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Relative Sea-Level Changes in China Over the Last 80 Years

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ABSTRACT

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Study of tide-gauge records from 32 stations shows that, in the last 20–80 years, relative sea level at 20 stations is rising and at 12 stations it is falling. This results not only from eustatic sea level rise but mainly from recent local crustal deformations or ground water withdrawal. Stations in subsiding deltas and coastal plains have rising sea level whereas those in uplifting blocks show falling sea level. Thus, the relative sea level changes in China differ considerably from place to place and a mean value for the whole country has little significance for the assessment of future coastal hazards.

Records at two key tide-gauge stations, Tanggu and Wusong, have been corrected for land subsidence and therefore do not reveal relative sea level changes in these localities. An unusually high rate of relative sea level rise (>10 mm/yr at Tanggu, Wusong and Taixi) is chiefly triggered by over-pumping of ground water. In order to mitigate disaster brought on by future sea level rise, strict measures should be taken to limit ground water withdrawal in coastal areas.

ADDITIONAL INDEX WORDS: *Relative sea level, eustatic sea level, tide-gauge record, land subsidence.*

INTRODUCTION

There are two kinds of sea levels: eustatic sea level and relative sea level. The former is global; its recent rise is chiefly due to global warming and the resulting melting of glaciers. On the contrary, the relative sea-level changes at a specific site are the sum of the eustatic sea-level rise plus local land-level change. Evidently, the latter is much more important for humankind and hence has greater socio-economic significance.

It should be pointed out that: (1) in time scale, our discussion focuses on relative sea-level changes during the past 80 years and does not include Quaternary and Holocene sea-level changes. (2) In resolution, the magnitude of change is in cm and the rate in mm/yr. The purpose of our research is to provide data for designing coastal protection measures (sea walls, storm barriers, *etc.*) against future sea-level rise.

A marked characteristic of the relative sea level changes in the world is its great difference between regions and between specific localities, both in its nature (rise or fall) and in its magnitude (rate of rise or fall). This has been demonstrated by many previous publications (*e.g.*, AUBREY and EMERY, 1986; EMERY and AUBREY, 1980, 1986, 1988, 1989; SCOR WG89, 1990). This is also true in China, as shown in this paper.

SHORT HISTORY OF THE STUDY OF RECENT SEA-LEVEL CHANGES IN CHINA

The first systematic treatment of recent (1950–1980) sea level changes in China was by EMERY and YOU (1981). However, their study was based on tide-gauge records of only 8 stations (including Hong Kong), therefore, the result was far from satisfactory. A later paper by EMERY and AUBREY (1986) discussed relative sea-level changes in China in great detail by using both simple regression analysis and eigen analysis. But insufficient tide-gauge records (only 13 stations, including 3 stations in Hong Kong) and incomplete knowledge of local environmental conditions (especially vertical deformation, ground water withdrawal, *etc.*) of specific stations prevented them from obtaining accurate conclusions. The same holds true for works of some Chinese scientists (*e.g.* WANG, Z.H., 1986). But detailed studies in recent years have improved our knowledge of sea-level changes in Shanghai (CHEN, X.Q., 1991; WANG, B.C. *et al.*, 1991). However, a comprehensive and more reliable account of relative sea-level changes for the whole of China is still lacking. It is hoped that this paper will help fill this gap.

In this connection, a very peculiar condition in Chinese tide-gauge records must be noted. Some

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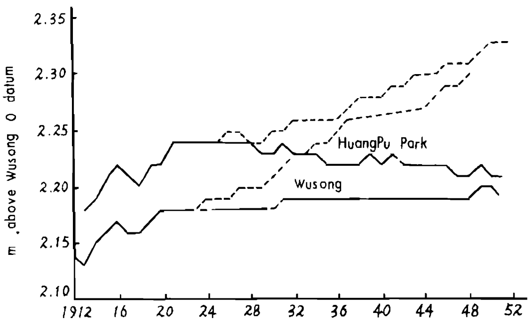

Figure 1. Sea level curves at Wusong and Huangpu Park before and after correction for land subsidence, 1912–1952. (after ZHU, 1990). (Solid line, after correction; dashed line, before correction.)

Chinese tide-gauge stations, notably two key stations at Tanggu and Wusong, have made land-subsidence corrections in their records, Tanggu since 1959, Wusong since 1922. It is evident that the corrected tide-gauge records do not reveal the true relative sea-level changes at the specific stations. This can be clearly seen by comparing sea-level curves of Wusong before and after correction (Figure 1).

Moreover, as zero datum at some stations had been changed through time, utmost care must be taken when using Chinese tide-gauge records. Overlooking this important fact has contributed to previous errors.

RELATIVE SEA-LEVEL CHANGES FROM TIDE-GAUGE RECORDS OF CHINA

In this paper, we have collected tide-gauge records from 28 stations (Figure 2), among which three stations have records of nearly 80 years (Tanggu, Wusong, Macao), thirteen stations have records of more than 30 years, seven stations have records of 20–30 years, four stations have records of 15–20 years, and one station (Haikou) has a record of only 14 years. The available tide records of four stations in Taiwan have a time span of less than 18 years, but the trends of relative sea level changes have been worked out (C.C. LIU, 1989). All records except the four Taiwan stations have been subjected to linear regression analysis. Because detailed Chinese tide-data are not easily accessible, only mean monthly water levels have been used in regression analysis, the results of which are shown in Figure 3 and Table 1.

It may be noted that the sea-water surface near the coast of China is not uniform, being higher in South China than in North China. Thus, the absolute elevation of Zhujiang (the Pearl River) zero datum, used by stations of Guangdong Province, is 59 cm higher than the Yellow Sea zero datum (Yellow Sea mean sea-water surface). In China, different zero data are used by tide-gauge stations in different parts of the country, the elevation of which differs considerably from each other. However, as this paper deals with relative sea-level changes, difference in elevation of zero datum will not affect our result.

All tide-gauge records have been carefully studied and evaluated in connection with local tectonic framework, recent vertical deformation, land subsidence and human activities.

