SOME PROBLEMS OF VULNERABILITY ASSESSMENT IN THE COASTAL ZONE OF CHINA

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ABSTRACT

The Chinese coastline is 32000 km long. The 12 coastal provinces are very important in terms of population and their contribution to the economy, and contain 41.9% and 72.5% of China's total, respectively. There are 8 coastal vulnerable areas and most of them are related to large deltas which presently have a large sediment-supply. 70% of muddy and sandy coasts suffer from erosion, but the main cause is usually related to reduced sediment supply such as beach mining. Coastal-wetland renewing is main trend so far and will likely decelerated with ASLR in the future. About 12000 km coastal engineering constructions protect coastal lowlands, however, extreme climate events resulted in mean-annual economic losses from 1990 to 1998 of 14.96 Millions USD, and 16.65 million people were flooded each year. Vulnerability assessments that include climate change, sea-level rise and human activity suggest that the Chinese coastal zone is relatively low compared to some other countries (see Nicholls and Mimura, 1998). However, further studies are required to provide the information for long-term coastal planning.

1. Introduction

The target area of the study is Chinese coastal zone, which covers 17^0N to 40^0N and 108^0E to 124.5^0E. The information for the assessment was collected from China Statistics Yearbooks, Marine Statistics Yearbooks of China and scientific papers.

Chinese coastline is 32000 km long, including main land (18000 km) and island (14000 km). The area of Chinese coastal provinces and cities is 1.6 millions km^2 with population of 527.6 millions, covering 41.9% of the China's total. GDP produced in the coastal provinces is more than 1.0 trillions USD, covering 72.5% of China's total (NBSC, 2000). Coastal vulnerable area is 143.9 thousands km^2 with population of 162.1 millions (Du, 1997). So the coastal zone is very important in economic development and population of China.

Table 1. General overview of Chinese coastal zone
(Data from NBSC, 2000; Du, 1997, with recalculation)

	Main Land	Islands	National total	
			Data	%
Coastline (km)	18000	14000	32000	
Area of coastal provinces (x10^{6}km^2)	1.248	0.36	1.608	16.75
Population of coastal provinces (x106)	498.5	6.72(H.K.) 21.93(T.W.) 0.43(Macao)	527.6	41.9
GDP of the provinces (10^{9}US$)	596.83	163.57 (H.K.) 268.6 (Taiwan) 6.16 (Macao)	1035.16	72.5
Coastal vulnerable area (10^3 km^2)	143.9		9600000 0	1.5
Population of the vulnerable area (10^6)	162.09		1259.09	0.13
Population density in the vulnerable area (people/km^2)	1126.5			

Study of sea level rise by tide-gauge records is flourished in 1980's in China and the main conclusion is sea level rise rate of 1.4-3.0 mm/year during last several decades (ESD-CAS, 1994; Du, 1997). Coastal vulnerability was firstly assessed and 8 vulnerable areas were distinguished (Han, 1995). Investigating SLR impacts in 1993, Chinese Academy of Sciences emphasized RSLR importance in regional coastal vulnerability assessment. RSLR components for Chinese coastal zone are: 1) eustatic sea level rise; 2) tectonic subsidence; 3) ground subsidence due to over-pumping ground and trend rise of river level due to delta progradation (ESD-CAS, 1994). New coastal vulnerability assessment concentrated on SLR prediction in the Chinese coastal zone; Calculation of vulnerable areas by applying topographical database on one-millionth scale and digital-elevation model and on Assessment of potential flooded area, people and economic loss by sea level rise (Du, 1997). The integrated coastal zone management is particularly important for Chinese coastal zone with dense population and strong human activity. The ICZM serious study is started in 1990s (Yang, 1999). The objectives of the paper are to summarize SLR impact and VA study and to evaluate the vulnerability class of Chinese coastal zone.

