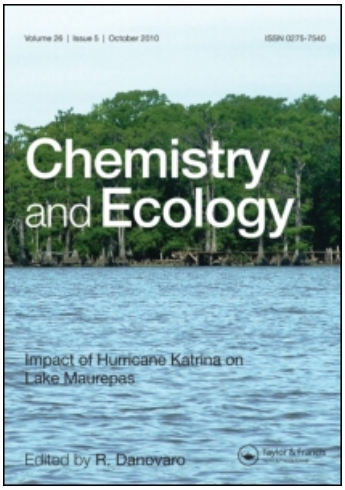

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The Coastal Environmental Characteristics of Taiwan

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THE COASTAL ENVIRONMENTAL CHARACTERISTICS OF TAIWAN

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There are three major factors affecting the coastal environment in Taiwan: tidal current, long-shore current and land subsidence. In Taiwan, most industrial areas are located on the southwestern coast. Most of the pollutants from the factories are discharged directly to the ocean, harbours or rivers. The pollutants in harbours or rivers will eventually be delivered to coastal waters. There, the tidal current is the major force dispersing the pollutants nearshore. The polluted water extends to an area about 5 km on both sides from the discharge source, and within about 3~4 km off-shore. In this study, Hsien-Da Harbour in southwestern Taiwan is cited to explain the effects of tidal current on the coastal environment. The long-shore current induced by breaking waves is the major force shaping the coastal morphology. Along the western coast of Taiwan, the long-shore current mainly flows northward along the southern section, and southward along the northern section. In the last one hundred years, in general, the coast has been eroded along the northern and southern sections of western coast, and some reclaimed lands were formed in the middle section. Recently, erosion in some coastal zones is quite serious because of excess groundwater extraction, especially along the southwestern coast. Groundwater extraction might also induce land subsidence. There are some areas near the coast which suffer serious land subsidence problems.

KEY WORDS: coasts, pollution, subsidence, Taiwan

INTRODUCTION

Most of the 21 major rivers and harbours in Taiwan are seriously polluted, especially on the western coast, where major pollutants come from harbours and rivers. The weather pattern in Taiwan also makes the situation worse; it is wet in the summer, and dry in the winter. Industrial effluents discharged from riverside factories into the almost dry river bed accumulate during the dry season. These pollutants are released to the coastal areas during the spring rainy season in large quantity, jeopardizing the mariculture environment. This paper cites conditions in Hsien-Da Harbour to exemplify the tidal current process which transports pollutants along the coast. Hsien-Da Harbour is located on the southwestern coast of Taiwan (see Figure 3), where green oysters were found (Hung and Han, 1991). The long-shore current induced by the breaking waves is the major force shaping the coastal morphology. Recently, land subsidence induced by groundwater extraction also plays an important role in affecting the coastal environment in Taiwan.

DISCUSSION

There are three major factors affecting the coastal environment; they are the near-shore tidal current, long-shore current induced by breaking waves and land subsidence.

1. *Tidal Current*

Along the western coast of Taiwan, the tidal current flows northward in the southern section, and southward in the northern section during flood tide. The current direction reverses during ebb tide (Fan, 1991) as shown in Figure 1. The semi-diurnal tide dominates the current in the vicinity of Hsien-Da Harbour (Chern, 1982). The current velocity ranges from 10 to 30 cms^{-1}, with the current direction mainly parallel to the coastline (Su *et al.*, 1986). The current flows in the NNW direction during flood tide, and in the SSE direction during ebb tide. Figure 2 shows the tidal range along the western coast of Taiwan, which is highest in middle Taiwan Strait and low at both ends. Hsien-Da Harbour is located about 16 km south of Tainan. The tidal range is only about one metre. The quantity of sea water flowing in and out of Hsien-Da Harbour is small, and the discharge from the harbour is small except during the summer flood period. Most of the pollutants in the harbour flow to the ocean only during the ebb tide.

