood hazard as well as economic and personal vulnerability to flood damage. Therefore, there is the urgent need to make the community resilient to flood hazard through the adoption of disaster reduction schemes. To identify adequate disaster reduction activities, a flood risk assessment based on hazard and vulnerability analysis is needed.

A mapped inventory of areas inundated or devastated during the 2000 catastrophic-level flooding should be published and distributed to the community at large. Such a map would remind the residents of the disastrous consequences of such flooding. The municipality must learn to live and cope with floods in order to reduce its vulnerability to flood damage and learn how to increase emergency preparedness to deal with loss of life and property.

4.4 Flood risk assessment.

1) Hazard analysis.

From the flood hazard map, it was estimated that 99.0, 400.0, 1110.0, 346.0 and 100.0 ha of the municipality's total land areas were subjected respectively to very low, low, moderate, high, and very high flood hazards (Table 10). Further analysis revealed that 137.4 ha (24.5 %) and 85.6 ha (21.4 %) of residential and public utility and facility areas respectively, face high and very high flood hazard levels (Figure 5 and Table 10). The flood risk map shows that 39.6, 654.6, 152.7, 664.5 and 543.6 ha of the municipality's land areas faced respectively very low, low, moderate, high, and very high flood risks (Figure 6 and Table 11). Moreover, all the residential, commercial, industrial and public utility and facility areas, equivalent to 1,188.0 ha (57.8 %) of the municipality's total land area, face high and very high levels of flood risk (Table 11).

Table 9. Flood water levels in Hat Yai Municipality during the 1988 and 2000 floods.

Flood water levels (cm)	Affected areas, the 1988 flood		Affected areas, the 2000 flood	
	ha	%	ha	%
0 – 50	564	27.4	389	18.9
50 – 100	517	25.2	300	14.6
100 – 150	558	27.2	369	18.0
150 – 200	302	14.7	545	26.5
200 – 250	94	4.6	328	16.0
250 – 300	14	0.7	108	5.3
> 300	6	0.3	16	0.8
Total	**2,055**	**100.00**	**2,055**	**100.00**

Table 10. Vulnerable features in Hat Yai Municipality for various hazard levels.

Land use	Areas (ha)	Hazard level (ha)				
		very low	low	moderate	high	very high
Residential areas	561.4	11.8	89.7	322.5	110.5	26.9
Commercial areas	200.9	8.5	33.4	127.8	24.0	7.2
Industrial areas	24.9	3.3	2.5	9.3	7.8	2.0
Public utilities and Facilities	400.9	20.0	83.0	212.3	68.3	17.3
Preservation and Recreation areas	10.6	0.3	6.5	3.8	-	-
Agricultural land	162.7	15.3	44.1	84.8	8.5	10.0
Waterbodies	52.1	0.6	15.8	16.8	16.3	2.6
Miscellaneous	641.5	39.2	125.0	332.6	110.6	34.1
Total	**2,055**	**99.0**	**400.0**	**1,110.0**	**346.0**	**100.0**

