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Natural hazards in Taiwan

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ABSTRACT: Due to the frequent earthquake, steep slope, weak geological formation, erodible soil, and intensive rainfall in summer season, several kinds of natural hazard such as earthquake, typhoon, flooding, landslide and landsubsidence have suffered in Taiwan. Landslide and soil loss are major hazards in mountains and hills while flooding and land subsidence in the alluvial plain and low land by the coast. The magnitude and occurrence of each kind of natural hazard are varied according to intensity of process and physical geographic environment. However, the research on natural hazards have been promoted by academic institution and numerous reduction treatments such as dams, dikes have been constructed to mitigate the vulnerability to natural hazards.

1. Introduction

Taiwan is located about 150 km southeast off the coast of mainland China. It is spindle in shape with an area of 36,000 km^2 and 390 km in length from north to south, 140 km in width from east to west. Geographically, Tropic of Cancer passes through mid Taiwan. It is warm, humid, and influenced by the monsoon and typhoon strongly. Under the multiple effects of climatic, geologic, geomorphic processes and human agency, Taiwan suffers a great damage from natural hazard each year.

2. Physical geographical environment

2.1. *Weak geology*

Taiwan is located on the collision zone between Eurasian plate and Philippine plate. Strong folding, faulting, uplift and frequent earthquake are resulted from continual stress coming from southeast. Schist is distributed in the eastern flank of Central Range and slate, interbedding sandstone – shale occupy widely in the Hsueh Shan (Snow Mt.) and Ali Mt. The new alluvium spreads over the western alluvial plain and coastal plain. The heterogenic lithology is the main factor of differential weathering and erosion.

2.2. *Steep topography*

By the influence of plates collision, Taiwan has been uplifted since early geologic time. Several mountains are paralleled from north to south which occupy one third of the island. The highest peak Yu Shan (Morison Mt.) is rising near 4000 m above sea level. The area ratio between plains, hills and mountains are 3:4:3 (Table 1) (Hsieh et al. 1975). It is obvious that Taiwan is a hilly mountainous island.

2.3. *Unevenly distributed rainfall*

Most of the annual of rainfall 2540 mm in Taiwan comes from typhoon and convection rain. Under the effect of landform and monsoon, the distribution of rainfall is not uniform both in time and space. Generally speaking, the amount of rainfall in mountains is larger than in plains, larger in eastern coast than in western coast. There are 1500–2000 mm in western plain and hills, and more than 3000 mm in mountains.

The rainfall concentrates in summer season, accounting for 65% in northern Taiwan. Toward the south, the concentration is increasing, 70–80% in the middle, over 90% in the south. Due to the concentration of the rainfall, the hazard of flooding and drought can occur easily, especially in southern Taiwan.

2.4. *Frequent earthquake*

Taiwan is located in the Circum-Pacific seismic zone. From the historical and instrumental records, Taiwan had 20,000 earthquakes with magnitude $\geqq$ 4.0 from 1604 to 1988 (Cheng et al. 1989). Most of them are distributed in eastern and western Taiwan. Isoseismal

Table 1. Altitude, slope and relief of Taiwan Island

	Altitude (m)	%	Slope (degree)	%	Relief (m/km^2)	%
Plain	0–100	31.2	< 10	33.0	0–100	31.4
Hill	100–1000	37.7	10–30	39.8	100–500	40.3
Mountain	1000–4000	31.1	30–55	28.2	500–1100	28.3
M	660 m		15° 40′		282 m	
QD	600 m		15° 00′		240 m	

maps of the earthquakes with maximum intensity greater than or equal to five show that Hualien, Chiayi and Miaoli are the three most active earthquake areas. Earthquakes either produce a destructive damage directly or cause slope failure indirectly.

3. Types and distribution of natural hazard

Due to weak geological formation, steep terrain, erodible soil, intensive rainfall and frequent earthquake, Taiwan has suffered a great damage from natural hazard since early time. The increase in population, economic development and urbanization force people to demand more land and public facilities. The damage of natural hazard has been increasing when the land is overused.