The tidal current is the main force dispersing the pollutants discharged from Hsien-Da Harbour during ebb tide. Since the semi-diurnal tide dominates the current in this area, the tidal current changes direction every 6 hours or so. With a tidal current velocity of 20 cms^{-1}, we can observe that, during 6 hours' ebb tide, the

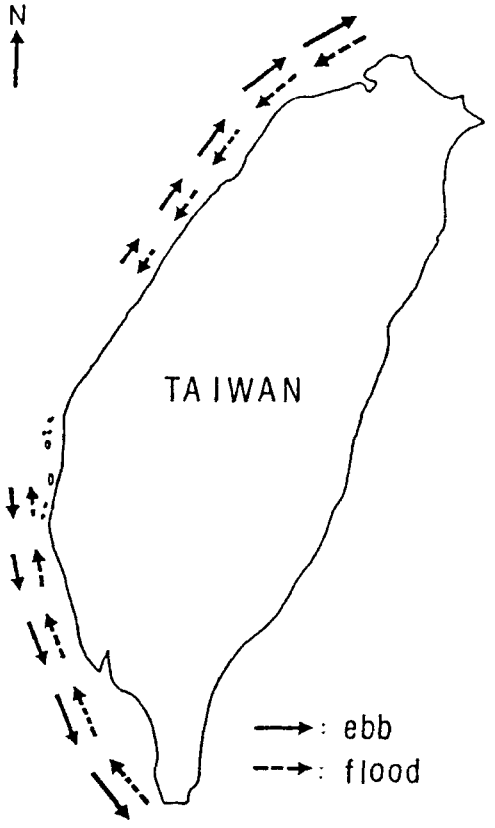

Figure 1 General tidal current patterns along the western coast of Taiwan.

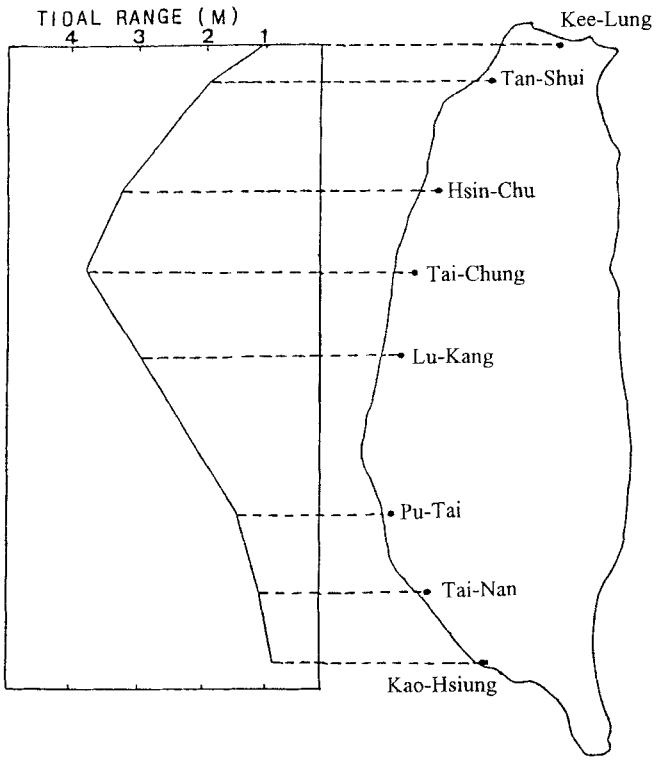

Figure 2 The average tidal ranges along the western coast of Taiwan.

polluted harbour water may flow to about 5 km south of the harbour. During the next 6 hours' flood tide, the polluted harbour water in the ocean, together with any newly discharged harbour water, flows to about 5 km north of the harbour as shown in Figure 3. So, the polluted water, in general, extends to an area of about 5 km on both sides from the discharge source, and within about 3–4 km offshore. In fact, the water discharged from Hsien-Da Harbour is seriously polluted and it is easy to distinguish the harbour water from the clean sea water. Sometimes, the boundary between harbour water and sea water can be recognized easily even five or six hours after the harbour water has discharged to the ocean.

In Taiwan, most rivers on the western coast are seriously polluted, especially on the southwestern coast and there are many pollutant sources along western coast. Sometimes, in one area, the sea water contains many different pollutants discharged from a variety of sources. For example, along the southwestern coast of Taiwan, from about 120 km from Pei-Kang River in the north to Tung-Kang River in the south (see Figure 4), there are four main pollutant sources:

(1) Harbours. There are three major harbours, all seriously polluted.

(2) Ocean outfalls. There are three ocean outfalls, Tso-Ying, Chung-Chou and Dah-Lin-Pwu, with the pipe lengths of only 5.07, 3.0 and 3.3 km, respectively. These three outfalls are located within 20 km.

