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RELATIVE SEA LEVEL RISE AND ITS EFFECTS ON ENVIRONMENT AND RESOURCES IN CHINA'S COASTAL AREAS

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ABSTRACT: Due to global climate warming and natural and man-made land subsidence etc., relative sea level rise in the coastal plains of China will exceed 2—3 times over the golbal mean value during the first half part of the 21st century. It will result in a series of adverse impacts on evolution of natural environment and socio-economic development of the coastal area. This paper analyses environmental and resource effects induced by relative sea level rise in China's coastal areas on the basis of rough estimate of future relative sea level rise. These effects include inundating tidal flat and wetlands and increase in inundated risk of coastal habitable land, exacerbating storm surge, coastal erosion, flooding and salt water intrusion hazards, as well as endangering land, water, tourism and living resources and their utilization.

KEY WORDS: China's coastal areas, relative sea level rise, environmental effect, resource effect.

I. INTRODUCTION

It is a certain result that global warming and accelerated man activities in the coastal area will bring about relative rise in sea level. Sea level rise would cause a series of harm on sustainable development of the coastal area, such as inundating wetlands and lowlands, aggravating coastal erosion, exacerbating flooding, threatening coastal structures, increase in the salinity of rivers and aquiers, and endangering natural resources. So this problem has become a hot spot in the research on global change and has been paid great attention by both the government officials and scientific workers of the world.

China is a great country with 18, 000 km and 14, 000 km of continental and

island coastline respectively. The coastal area has the most dense population and best developed economy in the country, which possesses 41% of population and over 50% of Gross National Product (GNP), although the habitable land only makes up 13% in the whole coutry. However, this area, especially coastal plains, would be one of the most vulnerable areas to future sea level rise in the world, due to lower surface elevation and higher rate of relative sea level rise. Han (1992) estimates that under one meter relative rise in sea level, the total area vulnerable to inundation could be greater than 125, 000 km^2 and the affected population could be more than 73 million in China[1]. Owing to complex physical and socio-economic terms, as well as lacking series of observed data and well-considered methods, research on the impacts of sea level rise on China's coastal area is more difficult. Based on some disperse and fragmentary achievements and data now available, this paper attempts to analyse systematically main environmental and resource effects caused by 40 to 100 cm relative rise in sea level in China.

II. ANALYSIS OF THE TREND OF FUTURE SEA LEVEL RISE

Most researchers unanimously agree that the reasons for global sea level rise are thermal expansion of the oceans and melting of land ice caused by greenhouse climate warming, over the last 100 years, global sea level has risen 10 to 20cm, averaging 1. 0 to 2. 0 mm a year. More and more evidences show that sea level rise would accelerate in the 21st century, due to existing many uncertain factors and lacking sufficient observed data, different authors have presented varying predictions. At present, accurate predictions of future sea level rise are not yet available, most thought that global warming might cause Antarctic Ice Sheet (constituting approximately 90% of total continental water quantity) to accumulate, not to melt; the results obtained by previous studies about West Antarctic Ice Sheet disintegrating in the next 2 to 3 centuries are no evidences, so it is impossible that global sea level rise would be far more than one metre in the 21st century, this estimate is lower than most previous studies, although it would still be far higher than the mean rate of past 100 years[2]. Most authors put their estimates in recent reports among the best estimates of four scenarios about global sea level rise of the next century issued by the Intergovernmental Panel on Climate Change (IPCC) in 1990, that is 20 to 31cm in 2050 and 32 to 66cm in 2100[3-7], meanwhile, the effects of local factors, such as land subsidence caused by tectonic movements and groundwater overpumping, on regional sea level rise have been paid greater attention by more and more researchers.

The State Oceanlogical Bureau of China announced that relative sea level along China's coast had risen 1. 4mm a year in the last decades, basically consisting with

global mean value[8]. Because the change in man-made land subsidence, the main component part of relative sea level rise of China's coastal plains, is much difficult to estimate, predicting relative sea level rise in China will be more difficult than in the other coastal countries. Summarising the estimates now available of land subsidence and global sea level rise, low estimate of relative sea level rise in main deltaic plains of China (on the basis of man-made land subsidence being strictly controlled) could be at least 2—3 times over above-mentioned global mean value. The rising range in North China Plain, such as the west bank area of Bohai Bay, would be higher than that in South China Plain, such as the Zhujiang Delta, due to greater man-made land subsidence caused by groundwater overpumping. For example, assuming global sea level rises 20 to 30cm in 2050, relative sea level of China's coastal plains would at least rise 40 to 90cm during the corresponding period. Table 1 shows a scenario of relative sea level rise in China's major deltaic plains during the first half part of the 21st century[5-6].