2. Factors Influencing Chinese Coastal Zone

2.1 Regional background

The factors influencing Chinese coastal zone are natural and antropogenic, and climatic and non-climatic. The natural factors are the highest mountain, Tibetan Plateau, strongest monsoon, warm pool in the southwestern Pacific Ocean and eastern India Ocean and accelerated sea level rise (ASLR). The highest mountain and strongest monsoon in the world lead to result in great rivers with abundant sediments and large deltas. There are 19 deltas with an area more than 10,000 km^2, 11 of which are located in Asia, 9 deltas are surrounding Tibetan Plateau (Coleman, 1975) and 3 in China. The warm pool tends to be a heat source to form lateral and transverse monsoon strongly influencing Asia (Li and Zhou, 1993; Li et al, 1998) and maybe also to promote the creation of Asian tropical cyclones. The Asian strong cyclones cover about 40% of world's total (Bao, 1991; Yang and Shi, 1998; Ali, 1999). Southern Chinese coastal zone is an area to be affected by cyclone. The big population and strong human activity directly and indirectly, positively and negatively influence the coastal zone and it should be a very important factor in the vulnerability assessment of Chinese coastal zone.

2.2 Tectonic activity and river-borne sediment distribution in Chinese coastal zone

Chinese coastline goes across tectonic subsidence and uplift belts. The coastal zones in the subsidence belts and grabens of the uplift belts receive more than 90% of all river-borne sediments transported into the sea and each km-coastline receives near 500,000 tons sediments in average. The coastal zones in uplift belts receive less than 10% of the total and each km-coastline receive about 7,000 tons in average (Li et al, 1991). This leads to form wide coastal plains with thick Quaternary strata in the subsidence belts and control the muddy and sandy coast distribution in China. In northern and eastern Chinese coastal lowlands, thick Quaternary strata usually trigger surface subsidence in case of ground water over-pumping. In the southern China the tropical cyclones, covering 75% of the total landed in China, exacerbate the risks of the coastal lowlands (Liu and Wang, 1991). So the wide coastal lowlands are main vulnerable areas in China (Han et al, 1995). There are 8 vulnerable areas in Chinese coastal zone, 5 from them are wide and more important and associated with deltas.

3. Importance of Relative Sea-Level Rise

The components of relative sea-level rise in Chinese coastal zone are very different. The SLR rate of last decades was 1.5-2.0 mm/a and the RSLR rate is tens and hundred mm/year for past decades. The ground subsidence, as one of important RSLR components, was changed in Shanghai, with a rate of 2.5- 110 mm/a during last 70 years (Table 2). The rates are much larger than that of global sea-level rise in the same period. Trend rise of river level is usually triggered by delta progradation. With delta progradation, sea-bed slope could not satisfy the gradient needed by delta propagation, and resulting water level rise. This is observed in the Huanghe Delta and the water level has rose 2-3 m since 1920s due to delta expansion (ESD-CAS, 1994).

Table 2. Change of ground subsidence rates in the City of Shanghai (ESD-CAS, 1994)

No.	Period	Ground subsidence rate (mm/a)	
		Average	Max.
1	1921-1948	24.0	42.0
2	1949-1956	40.0	96.0
3	1957-1961	110.0	287.0
4	1962-1965	59.0	164.0
5	1966-1992	2.5	19.3
6	1993-1998	10.0-15.0	

According to above-mentioned RSLR components, the relative sea level rise is estimated considering ASLR and strict coastal zone management (Table 3). The estimated RSLR are changed from delta to delta and are much larger than global ASLR. Whether the estimated RSLR is correct depends strongly on the change of natural and antropogenic factors, such as delta progradation rate, strict control of ground water pumping, etc.

Table 3. Estimated RSLR in Chinese large deltas by 2010 and 2050 (ESD-CAS, 1994)

	2010	2050
Zhujiang Delta	15-30	40-60 cm
Changjiang Delta		50-70 cm
Huanghe Delta		40-50 cm
Old Huanghe Delta		70-100 cm

4. RSLR Impacts and Coastal Zone VA

Non-climate factors are main causes resulting in local relative sea level rise, however climate factors, particularly climate extreme events, play a dominated role to result in serious impacts in Chinese coastal zone.

4.1 Delta progradation and wetland renewing

Coastal wetland loss is one of important consequences of global sea level rise (Titus, 1990; Nicholls, 1999). However, wetland loss seems not to be the main trend of the Chinese coastal wetland, particularly for large deltas. Chinese deltas are growing seaward with rates of 11-21 km^2/year due to abundant sediment supply (Table 4). With delta progradation, the coastal wetland is renewing, for example, 786 km^2 in Shanghai and 344 km^2 of wetland in the Zhujiang Delta have been reclaimed, but the wetland maintains the same area nowadays (Chen and Chen, 1998; Liu et al, 1998; Lang, et al., 1998). Coastal wetland renewing is very important characteristics for Chinese deltas with abundant sediment-supply. New reclamation of coastal wetland has been planned in Shanghai, Changjiang Delta, and 400km^2 coastal wetland will be reclaimed by 2010.