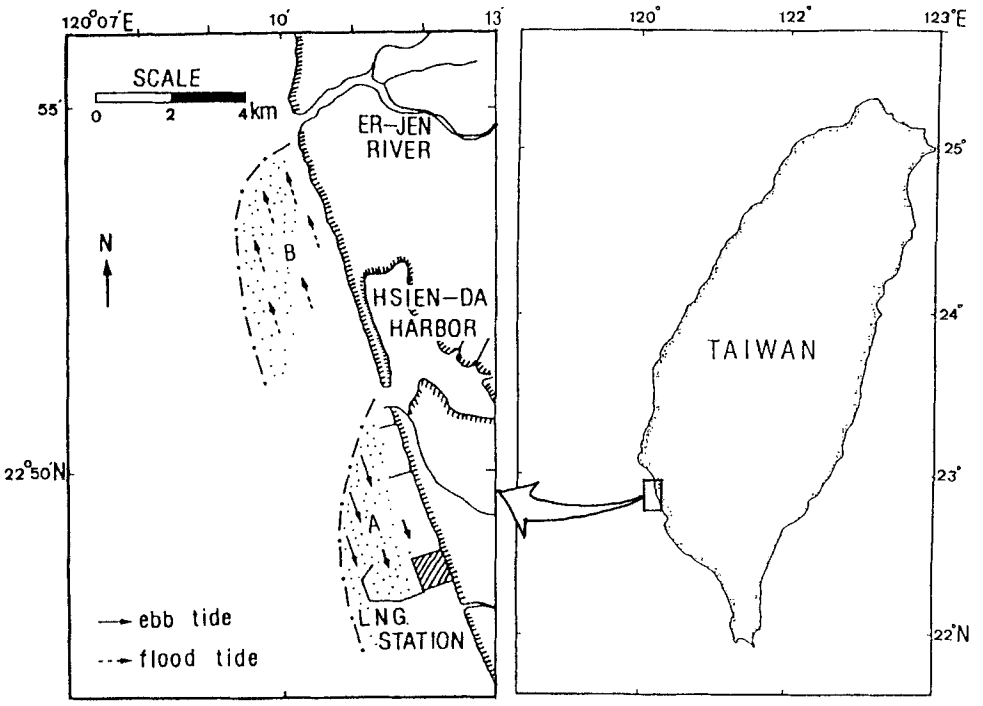

Figure 3 The major area affected by the polluted water discharged from Hsien-Da Harbour during ebb tide (A), and during flood tide (B).

(3) Rivers. There are nine major rivers. The water in the two southernmost rivers, Kao-Ping River and Tung-Kang River, is slightly polluted. The other seven rivers are seriously polluted.

(4) Industrial districts. There are three big industrial districts with many different factories, which discharge many kinds of pollutant without proper treatment.

In addition, there are also many other pollutant sources along the coast, such as power plants and trash dumpsites.

The sea water along the southwestern coast is heavily contaminated. It has already jeopardized coastal mariculture. Han (1989) measured the copper concentration in oysters in 12 major culture areas along the western coast of Taiwan, finding concentrations as shown in Figure 5. In general, the oyster becomes green when it contains over 500 ppm copper dry weight (Zamuda, 1984). Figure 5 shows that in the No. 11 district, the oysters contain copper at 1,000–2,000 ppm, and in the No. 10 district, located in Er-Jen River estuary, over 4,000 ppm (also see Figure 3)

The weather type in Taiwan also makes the situation worse. On average, 76% of the rainfall in Taiwan is in the six-month season from May to October. The other six-month period, from November to April, is considered the dry season. The contrast of being dry in winter and wet in summer is even more evident in southern Taiwan, with even 90% of the rainfall in the wet season (Hsu and Ching, 1978). In the dry season, the river water is dirty. When the spring rainy season begins, the pollutants

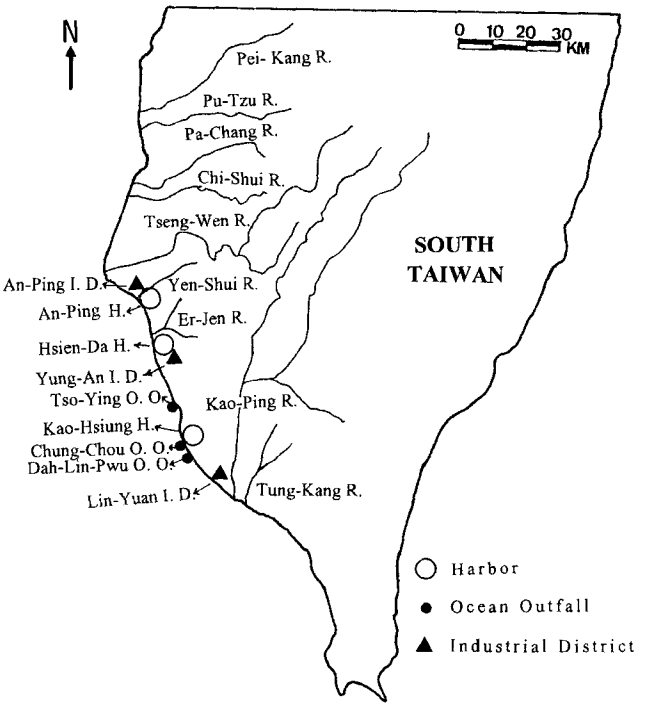

Figure 4 The main pollutant sources along the SW coast of Taiwan.