The relative sea-level change at a specific site is greatly affected by land subsidence because the rate of land subsidence may be 10–100 times greater than that of eustatic sea-level rise. The cause of land subsidence may be natural or human induced. The most important natural factor is recent vertical crustal movement or vertical deformation. Between 1951–1982, repeated precise levelling was carried out over the whole country and a map on recent vertical deformation in North China has been published (Figure 4). The map shows that deltas and coastal plains are areas of subsidence whereas rocky mountainous coast is often undergoing uplift. The rate of subsidence and uplift is generally 1–4 mm/yr (SHEN, 1986; YING, 1988).

In China, human-induced land subsidence is mainly triggered by over-pumping of ground water. Tianjin (Tanggu) and Shanghai (Wusong) may be cited as typical examples. Both cities are located in the great deltas, the former in the old delta formed by the Yellow River in 3000 BC–1128 AD, and the latter in Yangtze River Delta. According to repeated precise levelling, the background value of recent crustal sinking in North China Plain is about 1.0–1.5 mm/yr. But it reached approximately 2.0 mm/yr in the Tianjin urban area where a benchmark subsided 38 mm between 1931 and 1951, averaging 1.9 mm/yr. Since over-

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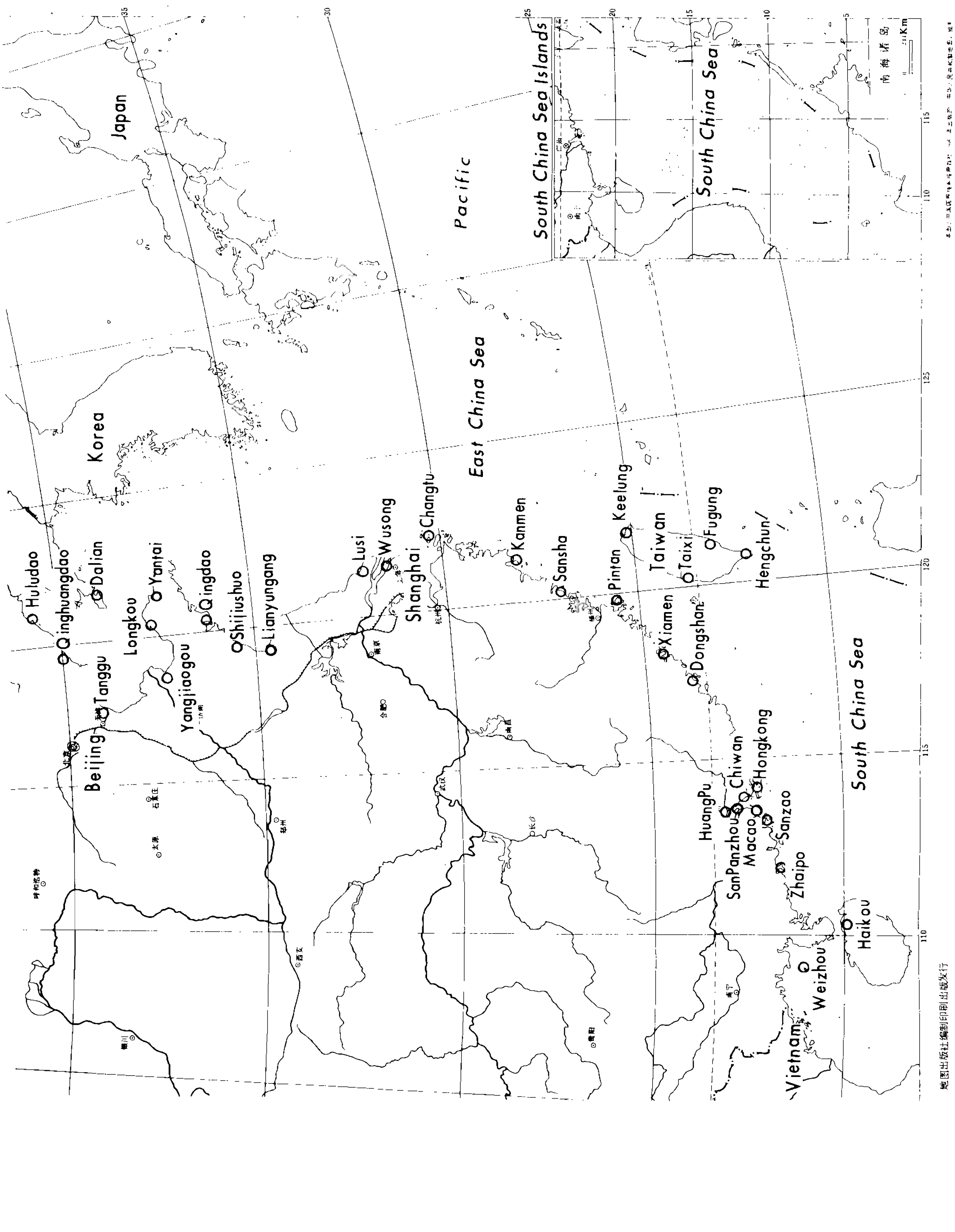
Figure 2. Tide-gauge stations in China.