Table 4. Growth rate of Chinese deltas

River	Progradation rate (m/a)	Growth rate (km^2/a)	Period	Reference
Huanghe	160	21.26	1855-1984	Qian et. al., 1993; Zeng, 1996
Changjiang	20-50	16.0	1950-1995	Chen and Chen, 1998; Chen 1998
Zhujiang		11.0	1966-1996	Liu et al, 1998

Big reservoir building and pumping Huanghe water for irrigation of farmland in the catchment area lead to decrease of water discharge and suspended load. Huanghe river-borne sediment is seriously reduced in 1990s, covering only 34% of that in 1950s to 1970s, and the River flow is interrupted for tens and hundred days each year since 1972 and the flow interruption even lasted 226 days in 1997 (Ye, 1998). The critical value of annual sediment supply, identifying the Huanghe Delta from overall construction to overall destruction, is studied. It is estimated as 215– 300 millions tons/year (Li and Liun, 1997) and serious coastal wetland loss will come at that time.

4.2 Coastal erosion

Coastal erosion is considered as one of important impacts of sea level rise (Titus, 1990; Nicholls, 1998). About 70% Chinese sandy and muddy coasts suffer from erosion (Xia, 1993). 1400 km^2 land in Jiangsu Province has been lost since 1855 (Ren, 1986) and 202 km^2 was lost during 1985-1996 in the Diaokao abandoned sub-delta of modern Huanghe Delta. Both of them result from reduction of sediment supply due to changing main course of the Huanghe River or its distributary (Ren, 1986; Chen, 1987).

1-3m/year coastline retreat has also been reported in sandy coasts of Shangdong Peninsula, Liadong Peninsula and South China Coast (Zhuang, 1989; Wang, 1992; Xia, 1993). The coastal erosion is usually ascribed to reducing river-borne sediment, mining beach sand and sea level rise (Zhuang et al 1989; Xia, 1993). Based on the 20-year systematical observation in 33km coast of southwestern Shangdong Peninsula, Zhuang et al (2000) has concluded that 40% coastal erosion comes from reducing river-borne sediment; 50% coastal erosion is due to mining beach sand and 10% coastal erosion may be ascribed to sea level rise.

Therefore, main cause of the erosion in either muddy or sandy coasts is sediment-supply change and prediction of beach erosion by Bruun Rule seems to be not reliable for most of Chinese coastal zone (Li et al, 2000).

4.3 Coastal flooding and engineering constructions

Sea level rise must result in coastal flooding in main vulnerable areas triggering economic loss and people at risk. Coastal flooding created by storm surge led to tens and hundreds of thousands of deaths before 1949 (Table 5). In order to protect coastal lowlands from storm surge and strong wave attack coastal engineering construction was built since Tan Dynasty, about thousand years ago, and was flourished in Min and Qing Dynasties, about 300-500 years ago. Protected coastline in Chinese main land is about 12000 km long (Du, 1997) and the engineering constructions are at various levels. High-level dykes are usually built in big cities and economic developed areas, such as in the Changjiang and Zhujiang Deltas and low-level dykes are constructed in economically less developed area, such as in the Huanghe Delta. The coastal protection constructions of 1/1000-year and that of 1/10-year coexist in Chinese coastal zone, however, most of them protect from 1/50-year to 1/100-year storm surges plus 10-grade wave (Li, 1993). The dykes and dams are heightened and reinforced every year. The engineering constructions play an important role in preventing flooding by storm surge and strong waves. The 9216 typhoon went across 6 provinces and two big cities and resulted in economic loss of 1.2 billion USD, but economic loss in Shanghai was only 344.8 thousands USD Guo et al, 1993), covering only 0.28%, even though Shanghai is naturally the most vulnerable area in Chinese coastal zone. This is because of strong dykes and dams in the Shanghai area.