According to investigation, the natural hazards occurred in Taiwan are earthquakes caused by endogenous process, typhoon, flooding, landsliding caused by exogenous process, and land subsidence, caused both by natural origin and human beings.

3.1. *Earthquake*

There were 97 hazardous earthquakes recorded during the period of 1898 to 1988. A great damage has been suffered from these earthquakes. Totally, 5567 persons were killed, while 18,902 injured, 50,986 houses were collapsed, and 138,136 houses were partially collapsed (Cheng et al. 1989). In addition, roads and bridges are broken. Among them, the largest 17 earthquakes are destructive (Table 2). All of them are shallow earthquakes and produce a greater loss of life, property and economic installation. Most of the damaged earthquakes are distributed in the plain and low hills in western Taiwan, such as Chiayi and Miaoli-Taichung and coastal plain in eastern Taiwan, such as Hualien and Ilan.

3.2. *Typhoon*

Apart from earthquake, typhoon is the most destructive natural hazard. Strong winds and heavy rainfall not only bring a direct loss of human life and property but also the soil and land loss. Frequent

Table 2. Major damaged earthquake from 1901–1988

Date	Location	Earthquake magnitude	Life loss		House loss		Geomorphic damage
			Killed	Injured	Collapsed	Partially damaged	
1904/11/06	Peikang	6.5	145	148	661	3178	Crack, blown sand
1906/03/17	Meishan	7.1	1258	2385	6769	14218	Fault, blown sand, crack
1906/04/14	Paiho	6.7	15	84	1794	10037	Blown sand, crack, landslide
1916/08/28	Sun Moon L.	6.5	16	159	614	4885	
1917/01/05	Puli	6.1	54	85	130	625	
1927/08/25	Hsinyin	6.6	11	63	214	1209	Crack, blown sand
1935/04/21	Shihtang	7.1	3276	12053	17907	36781	Fault, crack, landslide
1935/07/17	Houlung	6.5	44	391	1734	5887	
1941/12/17	Chiayi	7.1	358	733	4520	11086	Landslide
1946/12/05	Hsinhwa	6.5	74	482	1954	2084	Landslide
1951/10/22	Hualien	7.3	68	856	–	2382	Landslide
1951/11/25	Taitung	7.3	17	320	1016	582	Landslide
1957/02/24	Hualien	7.3	11	12	44	64	Landslide
1959/08/15	Hengchun	6.9	17	68	1214	1375	Landslide
1964/01/18	Naihsi	6.5	106	650	10502	25818	Landslide
1972/04/24	Juishui	6.9	5	17	50	98	Landslide
1986/11/15	Hualien	6.7	15	62	35	32	Landslide

typhoons hit Taiwan from April to November and concentrate on summer in July, August and September. According to the records from 1961 to 1990, 89 typhoons pass or land on Taiwan totally. The tracks of typhoon can be classified into seven categories. Two-thirds of 89 typhoons pass through northern and southern Taiwan (Figure 1).

The damage of typhoon is borne due to its strong wind and heavy rain. The magnitude of damage depends on its intensity and track. Because typhoons hit on eastern Taiwan frequently, destruction was brought in this area. Under the interruption of Mountain, western Taiwan was protected and intensive typhoon turned to light cyclone depression when passing over Central Range. But if typhoons land on western Taiwan directly, western plain is attacked by torrential storm without mountain protection. For example, Thelma hit on Kaoshiung located southwestern Taiwan on 25 July 1977. Under the strong wind attack (maximum wind velocity 29 m/sec), western plain was destructed although it is not the highest speed in the records. At Kaoshiung Harbor, eight gantry cranes and 46 electric towers were broken down, fourteen ships were sunk. In addition, 49 persons were killed and lost, 298 persons were injured, near 5,000 houses were all torn down, 22,000 houses were partially damaged.