Japan
Korea
Pacific
East China Sea
South China Sea
South China Sea Islands
Huludao
Qinghuangdao
Dalian
Beijing
Tanggu
Longkou
Yantai
Yangjiaogou
Qingdao
Shijiushuo
Lianyungang
Lusi
Wusong
Shanghai
Changtu
Kanmen
Sansha
Pintan
Keelung
Taiwan
Taixi
Fugung
Hengchun
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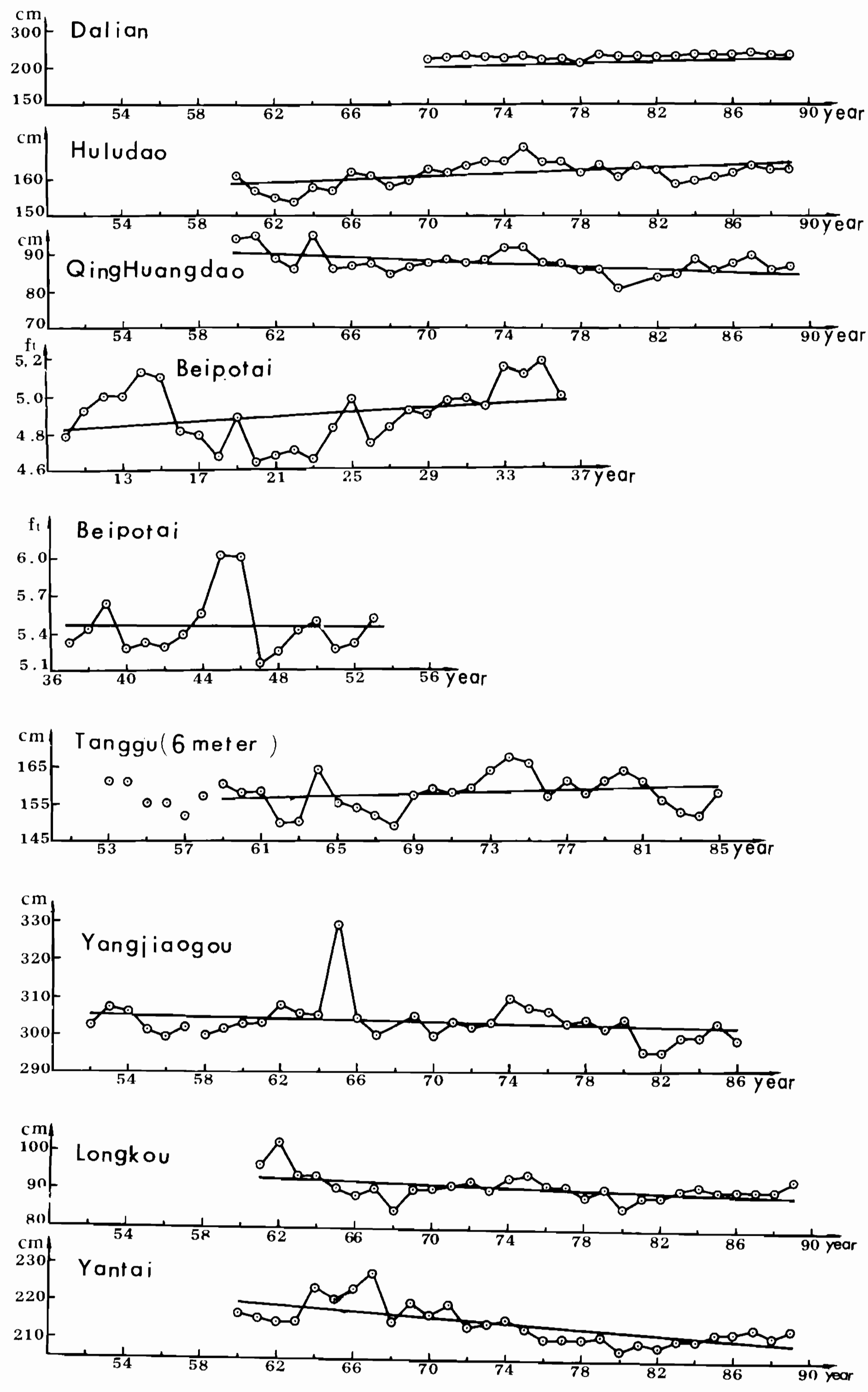
Dalian
Huludao
QingHuangdao
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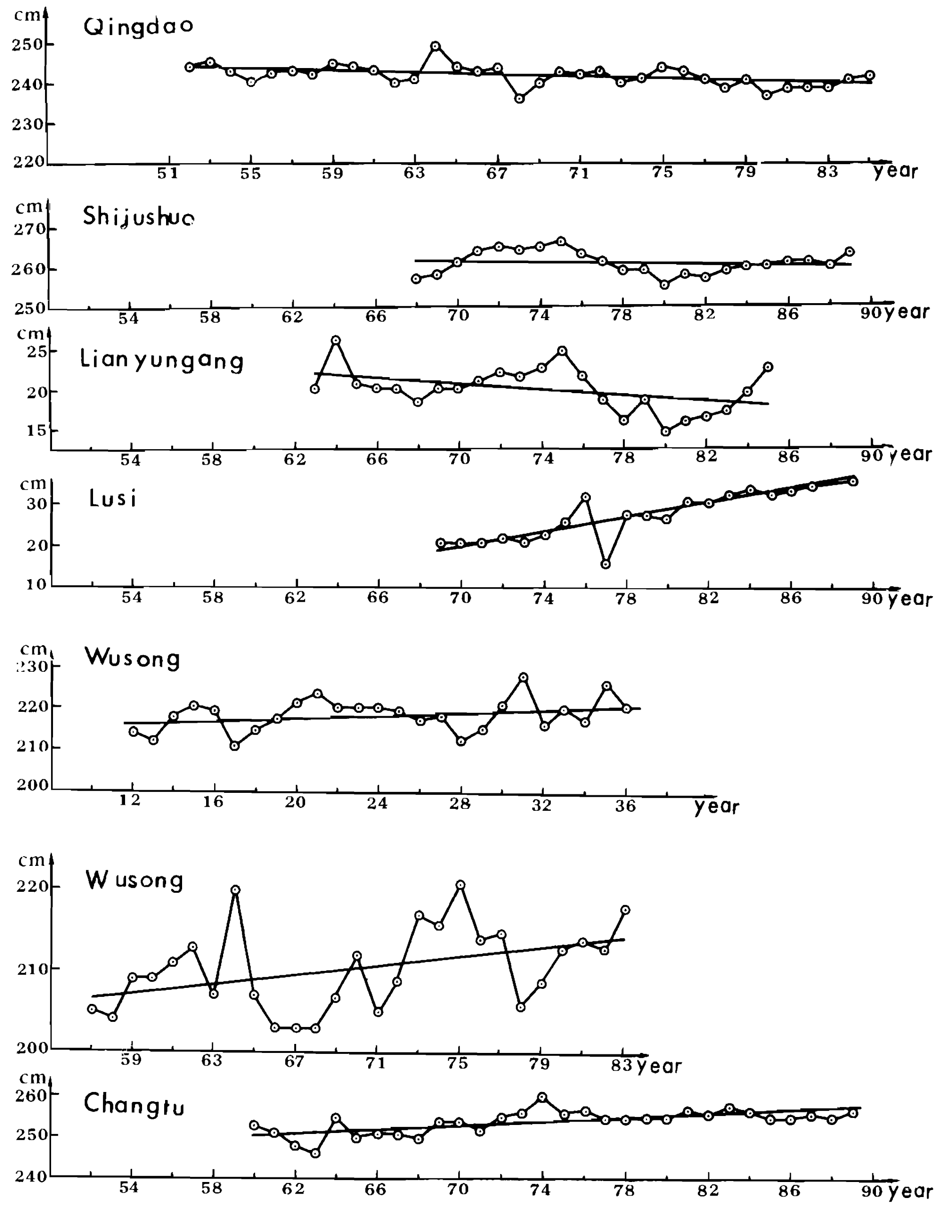
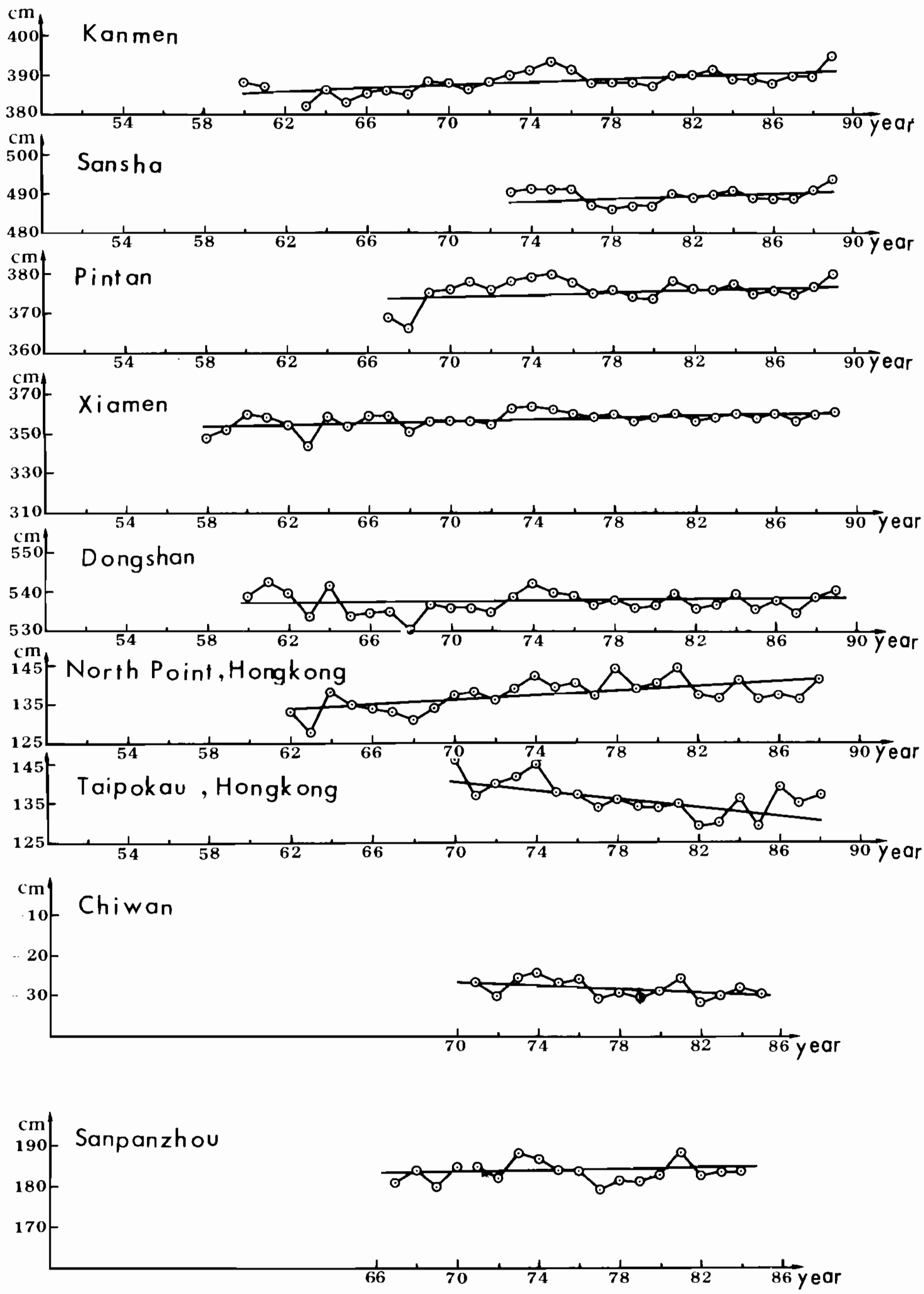
Beipotai
Tanggu(6 meter)
Yangjiaogou
Longkou
Yantai
cm
ft
year