Table 5 Tropical cyclones effecting Asian coastal zone
(ESD-CAS, 1994; Yang 1999)

Year, month	Country	People death	Economic loss ($\times 10^9$ Chinese Yuan)
1694.6	Shanghai	100,000	
1724	Jiangsu Province	70,000	
1862	Zhujiang Delta	80,000	
1922. 8	Santao, Guangdong	70,000	
1980. 8	Guangdong Province	414	0.5
1989. 7	Zhujiang Delta	30	1.1
1989. 9	Zhejiang Province	200	1.3
1992. 9	6 provinces	300	9.2
1994 9	Fujian Province	1216	13.5
1996.9	Zhujiang Delta		14.7
1997.8	7 provinces	254	51.2

Although coastal engineering constructions are important to protect coastal lowlands, climate extreme events still result in serious disasters each year. High storm surge and heave rainfall associated with typhoon in high spring tide during flood season are very dangerous for Chinese coastal zone, usually creating economic loss and people at risk (ESD-CAS, 1994). Annual average economic loss is 14.96 millions USD and people flooded is 16.65 millions in 1990-1998, covering 0.02-0.43% GDP and 0.6-20.1% of national population respectively (Table 6).

Table 6. 1990-1998 capital value at loss and people at risk (NSBC, 2000, with recalculation)

Year	Capital value at loss (Total loss/year GDP)*100%	People flooded in the coastal zone (People flooded/national population)*100%
1990	0.12	8.4 (Medium)
1991	0.18	No data
1992	0.36	9.3 (Medium)
1993	0.20	13.1 (High)
1994	0.40	11.5 (High)
1995	0.17	14.9 (High)
1996	0.43	20.1 (High)
1997	0.40	8.3 (Medium)
1998	0.02	0.6 (Low)

The infrastructures have been considered when assessing impacts of coastal flooding caused by sea level rise. Table 7 shows that flooded areas by sea level rise of 30 cm are very different between non-protected and existing-protected circumstances in the Changjiang and Zhujiang Deltas because of high-level dykes and they are quite close to each other in the Huanghe Delta due to low-level dykes. The flooded areas are almost the same when sea level rises 100 cm, assuming protection constructions keep the present level.

Table 7. Flooded area (km^2) by SLR 30 cm, 65 cm and 100 cm in the main vulnerable areas of China (Du, B.L., 1997)

Main vulnerable area	Protect situation	30 cm	65 cm	100 cm
Zhujiang Delta	No protection	5546	5967	6543
	Existing protection	1152	3457	6520
Yangtze Delta and Jiangsu coastal Plain	No protection	54547	58663	61288
	Existing protection	898	22242	52091
Huanghe Delta and North China Plain	No protection	21255	23106	25428
	Existing protection	21010	23100	25428
Total	No protection	81348	87736	93259
	Existing protection	23060	48799	84039

4.4 Vulnerable class of Chinese coastal zone

The Chinese coastal zone is subjected to marine flooding almost every year with tens millions of people affected and economic loss of tens millions USD. According to the classification used as part of the IPCC Common Methodology (see Nicholls and Mimura, 1998) the economic loss less than 1% of national GDP (Table 6) belongs to low vulnerability class and the people at risk, being 8-20% of national population, belongs to high vulnerability class. Impacts of sea-level rise by 65 cm and 100 cm have been predicted (Du, 1997). The economic losses, wetland and land losses, protection/adaptation costs are all of low vulnerability class, and people affected still belong to the medium-high class. It must be noted that the predicted capital value at loss (total loss/1990 GDP) is quite low, because protection measures are considered in the vulnerability assessment of Chinese coastal zone. Therefore, these preliminary analyses suggest that the Chinese coastal zone has a lower vulnerability to sea-level rise than previously reported (e.g., Han et al., 1995). However, more detailed analyses of future trends are necessary to improve these assessments and guide long-term coastal planning.

5. Conclusions

Coastal provinces are very important in Chinese population and economic development, and suffer from serious impacts of climate change and sea-level rise, and human activity as well. Chinese coastal zone, developed under Asian distinct circumstances, has a series of characteristics different from coastal zones in other continents. Main coastal vulnerable areas are related to large deltas with abundant sediment-supply and RSLR is very important for assessment of national and local impacts. They are subject to coastal erosion, but its main cause is usually change of sediment-supply. Coastal-wetland renewing is main trend so far and will likely decelerated with ASLR in the future. There exist more than ten-thousand-kilometer coastal engineering constructions protecting coastal lowlands from marine disasters, however, climate extreme events lead annually to huge economic losses and tens millions people at risk. These controversy factors should be considered in vulnerability assessment of Chinese coastal zone. Chinese coastal zone should belong to low-vulnerability class by the classification of Nicholls and Mimura, if comprehensively assessing the impacts of climate change, sea-level rise and human activity.

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