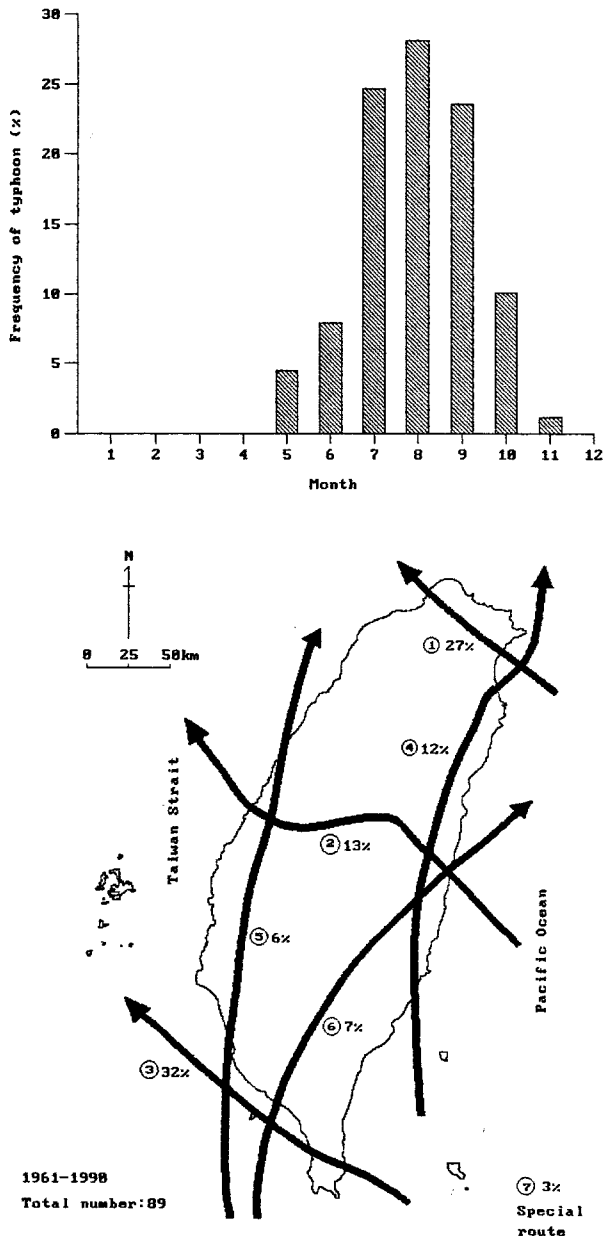

Figure 1. The frequency of typhoon's track in Taiwan.

3.3. *Flooding*

Most of flooding in Taiwan has been resulted from typhoon and cyclone. The torrential rainfall exceeds the capacity of stream channel and drainage ditch. People who live in the lowland were suffered from flooding. The damage area of flooding are varies from different typhoon's track (Chen 1986). 26 major floodings have occurred during 1945 and 1990. Most of them, the maximum rainfall exceeded 500 mm in two or three days (Chih 1978). A great damage, including personal life, property and public facilities has been suffered (Table 3). For example, the largest flooding occurred on 7 August 1959 which was so called "August 7th Flooding". There were 500–1000 mm, in the middle and south area in two days, torrential stream water breaks the river bank of Tatu and Choshui River and inundate paddy field, village and urban area. Damaged area covers 1047 km^2, 300 thousands persons are ravaged, with a total loss is 3.7 billion dollars which accounted for one tenth of GNP in that year (Chen 1967).

Easily inundated areas in Taiwan are distributed in low hills, alluvial plain and lowlands by coast that cover an area of 114893 ha. approximately according the survey reports of drainage improvement works by Water Conservancy Bureau (1991). The flooding area could be classified into three zones:

1) *Coastal zone*: Low relief, land subsidence and tide intrusion reduce the capacity of water seepage. When surging waves spill over sea dike or extreme peak flow comes from upstream, the coastal zone will be ravaged. Such damaged zone is distributed in western coast and northeastern coast.