pumping of ground water had not begun in this time, the rate of subsidence of the benchmark may roughly represent the background value of recent crustal sinking in the Tianjin urban area. Since 1959, owing to over-pumping of ground water, the rate of land subsidence in the Tianjin urban area rapidly increased, reaching 81.6 mm/yr between 1970 and 1984 (Figure 5).

The situation in Tianjin coastal area is similar to the urban center. In Tanggu, with over-pumping of ground water, the rate of land subsidence was greatly increased since the mid-1970's, reaching 137 mm in 1984. Since 1985, strict measures were taken to limit ground water pumping and land subsidence was reduced to 28 mm in 1988. The trend of land subsidence on the coast near



Tanggu may be seen from the land subsidence curve at Haihe Lock which is only 3 km from Tanggu tide-gauge station (Figures 6, 7).

Records at Tanggu tide-gauge station (including Beipotai station) began in 1910. Average rate of relative sea-level rise was 1.77 mm/yr between 1910–1937 when ground water had not been exploited. This figure approximately indicates the

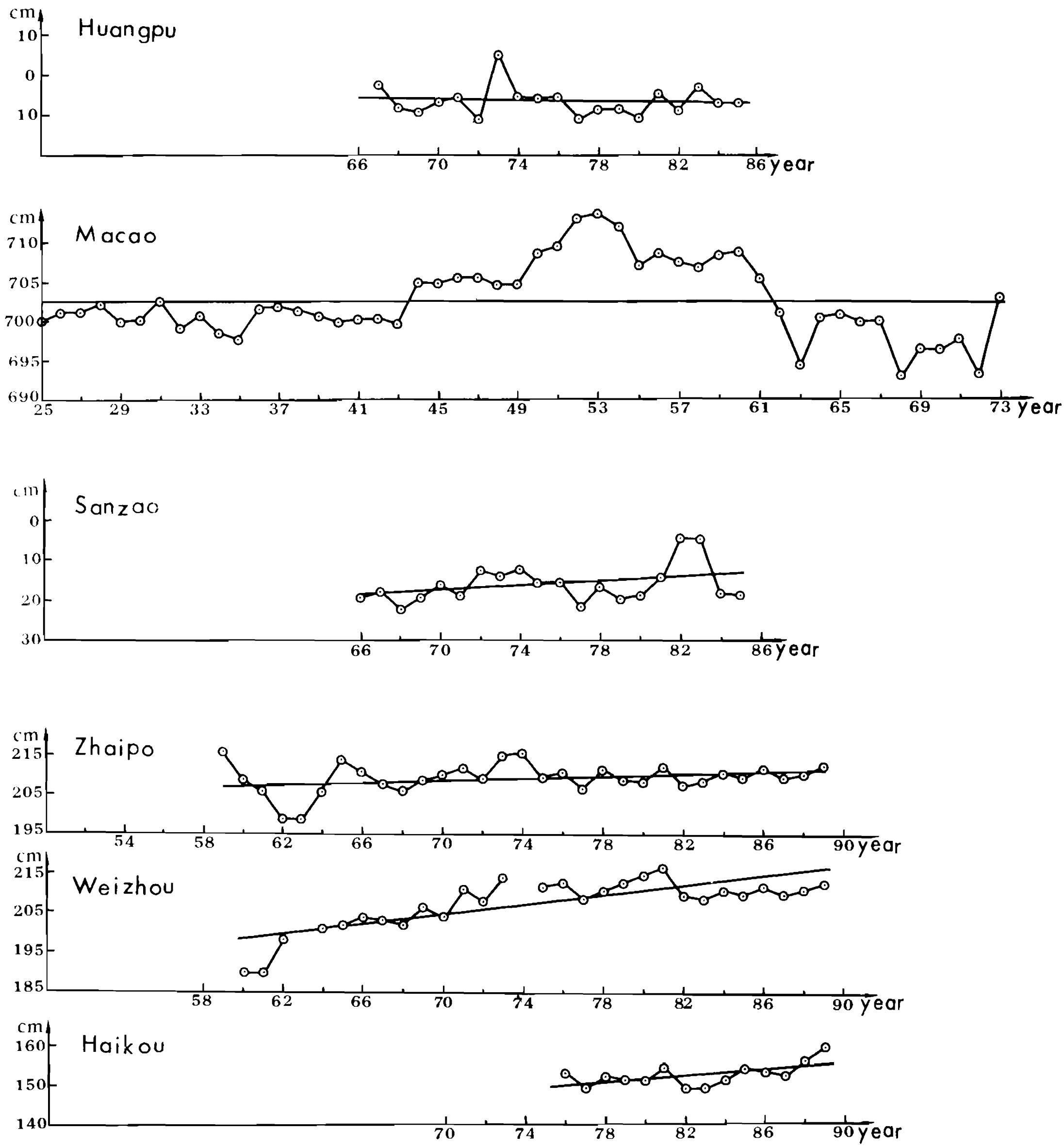


Figure 3. Linear regression line of tide-gauge records in 28 Chinese stations listed in Table 1.

sum of eustatic sea-level rise plus neotectonic sinking. But, it is utterly incomprehensible that according to the tide-gauge record, the average rate of relative sea-level rise was only 1.2 mm/yr between 1959–1985 when large quantities of ground water were pumped. The explanation lies in the fact that since 1959, correction for land subsidence has been made in tide-gauge records. Between 1959–1985, the correction totals 129 cm or 47.8 mm/yr. Also, the zero benchmark at Tanggu tide-gauge station sunk 48.9 cm between 1966–1985, or 24.5 mm/yr. From the above, it is ap-

Table 1. *Relative sea-level changes at major tide-gauge station in China during the last 20–80 years.*

No.	Station	Period	Rise (+) or Fall (−)	Rate (mm/a)
1	Dalian	1970–1989	+	3.07
2	Huludao	1960–1989	+	1.86
3	Qinghuangdao	1960–1989	−	1.95
4	Tanggu			
4(1)	Beipotai	1910–1936	+	1.77
4(2)	Beipotai	1937–1953	−	0.43
4(3)	6 meter	1959–1985	+	1.20
5	Yangjiaoguo	1952–1986	−	1.20
6	Longkou	1961–1989	−	1.31
7	Yangtai	1960–1989	−	3.39
8	Qingdao	1952–1985	−	1.07
9	Shijiushao	1968–1989	−	0.85
10	Lianyungang	1963–1985	−	1.86
11	Lusi	1969–1989	+	8.72
12	Wusong	1912–1936	+	2.50
		1957–1983	+	3.00
13	Changtu	1960–1989	+	2.42
14	Kanmen	1960–1961	+	2.10
		1963–1989	+	2.10
15	Sansha	1973–1989	+	1.10
16	Pintan	1967–1989	+	1.77
17	Xiamen	1958–1989	+	2.31
18	Dongshan	1960–1989	+	0.24
19	North Point, Hongkong	1962–1988	+	2.60
20	Taipokau, Hongkong	1970–1988	−	5.00
21	Chiwan	1971–1985	−	2.00
22	Sanpanzhou	1967–1984	+	0.39
23	Huangpu	1967–1985	−	0.69
24	Macao	1925–1973	−	0.09
25	Sanzao	1966–1985	+	3.28
26	Zhaipo	1959–1989	+	2.60
27	Weizhou	1960–1989	+	6.09
28	Haikou	1976–1989	+	3.85
29	Keelung		+	6.00*
30	Taixi		+	27.80
31	Hengchun		+	0.20
32	Fugung		−	24.50

* Figures of four Taiwan stations (station No. 29–32) after C. C. LIU, 1989.

parent that during the last 30 years, the true rate of relative sea-level rise at Tanggu should be 24–48 mm/yr.