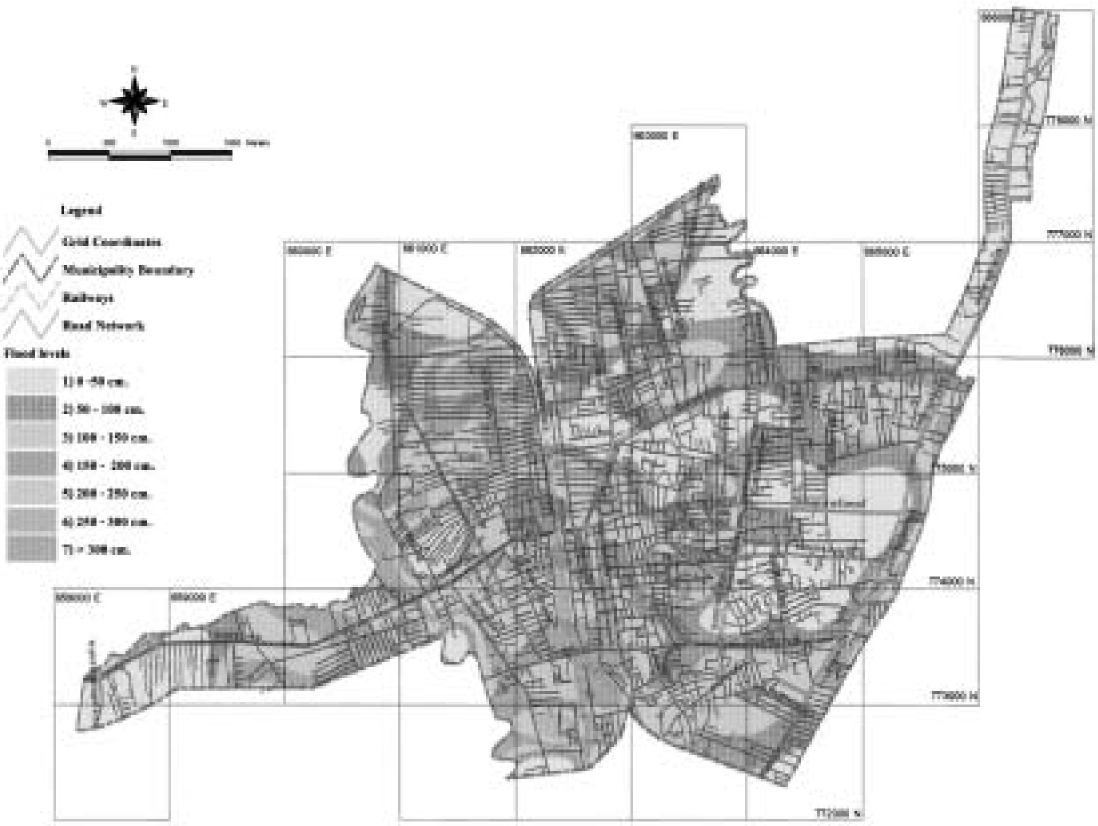

Fig. 3 Map of water level in 1988 flood event in Hat Yai Municipality.

Fig. 4 Map of water level in 2000 flood event in Hat Yai Municipality.

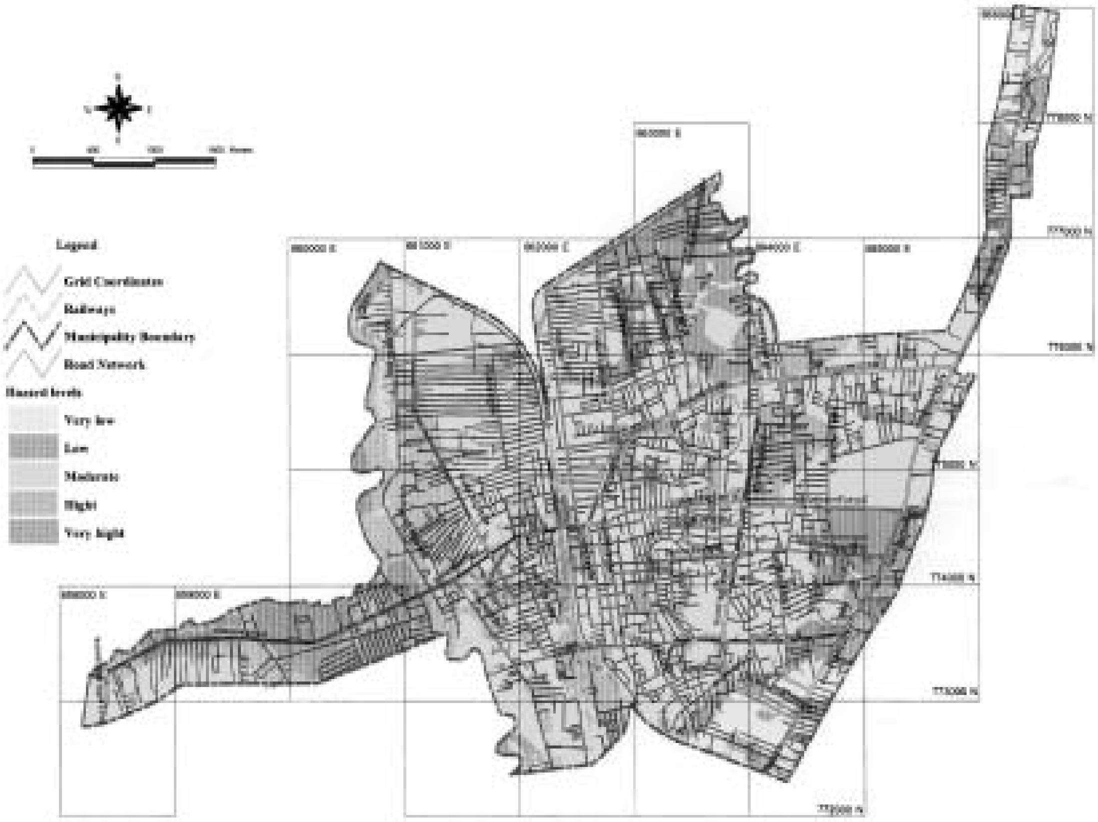

Fig. 5 Flood hazard map of Hat Yai Municipality.