2) *Urban and suburban area*: Due to rapid population growth and urbanization, people demand more land for living urgently. The forest lands have changed for settlement. The old drainages can not afford enough capacity for the increasing peak flow that riverain lowlands have been inundated. Such damaged zones are distributed in Taipei, Taichung, and Taoyuan etc.

3) *Rural area*: Insufficient irrigation and drainage ditch in the cultivated field cannot drain water out in raining season. A great loss of the inundation for the agriculture is borne islandwide.

Table 3. Major damaging typhoon in Taiwan during 1945–1990

Date	Name of typhoon	Rainfall (max.) mm	Damage area	Life loss		Houses damage	
				Killed	Injured	Collaped	Partially damaged
1959 08/07–08/08	Ellen	1109	M,S	1075	942	27466	18303
1960 07/31–08/02	Shioley	1060	M,S	183	430	10513	13404
1963 09/09–09/12	Gloria	1735	N,M	312	450	13950	10783
1967 10/16–10/18	Carla	1000	N,NE	82	203	984	1049
1968 09/28–10/01	Elaine	1193	E,N	60	27	1413	765
1969 09/26–09/27	Elsie	684	M,S	105	371	12264	20582
1969 10/01–10/04	Flossie	2145	N,NE	105	41	2647	3322
1970 09/06–09/07	Fran	532	M,N	130	47	2002	863
1972 08/15–08/17	Betty	825	M,N	27	17	666	11
1973 10/07–10/10	Nora	1962	E	68	85	1251	433
1974 09/27–09/29	Wendy	552	N,E	54	40	201	141
1974 10/10–10/12	Bess	1965	E,N	17	3	264	112
1975 09/22–09/23	Betty	582	E	20	47	957	1798
1976 09/09–08/10	Billie	683	N	12	24	245	702
1977 08/24–07/25	Thelma	608	S	49	298	3385	22038
1977 07/31–08/01	Vera	515	N	114	65	1472	6642
1982 07/26–07/29	Andy	750	N	21	24	319	838
1982 08/06–08/11	Cecil	454	N	27	9	57	44
1985 08/22–08/24	Nelson	785	N	10	24	11	12
1986 08/21–09/03	Wayne	487	M,S	87	422	6624	31532
1986 09/17–09/20	Abby	986	M,S,E	14	39	98	312
1987 10/23–10/27	Lynn	739	N	63	8	254	277
1988 08/14–08/16	Doyle	536	M,S	20	6	56	90
1989 09/08–09/13	Sarah	719	E,M,S	52	47	430	760
1990 06/21–06/23	Ofelia	470	E	38	10	88	139
1990 08/18–08/19	Yancy	467	N	30	15	45	96

M: Middle Taiwan; S: Southern; N: Northern; E: Eastern; NE: Northeastern.

3.4. *Landslide*

Due to steep terrain, weak geological formation erodible soil and intensive rainfall in summer season, the landslides on the slopeland above 1100 m occur frequently. According to the investigation of the Soil Conservation Bureau, there are 2535 landslides totally with an area of 8,100 ha. of slopeland during 1981 and 1989 (Wu et al. 1989). Geographically, 60% of landslides occur on the slopeland ranging 100–500 m in altitude and 15–40° in slope. The landslides range 0.1–1 ha. in area and 0.5–2 m in depth. They are significant by weak formation such as mudstone, shale and unconsolidated soil and gravel bed. The types of landslide include falling, sliding, debris flow and creep. About 80% of them is sliding. The main causes of landslide have been identified as weak rock, runoff concentration, undercutting and deepening by the stream, reclamation and road construction (Chang 1993). Among them, road construction, weak rock and runoff concentration are the three major causes. The estimated damage induced by landslide is about 3 billion dollars each year averagely. The damaged landslides to human life and property are distributed in the slopeland around urban and suburban area.