accumulated in the river bed are released to the coastal areas endangering the cultured oysters, clams and fishes.

2. *Alongshore Current*

When waves come close to the coastline, where the water depth becomes shallow, then waves break. If the propagating direction is not perpendicular to the coastline, then there will be a long-shore movement generated as the wave breaks. This long-shore current is strong enough to displace sand near the shoreline. The sands then drift along the coast area. On some coasts, the sands accumulate to form reclaimed land, while elsewhere the beaches are eroded. The major waves, mainly induced by wind, approach northern Taiwan from the N-NNE direction, and in southern Taiwan from the WSW-SW direction. These major wave directions in Taiwan Strait will induce the long-shore current to flow southward in northern Taiwan, and northward in southern Taiwan (Lee and Hou, 1979). The major wind and sand drift directions are shown in Figure 6. This current can not only transport the pollutants in sea water near the shore, but it can also move the coastal sand to change the coastline morphology. Generally, the coasts have eroded in the northern and southern sections of the western coast, while in the middle section, the drift sands, either from the littoral zone or suspended particles in the river discharges, are deposited reducing water depth, or even forming new land. In the past two decades, coastal erosion has become serious, especially along the western coast (see Figure 7). Most areas have coastal dykes to protect the land. Figure 7 also shows six districts with serious

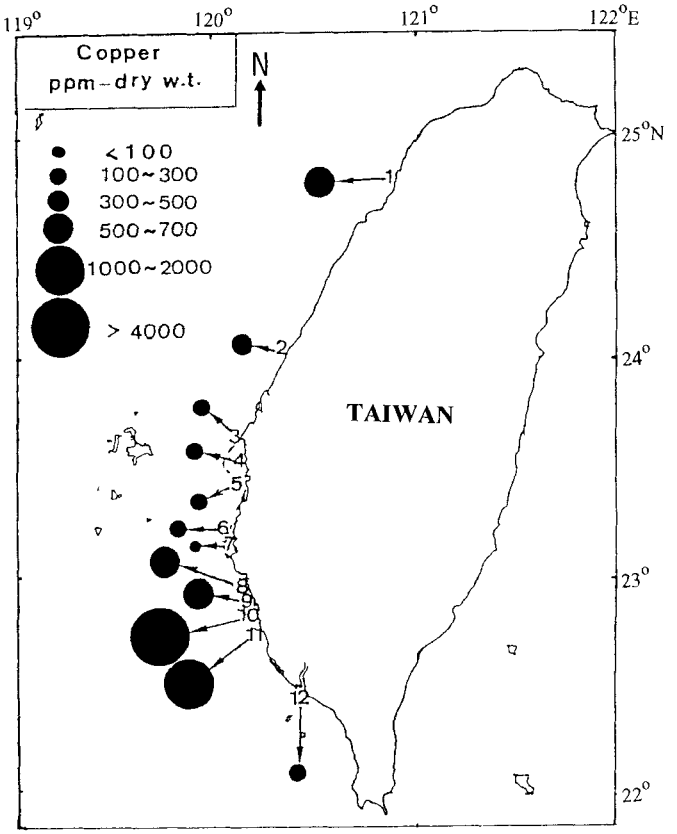

Figure 5 The average values of copper (ppm, dry wt.) in oysters (*Crassostrea gigas*) collected from different culture areas (after Han, 1989).

erosion problems, where even the coastal dykes are destroyed frequently (Chang, 1993). Among the six districts, only the No.1 district along the SE coast of Taiwan has long been an erosion coast because it gets large wave energy, frequently from the SE direction especially during the summer typhoon season. The main reasons for recent serious coastal erosion for the other five districts can be attributed to:

(1) construction of many dams upstream in the rivers in the past 20 years, reducing the transfer of some sand to the littoral zones;

(2) over-extraction of groundwater by fishermen for mariculture making the coastal zones unstable and inducing erosion (to be described below).