In areas of rapid land subsidence due to ground water over-pumping, great temporal and spatial variability in the rate of relative sea-level rise should be noted. With increased ground water pumping, subsidence of the zero benchmark at Tanggu tide-gauge station increased from 3.5 mm/yr between 1966–1970 to 44 mm/yr between 1977–1985 and the rate of relative sea-level rise must be correspondingly increased. Drastic reduction of ground water pumping had reduced subsidence of the zero benchmark to 4 mm between November, 1985 and October, 1986. Hence, the relative sea-level rise should also decrease to about 5 mm (the sum of land subsidence plus eustatic sea-level rise). However, the low figure (4 mm subsidence) is limited to the site of the tide-gauge station. The land subsidence in this period was much greater (10–20 mm/yr) in the whole area of Tianjin New Port where the tide-gauge station is located. Also, Hangu and Dagong, a little north and south of Tanggu, are still subsiding at a rate of 100 mm/yr. It is evident the rate of relative sea-level rise at Tanggu tide-gauge station is not true for other parts of the coast of Tianjin. Therefore, in the risk assessment on future sea-level rise, care should be taken in using the record of one key station as a basic scenario for the coast of the whole delta.

The case of Shanghai is similar. According to records at Wusong station, the average rate of sea-level rise is 2.79 mm/yr between 1955–1989. But tide-gauge records have been corrected for land subsidence since 1922, the total amount of correction reaching 87.7 cm between 1923–1963, or 21.4 mm/yr. The great temporal variation of the rate of land subsidence at Wusong is shown in Figure 8. In the Shanghai urban area, although land subsidence has been essentially brought under control since 1965 it is still considerable at Wusong where a benchmark sunk 6.8 mm/yr between 1975–1985. Therefore, the true relative sea-level rise at Wusong in the last twenty years should be the sum of 2.79 mm plus land subsidence 6.8 mm, *i.e.* 9.59 mm. Along the Huangpu River, a little upstream from Wusong, the rate of land subsidence in several localities is about 10 mm/yr. For the Shanghai urban area, Guo documented that between 1921–1987 the total amount of land subsidence was 1.80 m, averaging 27.2 mm/yr. According to recent measurements at 265 points in 128 km^2 area of Shanghai, the mean rate of subsidence between 1978–1987 was 4.68 mm/yr (13.6 mm in 1987) (GUO, 1991).

In Taiwan, Taixi on the western coast has the largest value of relative sea-level rise, 27.8 mm/yr. This is also mainly due to over-pumping of ground water for aquaculture.

The example of Hong Kong also illustrates the important role of humans affecting local relative sea level. North Point and Taipokou stations are only 17 km apart (Figure 9), but the former registers a rising sea level while the latter has a falling sea level. The main reason for this discrepancy is

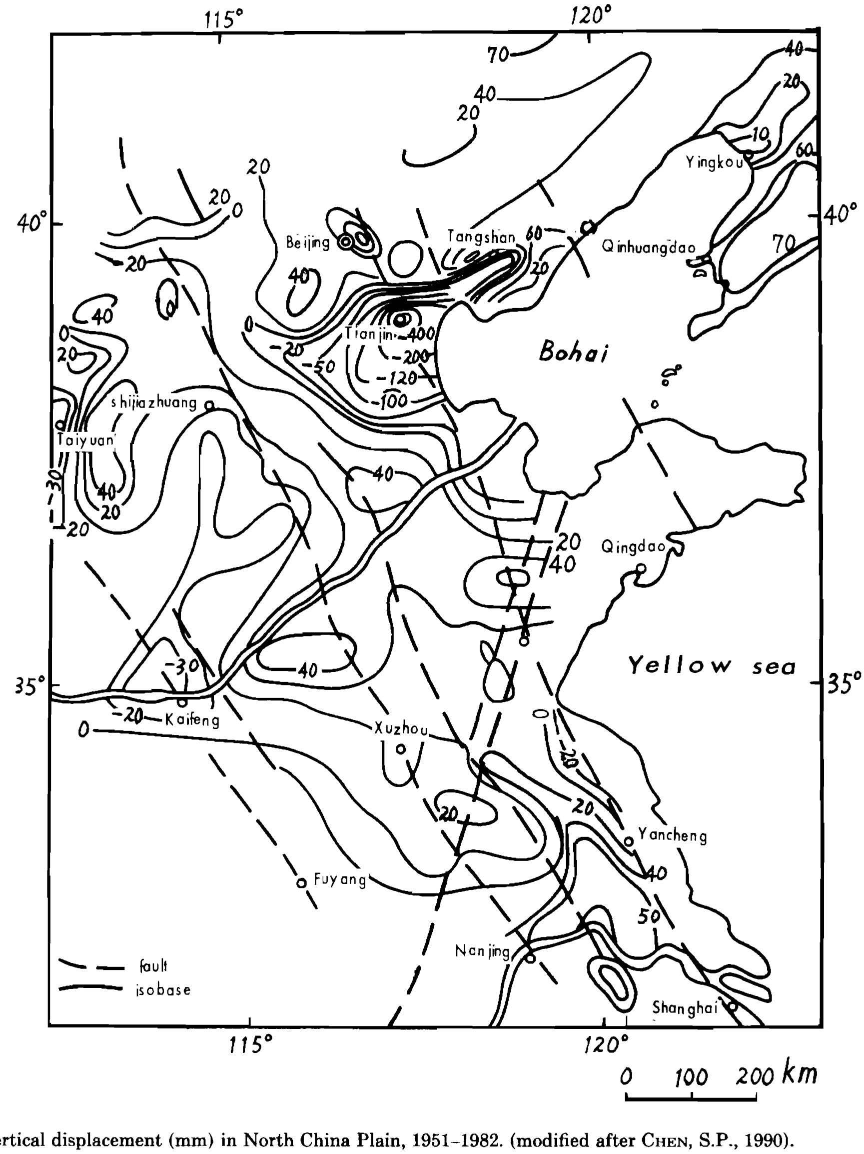


Figure 4. Vertical displacement (mm) in North China Plain, 1951–1982. (modified after CHEN, S.P., 1990).

that the former is located on newly reclaimed land which is still subsiding whereas the latter lies on a rocky basement which is uplifting along an active fault zone (YIM, 1988).