Fig. 6 Flood risk map of Hat Yai Municipality.

Table 11. Vulnerable features in Hat Yai Municipality for various risk levels.

Land use	Areas (ha)	Risk level (ha)				
		very low	low	moderate	high	very high
Residential areas	561.4	-	-	-	424.0	137.4
Commercial areas	200.9	-	-	-	41.9	159.0
Industrial areas	24.9	-	-	-	13.1	11.8
Public utilities and Facilities	400.9	-	-	-	165.5	235.4
Preservation and recreation areas	10.6	-	-	0.4	10.2	-
Agricultural land	162.7	-	0.6	152.3	9.8	-
Waterbodies	52.1	0.3	51.8	-	-	-
Miscellaneous	641.5	39.3	602.2	-	-	-
Total	**2,055**	**39.6**	**654.6**	**152.7**	**664.5**	**543.6**

Table 12. Distribution of areas susceptible to flood hazard in Hat Yai Municipality.

Community name	Areas (ha)	Hazard level (ha)				
		very low	low	moderate	high	very high
Na suan	34.94	5.83	9.04	12.12	7.95	-
Na kai	42.52	0.64	6.20	5.98	29.54	0.16
U tor sor	30.58	-	5.87	9.34	12.85	2.52
Klong tei	128.74	2.18	61.53	21.16	43.87	-
Lung sanamgila	101.90	1.02	22.32	21.36	57.19	-
Na sanamgila	62.58	-	18.26	3.68	40.64	-
Tud utid	24.15	-	3.76	0.30	20.09	-
Muslim	4.54	-	-	-	4.54	-
Jiranakorn	89.59	0.37	29.82	7.44	51.96	-
Tengseting	55.70	-	8.50	3.15	44.05	-
Banja	103.95	-	26.06	21.39	45.70	10.80
Klangna	121.06	-	41.43	41.03	38.60	-
Klongrein	86.91	0.19	32.18	11.34	43.20	-
Tungree	70.64	11.26	16.06	30.41	12.91	-
Uyeepun	7.05	-	1.04	6.01	-	-
Tungsao	104.26	31.62	26.95	45.46	0.23	-
Ratanaviboon	10.75	-	-	7.43	3.32	-
Jarnviroj	23.50	-	-	5.21	18.29	-
Takien	70.61	0.11	6.58	43.17	20.75	-
Flatkarnkeha	21.12	-	-	10.60	10.52	-
Thaihotel	24.26	-	-	16.13	8.13	-
Lungamphur	34.01	-	-	9.75	24.26	-
Nasataneerotfai	21.74	-	-	8.51	13.23	-
Chokesamarn	49.83	-	-	35.73	14.10	-
Ratanautid	142.74	0.18	7.40	125.94	9.22	-
Banghuk	130.09	-	9.38	38.46	76.95	5.30
Mongkolpracha	34.07	-	-	8.44	25.63	-
Nawathadyainai	35.58	-	-	-	6.57	29.01
Sahasart	28.26	-	-	-	6.64	21.62
Rimkuen	126.82	-	-	41.99	40.77	44.06
Panichayagrum	158.44	-	16.49	129.05	12.90	-
Suensatarana	33.14	15.69	16.03	1.42	-	-
Moor	40.93	1.02	18.67	21.24	-	-
Total	**2,055.00**	**70.11**	**383.58**	**743.24**	**744.60**	**113.47**

Consideration therefore should be given to adopting adequate measures to decrease the flood hazard in these areas.

2) Vulnerability analysis.

Utilizing the overlay facility provided in the GIS ArcInfo, the hazard map was overlaid with the municipality's land-use map. The findings explicitly show that 137.4 ha (24.5 %) of residential areas face high or very high flood hazards, and that 85.6 ha (21.4 %) of these areas used for public utilities and facilities are subject to high and very high flood hazards (Table 10). Furthermore, 82.3 ha (63.2 %) of Banghuk Community's total land area and 84.8 ha (66.9 %) of the Rimkuen Community area respectively face high and very high flood hazards (Table 12). Further analysis showed

Table 13. Distribution of areas susceptible to flood risk in Hat Yai Municipality.