3. *Land Subsidence*

Since 1983, the impact of groundwater extraction for mariculture has caused a serious land subsidence problem along the littoral zone in Taiwan (Tseng and Yen, 1993). There are eight districts which suffer from serious land subsidence problems. Among these, only the Taipei basin is located inland. The other seven are located along the littoral zone in seven counties (see Figure 8). Figure 8 shows that:

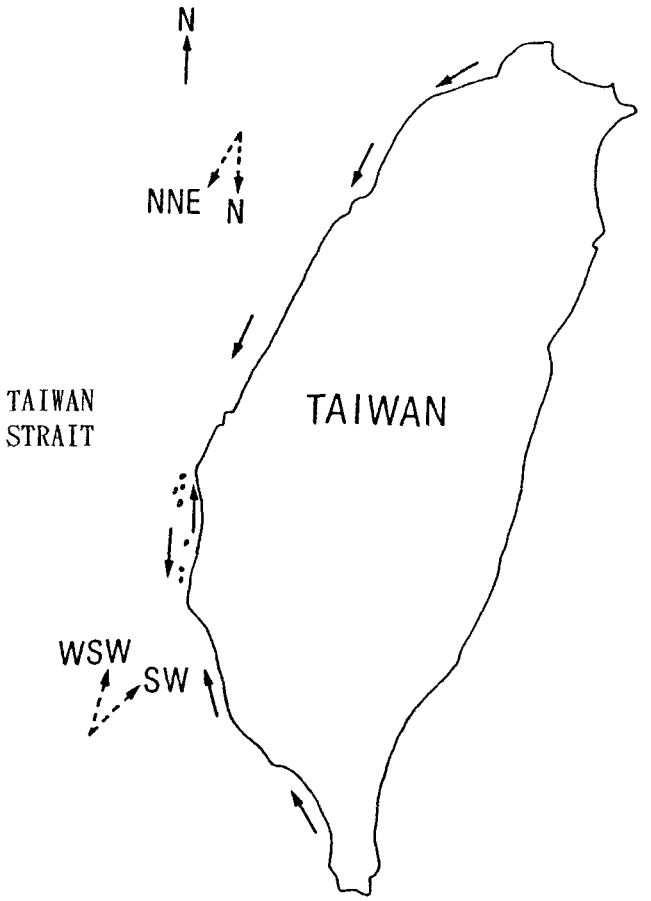

Figure 6 The major wave directions (---→) in Taiwan Strait and the long-shore current directions (→) along western Taiwan coast.

(1) The biggest subsidence area covering three counties, Chang-Hua, Yun-Lin and Chia-Yih, is located in the middle part of the western coast, an area reclaimed in the last one hundred years.

(2) Two districts with a subsidence depth of over 2 metres are the No.8 Ping-Tung district in southern Taiwan, where the maximum subsidence depth is 2.54 m, and No.2 Taipei basin, and located in northern Taiwan where the maximum subsidence depth is 2.24 m. The Government has restricted pumping of groundwater in the Taipei basin in 1978, since when the land has subsided no more than 1 cm a year (Chang, 1993).

(3) Groundwater extraction has not only caused land subsidence, but has also resulted in a progressive deterioration of groundwater quality. Sea water intrusion was first detected in the Yun-Lin destrict, now the largest land subsidence area in Taiwan (see Figure 8). The county has more than 6,000 deep wells for pumping groundwater, most for fishery business (Tsao, 1983). Once the land subsidence occurs, even if the groundwater level recovers in the future, the ground-layer

Figure 7 Coasts with erosion problems in Taiwan (after Chang, 1993).

will not be able to recover, and will lead to the loss of national land resources, the exhaustion of groundwater resources and problems of sea water intrusion and flooding of coastal villages. Almost every year in the summer typhoon season, storm surges often destroy the coastal dykes, and sea water floods the coastal villages, especially along the western and southwestern coasts (Fan, 1993). In some villages, the flood water rises to 2 metres deep or more during flood tide. Some villages even have to evacuate people to other safe places. These phenomena