3.5. *Coast erosion*

Coast in Taiwan can be classified into four types by geomorphic characteristics: rocky coast in north, sandy coast in west, coral coast in south and fault coast in east. Most of the coast keeps in emergence under the continual uplift circumstance. But active weathering and strong erosion lead a high rate of denudation to the island. Eastern coast with significant with emergence and erosion while western is emergence and progradation. Western coast has been prograded westward with a rate about 50 m/year in the past 300 years (Shih 1979). But since half century ago, works of soil conservation have been done, sand supply has been decreased by the interruption of reservoirs and check dams. On the other hand, the construction of the jetties to prevent harbor from the wave interfere the supply of drift sand along the coast. The coast has been eroded if the sand cannot be fed by river and longshore current sufficiently. Another cause to coast erosion is land subsidence which has been caused by the over pumping for aquaculture. Coast land has been inundated by rising water level and even been eroded whenever the intensive typhoon passed.

According to Water Conservance Bureau investi-

gation, it is obvious to find western sandy coast being eroded especially in Yunlin, Chiayi, Tainan, Kaoshiung and Pingtung coast. In these areas, coastline has been retreated about several ten centimeters to 2 meters per year. Eastern coast is quite stable compared to western coast, but strong storm attacking weak rock coast still produces a serious shoreline retreation. The eroded coast at Tawu, Chintsun and Hsinkang in Taitung county and Tanman in Hualien county. The coasts have retreated 2–3 m in average per year that force roads and houses to move toward inland. In the vicinity of Hualien, the extension break-water of Hualien Harbor changes the balance of coastal stability. The coastal land has been attacked by the reflecting wave although it is protected by sea wall. The coast line has retreated 200 m during 1984–1990.

3.6. *Land subsidence*

In Taiwan, land subsidence occurred due to coal mining since last century. There is not much damage from mining, but since 1950, in response of rapid economic and industrial growth groundwater has been developed out of great demand. After 1970, along coastal lowland, the ground water has been pumped for irrigation and aquaculture. The damage of land subsidence takes place when the water is overpumped at specific area in short time. Taipei Basin and western coast and Ilan coast are the areas with the most serious subsidence.

3.6.1. *Taipei Basin*

To supply sufficient water for domestic and industrial use, ground water has been pumped. Without control, the withdrawal exceeds recharge that induces land subsidence. In the past 10 years from 1960 to 1970, the annual rate of subsidence is above 10 cm. According to bench mark levelling, accumulative amount of subsidence are 221 cm at Hsinshenshe, 214 cm at North Gate, 158 cm at Hsinchuang and 112 cm at Shihkueili in Taipei Basin (Yang 1985). After 1970, the ground water withdrawal has been controlled while the center of subsidence shifts to northwestern suburban area of Taipei. Since 1967 the rice paddy and vegetation garden have become inundated and turned into marshland. The area covers 500 ha. and with a depth of 0.5~1.1 m (Shih et al. 1982). From 1974 to 1978, the rate of land subsidence is more than 10 cm each year.

Since 1980, in order to control the land subsidence and flooding in this area, Water Coservancy Bureau has built a 7.7 km spillway, using the northern part of marshland as a stagnant flood area. In contrast to it, the southern part of marshland is filled up to 3.4 m by 6.6 million m^3 lateritic soil and gravel dug out from Linkou Tableland (Figure 2). The filled up area is constructed as an industrial park. Also, the dug out

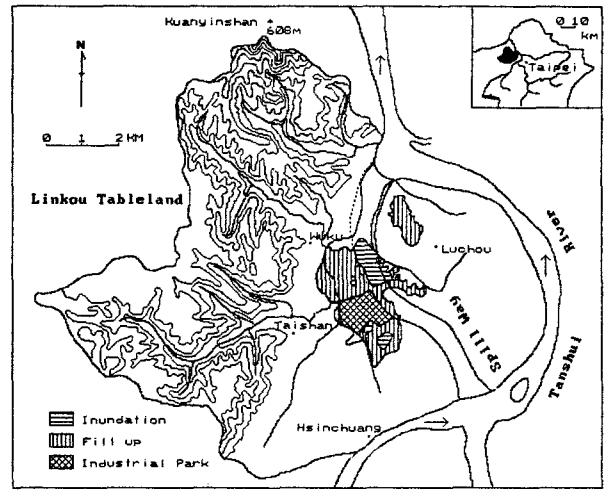

Figure 2. The changes of marshland in Taipei Basin.

slopeland of 12 ha. is designed as a new community site.