The Pearl River Delta is different from both the Yellow River Delta and Yangtze River Delta in that it is criss-crossed by a complex set of active faults; Quaternary sediment cover is thin (generally 20–30 m); withdrawal of ground water is insignificant and the surface is dotted with many rocky hills. Therefore, in the Pearl River Delta, relative sea-level changes are essentially determined by vertical movements of active faults. Stations on sedimentary layers generally have a rising sea level but a few stations near or on rocky terrain register a falling sea level (*e.g.* at Huangpu and Chiwan).

The dominant influence of geotectonics on the relative sea-level changes is vividly shown in the contrast between the relative sea level in Yellow

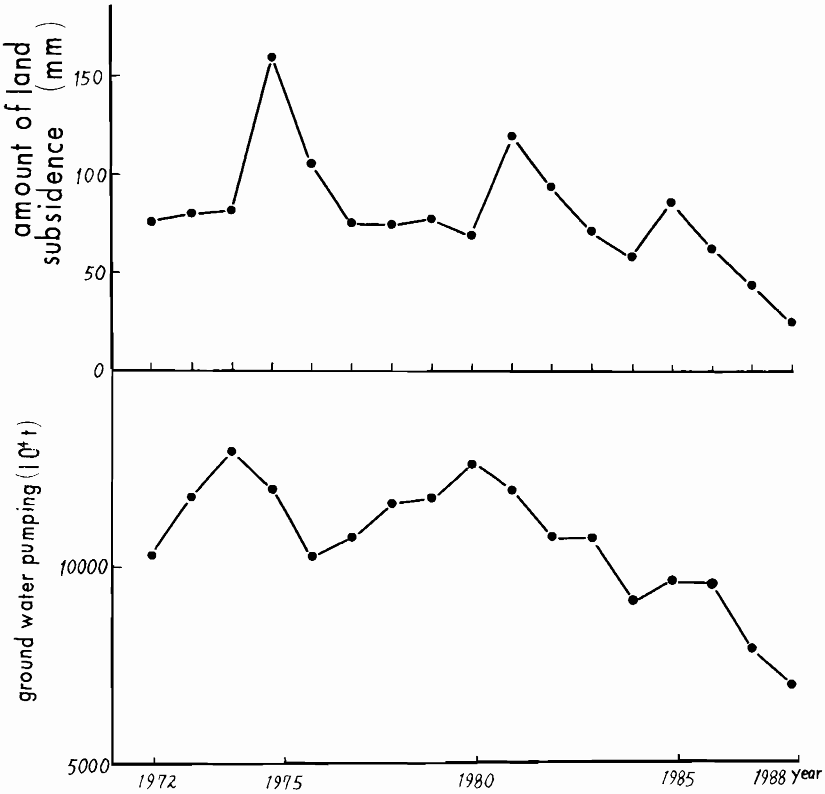


Figure 5. Relation between amount of ground water pumping and land subsidence in Tianjin urban area (400 km^2).

River and Yangtze River deltas and their adjacent rocky terrain. The former are located in subsiding basins; hence Tanggu and Wusong record rising sea level. On the contrary, the latter are uplifting areas of the Yanshan Mountains and Shandong Massif; hence, all six stations, including the important ports of Qinghuangdao and Qingdao have falling sea levels. In Taiwan, the great difference of relative sea-level changes between the east and west coast is striking. Influenced by the rapid uplifting of the Coastal Range of Taiwan, Fugung (north of Taitung) on the east coast records a very large rate of falling sea level (24.5 mm/yr). By contrast, Taixi, located on the subsiding west coastal plain and greatly affected by over-pumping of ground water, has a rising sea level amounting to 27.8 mm/yr. Similarly, the relative sea level is rising at Keelung (6 mm/yr) in the north coast but is approximately stable at Hengchun (0.2 mm/yr) in the south coast. The disparity may be attributed to the fact that Keelung is in a subsiding area and that the Keelung station is located on a pier which has recently been tilted, whereas the coast near Hengchun is slowly uplifting (C.C. LIU, 1989; T.K. LIU, 1990). Two stations (Lusi and Weizhou) on the mainland coast also record a large relative sea-level rise. Both stations have quite unique local environments. Lusi is located on a sandy islet off the coast of Jiangsu Province and Weizhou is on a volcanic island near a deep fault with strong vertical displacement.

SUMMARY AND CONCLUSIONS

(1) Of the 32 stations listed in this paper, 20 stations have rising relative sea level but relative sea level in 12 stations is falling (about one-third of the total number of stations). Influenced by local environmental conditions and human activities, relative sea-level changes vary greatly from place to place. Therefore, an average rate of sea-level rise has little significance in coastal disaster prevention and risk assessment.