Community name	Areas (ha)	Risk level (ha)				
		very low	low	moderate	high	very high
Na suan	34.94	5.83	6.38	3.23	17.60	1.90
Na kai	42.52	0.64	5.89	0.41	28.41	7.17
U tor sor	30.58	-	14.91	-	5.51	10.16
Klong tei	128.72	2.18	46.73	24.79	47.04	7.98
Lung sanamgila	101.90	1.02	20.31	2.02	67.66	10.89
Na sanamgila	62.57	-	18.26	-	35.43	8.88
Tud utid	24.15	-	3.76	-	16.71	3.68
Muslim	4.57	-	-	-	3.22	1.35
Jiranakorn	89.59	0.37	27.78	2.46	37.10	21.88
Tengseting	55.69	-	8.50	-	25.43	21.76
Banja	103.95	-	43.84	1.30	22.28	36.53
Klangna	121.16	-	26.03	50.47	28.25	16.41
Klongrein	86.92	0.19	29.76	4.71	38.43	13.83
Tungree	70.65	11.26	14.18	1.75	40.72	2.74
Uyeepun	7.05	-	1.43	-	2.44	3.18
Tungsao	104.26	9.05	16.92	13.89	45.77	18.63
Ratanaviboon	10.76	-	3.87	-	2.92	3.97
Jarnviroj	23.57	-	9.69	4.54	1.14	8.20
Takien	70.61	0.11	36.89	6.56	8.30	18.75
Flatkarnkeha	21.13	-	6.31	-	2.84	11.98
Thaihotel	24.27	-	10.73	-	5.92	7.62
Lungamphur	34.00	-	15.82	-	1.53	16.65
Nasataneerotfai	21.75	-	4.13	-	3.10	14.52
Chokesamarn	49.83	-	10.59	-	21.59	17.65
Ratanautid	142.74	0.07	77.66	4.85	39.15	21.01
Banghuk	130.08	-	68.79	16.51	7.95	36.83
Mongkolpracha	34.07	-	9.79	-	2.20	22.08
Nawathadyainai	35.58	-	17.64	0.43	2.15	15.36
Sahasart	28.26	-	3.66	0.45	-	24.15
Rimkuen	126.82	-	49.06	13.67	19.11	44.98
Panichayagrum	158.44	-	35.67	0.15	38.11	84.51
Suensatarana	33.14	9.74	6.87	0.41	15.69	0.43
Moor	40.74	-	3.66	-	29.21	7.86
Total	**2,055.00**	**40.47**	**655.50**	**152.58**	**662.92**	**543.53**

that 64.1 ha (50.5%) of Rimkuen Community's land area was subject to high and very high flood risk (Table 13).

It is important that Hat Yai Municipality publishes hazard and risk maps in hard copy and distribute them to the communities in order to enhance public awareness about the levels of flood hazard and flood risk they are likely to face. As of today, no municipality in Thailand has maps of this level of accuracy and degree of detail.

4.5 Risk reduction measures.

Complete prevention of floods through structural measures is almost a physical impossibility and is uneconomic (Askew, 1991). Properly designed and operated flood works, however, can prevent or mitigate flood damage within physical and economical limits. The application of structural mitigation activities, however, may have a negative impact on life, property and the natural environment (Ertuna, 1991). For instance, construction of levees through out low-lying areas without providing adequate drainage facilities can lead to internal flooding that adversely affects residents. Levees may also worsen the hazard in other locations by diverting water from one area into another, and may deprive the natural environment of critical habitats, such as wetlands. Furthermore, construction of large infrastructure type projects, such as drainage canals or diversion channels, to prevent and mitigate flood disasters is realized as no longer feasible in Hat Yai Municipality due to the scarcity of available land and the impact on the natural environment. Structural mitigation practices therefore should not be viewed as a panacea for all the problems associated with flooding in this municipality. To effectively reduce the risk of flooding, an alternative approach that focuses on non-structural measures is needed to supplement existing structural efforts. Such non-structural alternatives would not involve major construction and therefore could have proportionately less environmental impact (Geipel, 1993).