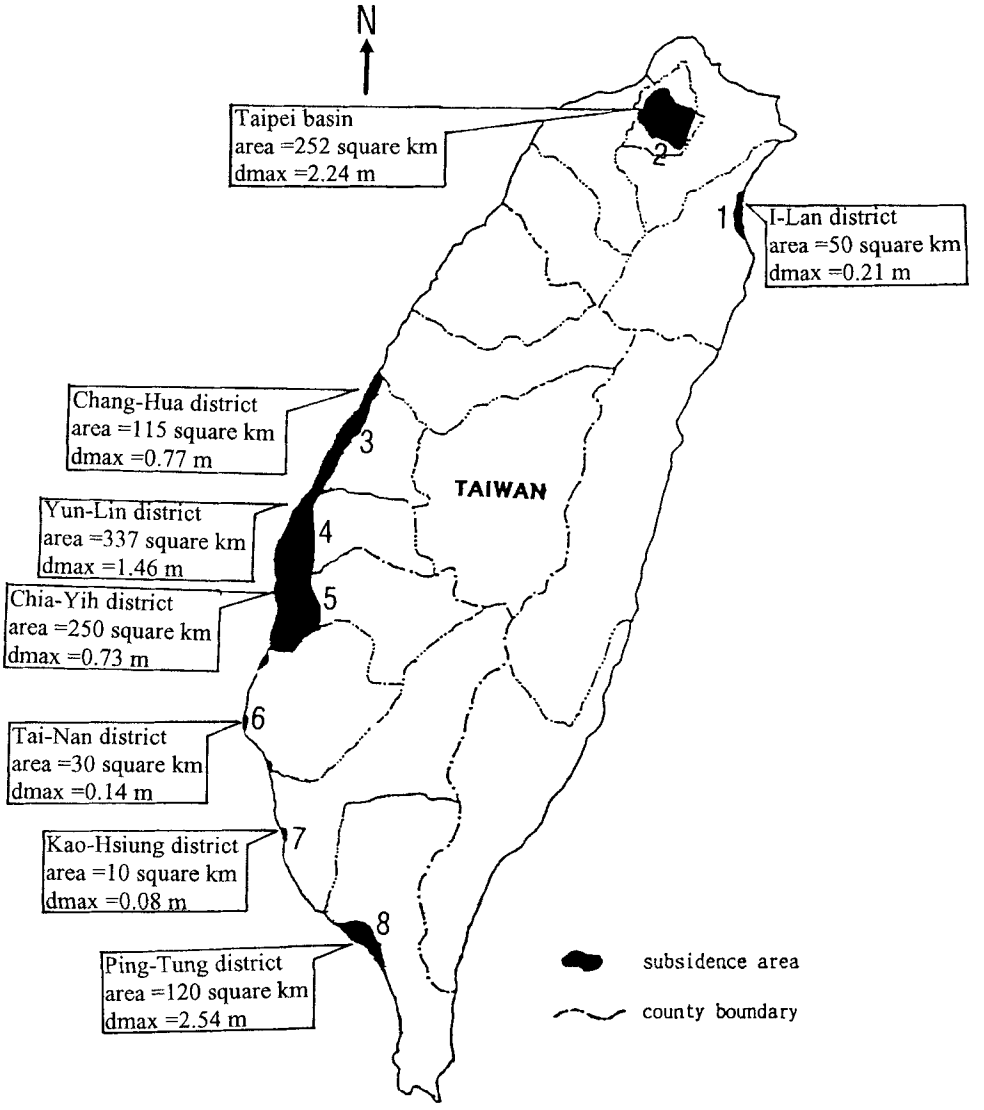

Figure 8 The map of land subsidence districts in Taiwan (after Tseng and Yen, 1993).

have happened almost every year during the summer typhoon season, especially in the No. 4, 5, 6 and 7 districts.

(4) The total land subsidence area is about 1,164 km^2; the area of Taiwan is about 36,000 km^2. This means that 3.23% of Taiwan suffers from land subsidence. In fact, most of Taiwan is mountainous. Plains have a total area of only 11,000 km^2, so that land subsidence covers 11% of the productive plains in Taiwan.

(5) In the No. 8 district, the land subsidence phenomena are even more peculiar; some old houses and tombs subsided into the ground, while some newly-built houses were lifted 1 to 3 metres above ground.

CONCLUDING REMARKS

When industrial effluents are discharged or dumped near coastal areas around Taiwan, they usually wander alongshore back and forth. Marine pollution has already jeopardized the mariculture environment along the western coast. It is highly undesirable that industrial wastes be discharged to the ocean or rivers on the western coast. It has been suggested that the mariculture beds be moved to eastern Taiwan where most coastal areas are still not polluted. However, Taiwan is a small island. If we continue to pollute the land, rivers and ocean, sooner or later, we will find no other places in Taiwan for mariculture or for a good living environment and our natural land and groundwater resources will be lost.

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