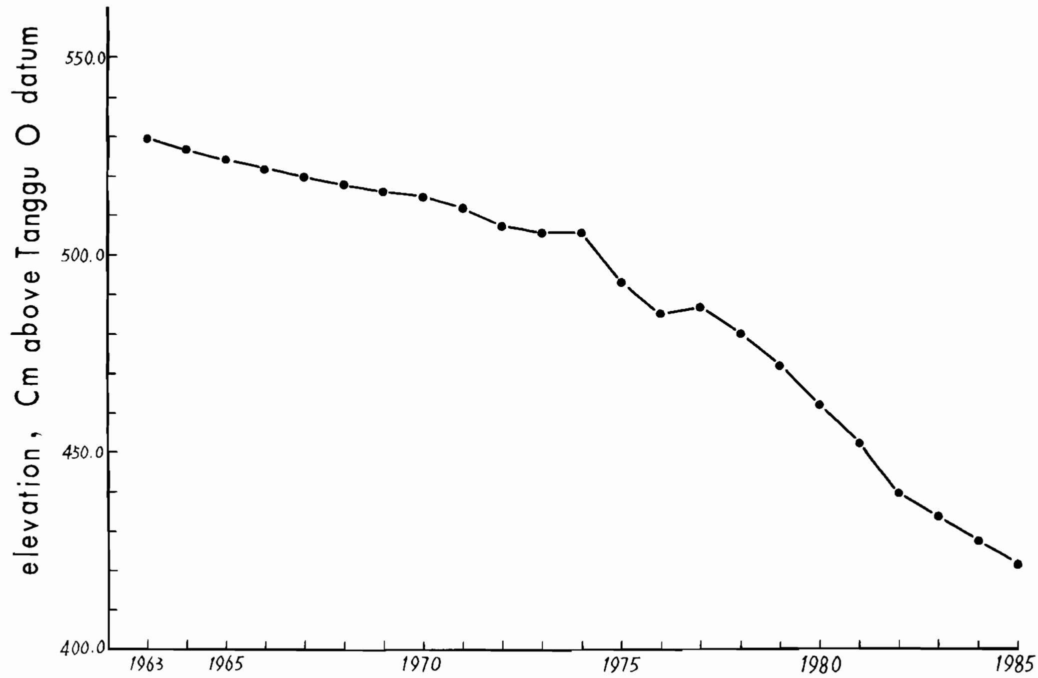


Figure 6. Trend of land subsidence at Haihe Lock, 1963–1985. The slight uplift in 1976–1977 is due to Tangshan earthquake, 1976.

(2) Owing to ignorance of corrections for land subsidence in tide-gauge records, many authors have published low figures for the rate of relative sea-level rise at Tanggu (0.2–1.5 mm/yr) and Wusong (0.2–2.0 mm/yr). They departed greatly from the actual situation and minimized the risk caused by future sea-level rise, giving a false picture of safety which is extremely harmful for evaluating future costal hazards and for formulating plans and measures for their prevention.

(3) Relative sea-level rise in China during the last 80 years is small, generally 1–4 mm/yr. Unusually high rates of relative sea-level rise of more than 10 mm/yr is common in deltas and coastal plains and largely caused by over-pumping of ground water. This is similar to other parts of the world, for example Bangkok in the Menam Delta (rate of sea-level rise 15.6 mm/yr between 1960–1982) (MILLIMAN, 1989). Therefore, to prevent future sea-level rise and the resulting disaster, a prime effort should be made to limit ground water withdrawal.

(4) The rate of eustatic sea-level rise in China over the last 80 years is small, about 1–2 mm/yr. This agrees with figures given by many scientists (*e.g.* REN, 1990). Although there are many uncertainties in the prediction, it is generally agreed that eustatic sea-level rise over the next century will not exceed 60–100 cm, or probably much less than this amount (KENNETT, 1988, 1990; MÖRNER, 1988, 1991; PIRAZZOLI, 1990).

(5) It is hard to predict future trends of relative sea-level change in Yellow River and Yangtze Riv-

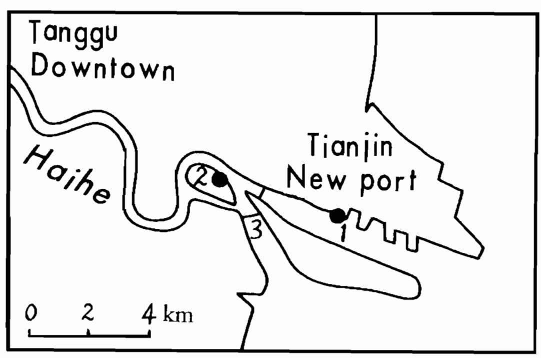


Figure 7. Sketch map of Tanggu area. (1, tide-gauge station at New Port; 2, Beipotai; 3, Haihe Lock.)

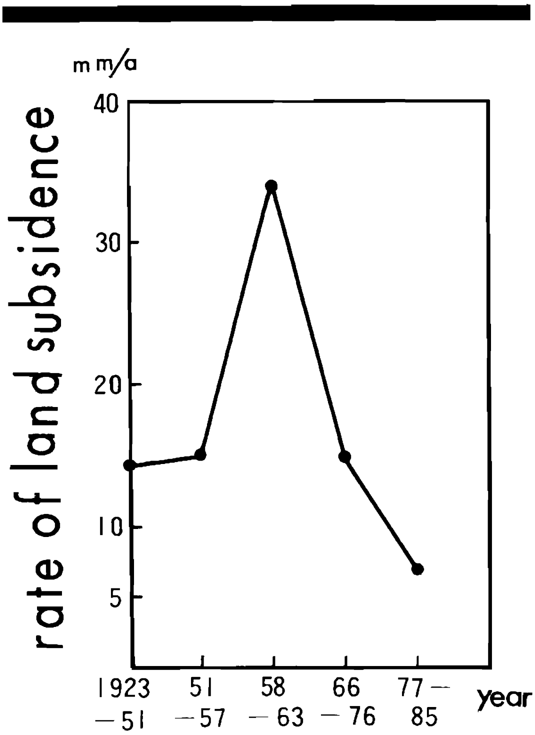


Figure 8. Variation of the rate of land subsidence (mm/yr) at Wusong, Shanghai, 1923–1985.

er deltas, the two most important regions on the coast of China because, in addition to eustatic changes, human activity plays a dominant role in the relative sea-level changes of these regions. As it is unlikely that over-pumping of ground water could be entirely stopped in the foreseeable future, the current rate of land subsidence at Tanggu and Wusong will probably continue for some time. Therefore, the best estimate for the rate of relative sea-level rise at Tanggu and Wusong over the next 25–50 years is about 12–16 and 8–12 mm/yr respectively, that is, a eustatic sea-level rise of 2–6 mm/yr plus land subsidence of 10 mm/yr for Tanggu, 6 mm/yr for Wusong.

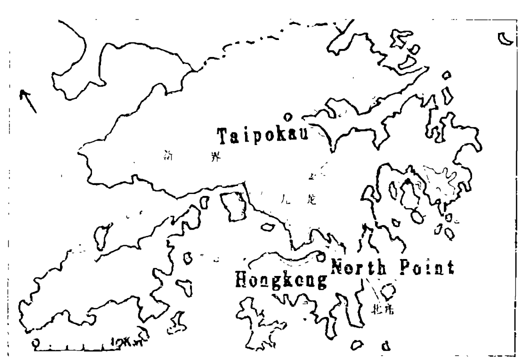


Figure 9. Location of tide-gauge stations in Hong Kong.

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