3.6.2. *Coastal land*

In a long term, western coast is water deficit due to intensive evapotranspiration. From September to January, the paddy fields need water supplied from an irrigation canal. Unfortunately, the water supply is normally not sufficient because it is located at the terminal part in the whole irrigation system. Consequently, ground water becomes the main water resource in the coastal area. Since 1960, under the rapid economic growth, aquaculture has been developed because the profit from fish culture is higher than agriculture. Without control, groundwater has been pumped to supply the great demanding for aquaculture. In Pingtung, concerning coastal land during 1957 and 1985, the numbers of pumping well has increased from 227 to 4936. The area of fish pond has been expanded 2–3 times. The withdrawal amount 320 million m^3 exceeds the recharged amount 189 million m^3. The intensive over-pumping takes place in narrow coastal land. And, that causes the environmental disaster including land subsidence, water saltilization, and land decertification. During 1975–1985, the damaged area is over 105 km^2, the total amount of subsidence is about 230 cm, shoreline reateated 100 m toward inland with a land loss of 40 ha. Since 1980, the same problem takes place in Yunlin, Chiayi and Ilan. The total amount of subsidence is 30–50 cm in Yunlin and Chiayi during 1981–1986 (Yang 1986) and 10–20 cm in Ilan during 1984–1990. The damaged areas cover 176 km^2 in Yunlin, 250 km^2 in Chiayi and 210 km^2 in Ilan.

4. Hazard precaution and reduction

Reviewing the natural hazard occurred in Taiwan, typhoon itself not only brings strong wind but also torrential rainfall and surge wave which is the most

seriously destructive process while compared with the others. The frequency of occurrence is 3.5 per year in average that is most frequent among the natural hazard. The total damage caused by typhoon is over several billion dollars including damage and recovery. Earthquake occurred one time per year in average is the second damage in Taiwan. Without any caution, it resulted in a great damage in densely populated city. According to the geographic region, the landslide and soil loss are major hazards in mountains and hills, while the earthquake, flooding, coastal erosion and land subsidence in plain. It is obvious to know that the western plain is the most prosperously cultivated area but bearing a great damage and potential hazard (Figure 3).

It is undoubted to know that Taiwan is stressed by the earthquake, typhoon, landslide, coastal erosion, and land subsidence, etc. However, the effort for precaution and mitigation of natural hazard is undertaken continually. The software is to understand the mechanism and process of each kind of natural hazard. Such as the research of nature of typhoon includes wind velocity, direction, rainfall, track, and the effect of topography. It is important to reduce the damage with a precise typhoon forecast. The hardware is to build dikes or spillways to prevent from flooding, construct sea wall and jetties to prevent the wave attack. The control of pumping water and disperse of the pumping well are helpful to gentle down the land subsidence, and it is important to set up coastal management law.