Risk of flooding can be reduced by decreasing hazards, reducing or eliminating the vulnerability of the elements at risk, or a combination of both actions (DeGraff, 1989). Adoption of non-structural risk reduction measures, including development of land-use planning, installation of flood forecasting and warning systems, adoption of preparedness measures against flooding, and creation of risk-transfer instruments, such as insurance, in flood risk areas can effectively reduce the effect of flooding on lives and property. Application of land-use planning can reduce flood hazards by allocating less vulnerable land uses to the most hazardous areas or by avoiding development in those locations. Relocation of the residents of high risk areas would reduce their vulnerability. Creation of a "culture of safety" in flood-prone areas also could reduce a flood-effected community's vulnerability by creating people's awareness of possible flooding or by the building of safer housing that will withstand flooding in areas vulnerable to future flood damage. The design and installation of flood-forecasting and -warning systems which allow people in high risk areas to move to less hazardous locations during flooding can effectively reduce the elements at risk. Local preparedness to cope with potential disasters also would effectively reduce loss of life and damage to property in high risk areas. Introduction of insurance to spread the losses of future floods among those directly affected also could be used to reduce risk of future floods.

Several environmental management measures could also be implemented to reduce the flood disaster risk (United Nations, 2002). For instance, maintenance of the environmental and ecological stability of the upland watershed through the enrichment of forest cover to restore its flood protection values, prevention of encroachment by cultivators to maintain a resilient environment to avert future disaster, and adoption of soil and water conservation measures in upland cultivation to reverse environmental degradation, can be used to reduce flood hazards. To enhance the natural resilience to future floods, the basin's headwater source areas should be demarcated for further enhancement of the forest environment. Wetland functions, particularly water storage, should be rehabilitated and conserved to absorb the impact of flooding. Prevention of drainage congestion by removing soil sediment, debris, and weeds that block stream channels also is an environmental action that reduces vulnerability. In addition, flood risk assessment should be incorporated in the requirements of the Environmental Impact Assessment (EIA). An expanded EIA process would provide the basis to ensure that all proposed initiatives would include considerations both of vulnerability reduction and lessening the environmental impact. It is anticipated that the adoption of non-structural risk reduction measures and the incorporation of environmental dimensions into risk reduction schemes would enable Hat Yai Municipality to become more resilient to the effects of flood hazards and support sustainable development both in the municipality and southern Thailand.

5. CONCLUSIONS AND RECOMMENDATIONS

Due to geographical characteristics, unplanned urbanization and deforestation in the upland watershed, Hat Yai Municipality has a high level of flood risk. Flooding has become a regular phenomenon and continues to threaten the vulnerable social and economic infrastructure of the municipality. Extreme flood events have had devastating effects on the standard of living of the population and on development prospects. In attempts to prevent and mitigate catastrophic flooding, considerable mitigation works have been undertaken in Hat Yai Municipality, most of them structural. The flooding of 10 December 2003, however, demonstrated that these structural measures undertaken so far are not adequate to withstand flood threats. Recognizing the frequency and increased severity of flooding in this municipality, non-structural alternatives to reduce flood risks need to be promoted to supplement existing structural investments. Therefore, it is recommended that Hat Yai Municipality adopt the following non-structural actions as a matter of priority to strengthen and improve its ability to better respond to flood risks:

1) Set up a Hat Yai Disaster Management Authority (HYDMA). The authority, chaired by the Songkla Governor, should comprise a body made up of representatives from concerned government agencies, experts, academics, NGOs and local residents. The authority would propose, for approval, policies and measures for flood disasters. An annual meeting of the authority would be held before the rainy season to study and review the progress of measures based on up-to-date information, to check operational readiness for potential flood disasters, and to prepare proper measures and action plans. The authority would also be responsible for managing and coordinating responses and relief measures during flooding.
2) Raise the awareness of the municipality's residents. They need to be aware of the natural hazards likely to be faced, what specific preparations need to be made before an event, what to do during the event, and what actions to take in its aftermath. Brochures, posters, calendars, and public service announcements on radio and television should be used to stimulate public awareness.
3) Improve the forecasting and warning systems. Notice of an impending flood disaster issued well in advance can protect lives and property. Prediction accuracy and lead times therefore should be improved through the application of such state-of-the-art science and technology as radar and weather satellite information. Concerted effort is also needed to improve social and organizational abilities to disseminate warnings.
4) Undertake research on disaster-related topics. Even though the prediction capability for flood hazards in the Khlong U–Taphao Basin, in which Hat Yai Municipality is located, have increased significantly, further research and modernization of weather prediction facilities are required to provide the accuracy and lead time critical to decision makers who need to activate evacuation plans. Application of advance techniques in soil physics, geotechnical engineering, GIS and remote sensing for flood risk assessment and reduction also are needed. Research should be accelerated to determine what the detrimental impacts of flood disasters are on human health and the natural environment.