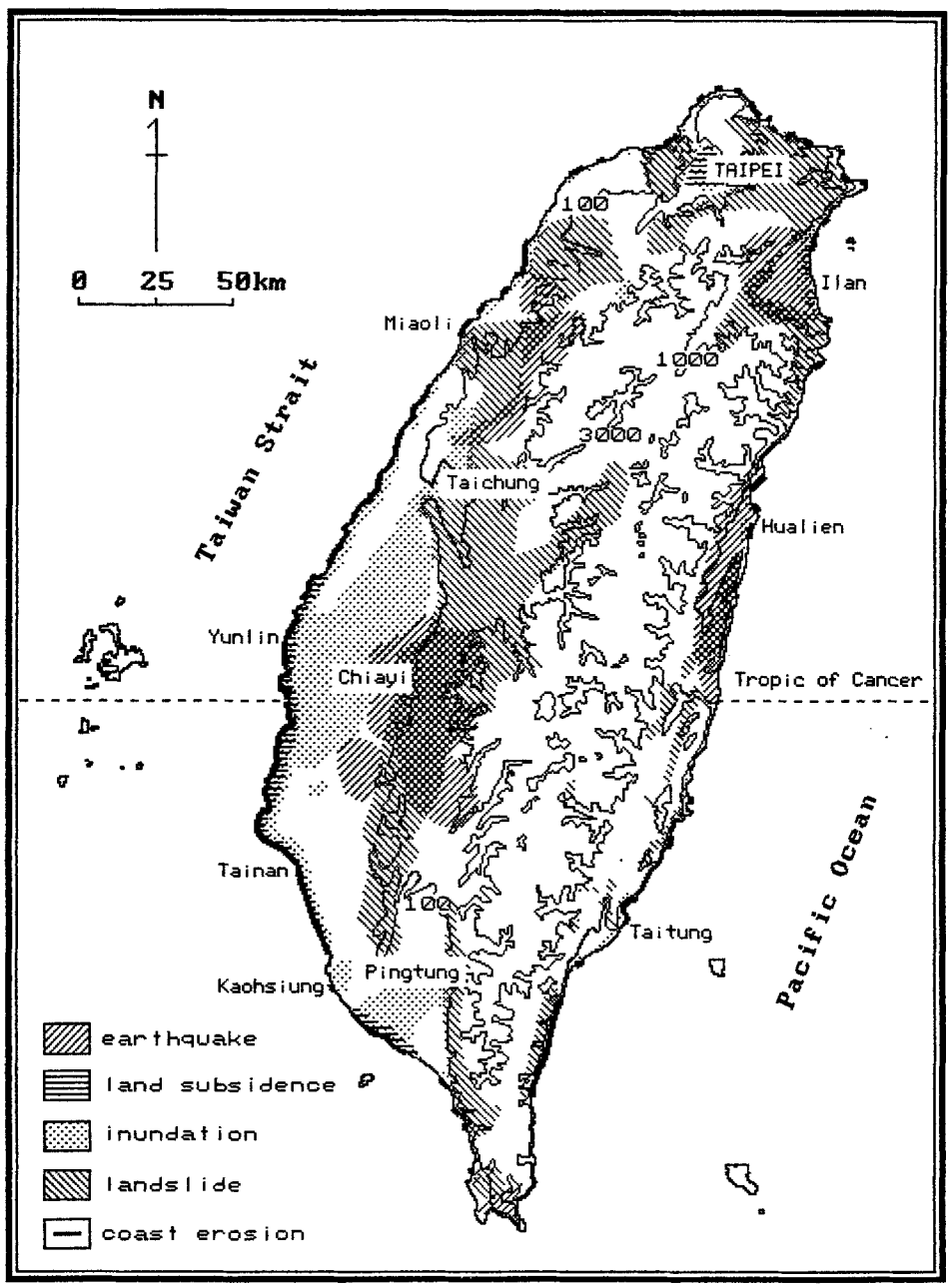

Figure 3. Geographical distribution of natural hazard in Taiwan.

5. Conclusion

Under the multiple effects of climatic, geologic, geomorphic processes and human agency, Taiwan suffers a great damage from earthquake, typhoon, flooding, landslide, coastal erosion, and land subsidence, etc. Through the understanding about the nature and geographic distribution of natural hazard, numerous reduction treatments have been done to reduce the risks associated with exposure to natural hazard. Such as rivers have been dammed, diked and deepened, coastline has been protected by sewalls, buildings have been elevated above the level of flooding and structures have been strengthened to reduce the damage of earthquake. We hope the efforts are effective to mitigate our vulnerability to natural hazard.

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