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REFERENCES

Askew, A. 1991. Learning to live with floods. Nature and Resources 27 (1) : 4-8.

Bangkok Post. 2000. Southern flooding: Aid pours in as death toll rises. Bangkok Post Newspaper. 25 November 2000. Bangkok.

DeGraff, J.V. 1989. Landslide activity resulting from the November 1988 storm events in southern Thailand and associated resource recovery needs. p. 1-43. *In* Safeguarding the Future. Restoration and Development in the South of Thailand. Jiramedha Advertising and Printing, Bangkok.

Donovan, D. G. 1989. Rehabilitation and development of forest and upland resources in the storm-damaged areas of southern Thailand. p. 197-244. *In* Safeguarding the Future. Restoration and Development in the South of Thailand. Jiramedha Advertising and Printing, Bangkok.

Ertuna, C. 1991. Integrated approach to flood disaster management and rural development. p. 93-110. *In* Disaster Management and Regional Development Planning with People's Participation. Vol. 2. United Nations Centre for Regional Development. Dhaka, Bangladesh.

ESCAP. 1989. ESCAP Technical Assistance to Flood-effected Areas in Southern Thailand. Mission to Surat Thanni and Nakhon Si Thammarat Province. 12-16 December 1988. ESCAP Mission Report. Bangkok.

French, S. P. 1991. Utilization of Geographic Information Systems for Land Use Planning and Disaster Preparedness. p. 3-28. *In* Disaster Management and Regional Development Planning with People's Participation. Vol. II. United Nations Centre for Regional Development. Dhaka, Bangladesh.

Geipel, R. 1993. The river Danube flood of 27 March 1986. p. 111-118. *In* Nemec, J., Nigg, J. and Siccardi, F (eds). Prediction and Perception of Natural Hazards. Symposium Proceedings. Dordrecht, The Netherlands.

Pachauri, A.K. and M. Pant. 1992. Landslide hazard mapping based on geological attributes. Engineering Geology 32 : 81-100.

Pramojanee, P., C. Tanavud, C. Yongchalermchai and C. Navanugraha. 1997. An application of GIS for mapping of flood hazard and risk area in Nakorn Sri Thammarat Province, South of Thailand. p. 198-207. *In* Proceedings of International Conference on Geo-Information for Sustainable Management. 17-21 August 1997. ITC. Enschede, The Netherlands.

Rau, J. L. 1991. Assessment and mitigation of landslides in rural areas in southeast Asia. p. 210-235. *In* Disaster Management and Regional Development Planning with People's Participation. Vol. 2. United Nations Centre for Regional Development. Dhaka, Bangladesh.

Shook, G. 1997. An assessment of disaster risk and its management in Thailand. Disasters 21 (1) : 77-88

Tanavud, C., C. Yongchalermchai, A. Bennui and C. Navanugraha. 2000. Application of GIS and Remote Sensing for Landslide Disaster Management in Southern Thailand. Journal of Natural Disaster Science. 22 (2) : 67-74

Tanavud, C., P. Kheowvongsri, C. Yongchalermchai, W. Leowarin, O. Densrisereekul, A. Bennui, J. Murase and M. Kimura. 2001a. Effects of land use patterns on soil and water quality in Khlong U-Taphao Basin. Thai. J. Agric. Sci. 34 (1-2) : 15-31.

Tanavud, C., C. Yongchalermchai, P. Pramojanee, W. Wangworawut, A. Bennui, O. Sukboon and P. Pramojanee. 2001b. Application of GIS and Remote sensing techniques for flood disaster management in Songkla Province. Songklanakarin. J. Sci. Technol. 23 (3) : 425-442.

Tobin, G.A. and B. E. Montz. 1997. Natural Hazards. The Guilford Press. London. 388 pp.

UNDP. 1994. Strengthening Disaster Management Strategies in Thailand. Asian Institute of Technology. Bangkok. 83 pp.

United Nations. 2002. Living with Risk. Disaster Reduction Strategy. United Nations, Geneva. 382 pp.

Usher, A.D. 1994. After the forest. Thai Development Newsletter. 26 : 20-32.

WHO. 2002. Environmental Health in Emergencies and Disasters. A Practical Guide. Marketing and Dissem ation. WHO. Geneva. 205 pp.