Table 1 The estimates of future relative sea level rise in China's major deltaic plains (cm)

Region	1991-2030	1991-2050
West bank of Baohai Bay	60	70—90
Huanghe Delta	30—35	40—55
Changjiang Delta	30—40	50—70
Zhujiang Delta	20—25	40—60

III. MAIN ENVIRONMENTAL AND RESOURCE EFFECTS

1. Inundation

Inundation is a direct effect caused by relative sea level rise, its loss depends on the range of relative sea level rise, the standards of coastal defense projects and local surface elevation. Low gradient tidal flat (including coastal wetlands) without protection would first be inundated by vertical increase in relative sea level. For example, a 50cm rise in relative sea level can make 5km of sea water intrude towards inland, assuming that tidal flat has a 1/10000 of low gradient. This loss will be very serious in China's coast with more than 20,700 km^2 of tidal flat, according to the typical estimates on the Changjiang Delta and North Jiangsu coastal plain (26% of total area of China's tidal flat is distributed over this region), 50 and 100cm rise in relative sea level would inundate 5% and 11% of tidal flat respectively[8]. Estimating from this, inundated area of tidal flat of the whole

China might reach at least 1,035 and 2,277km^2 respectively corresponding 50 and 100 cm rise in relative sea level.

Relative sea level rise would also increase inundated risk of low-lying coastal habitable land. The landforms of China's coastal plains are in general low and flat, the overwhelming majority of habitable land is below 5m of elevation, especially in densely populated and well developed Changjiang, Zhujiang and Huanghe deltaic plains. Mean elevation is only 2 to 3m, some low-lying areas are even below present mean sea level. For example, in the west bank area of Bohai Bay near Tianjin, the area below 3m elevation reaches 10,800 km^2, making up 75% of the total area[9]; in the Huanghe Delta and the Changjiang Delta, approximately 2,000 km^2 and 15,700 km^2 of dry land respectively lie at a mean altitude of 2m or less[10]; in the Zhujiang Delta, there is lower land form, the area with elevation below 2.4m is about 5,100 km^2, making up 82% of the total area, and approximately 50% of dry land lies at a mean altitude of 1m or less[11]. At present, these lowlands fully depend on the protection of various coastal defense projects. Relative sea level rise will undoubtedly decline the ability of these projects to holding back the sea and markedly increase inundated risk of these lowlands. According to analysis of defense ability of tidal establishment of Tianjin, Shanghai and Guangzhou areas through estimates of increase in extremely high tidal level caused by relative sea level rise, in urban and industrial zones, a 50cm rise in relative sea level could decline defense ability of local dykes from once in 20 or 40 years today to future approximately once in 5 years at Tianjin; from once in 100 or 1000 years to once in 10 or 100 years at Shanghai and from once in 40 or 50 years to approximately once in 10 years at Guangzhou. If future relative sea level rises 100 cm, the majority of dykes would lose their effectiveness. In rural and agricultural zones, inundated risk would be higher due to lower defense ability of dykes. If present coastal defense projects with low standards were not to be improved, inundating these lowlands would be not to be avoided. Han et al. (1994) estimate that under the situation of lacking protection, a 50cm rise in relative sea level could cause 11,640 km^2 of dry land to be inundated in Tianjin area, assuming hitted by storm surge with the reoccurence period of once in 100 years, approximately 26% of total population would be affected[12]. In the other deltaic plains with lower surface elevation, latent inundated scope would be wider.

2. **Exacerbating Coastal Hazards**

2.1 *storm surge*

China is one of the three countries (the others are Bangladesh and USA)

which suffer the heaviest casualties and losses from storm surge in the world, the yearly economic loss varies from several to over ten billions and appears increase trend year by year. In recent years (1989-1992), extremely severe storm surge disasters happened four times, for example, a storm surge during August 29 to September 1, 1992 resulted in 9.2 billion RMB yuan of direct economic loss along the coast from Fujian-Taiwan in the south to Liaoning-Hebei in the north. Sea level rise would shorten reoccurence period of extremely high tidal level of storm surge due to increase in initial mean sea level and exacerbate storm surge disaster. At Huangpu Park tidal guage, Shanghai, extremely high tidal level has appeared a increase trend in recent 40 years (1950-1990), for example, observed highest tidal level was 4.65m in the 1950s (1954), 4.76m in the 1960s (1962), in the 1970s and the 1980s, it was 4.98m (1974) and 5.22m (1981) respectively, the probability of yearly highest tidal level over 4.65 m is once per decade respectively in the former two decades, but it is two and four times respectively in the latest two decades. Peng et al. (1994) estimate that a 50cm rise in relative sea level would increase a storm surge level with a probability of occurence from 1/100 to 1/10 in the west bank of Bohai Bay[13]; in the Changjiang estuary area, a 50cm rise in relative sea level could shorten the reoccurence periods of storm surge level from once in 1000 years to once in 100 years or from once in 100 years to once in 10 years; in the Zhujiang estuary area, He (1994) concludes that 50cm of relative sea level rise could increase the probability of exceedance from 1/100 to approximately 1/20 or from 1/50 to 1/10[14] (Table 2).

2.2 *Coastal erosion*

In China, silt of 1.75 billion tons a year from great rivers is accumulated along the deltaic coast, so constant accretion of shoreline is the most important feature of China's coast development. But in recent 30 years, most sandy beaches and mud flat have been changing from accretion to erosion, and the eroding scope is gradually expanding. For example, in the Huanghe Delta and its adjacent area, all coast sections are experiencing rapid erosion, except in the limits of 20km around the river mouth still maintaining accretion, mean rate of coast retreat exceeds 100 — 150m a year in some sections[15]; in the Changjiang Delta and North Jiangsu coastal plain, the length of eroding coast has been over 379km, making up approximately 41% of total length of the coastline, in which, newly developed one reaches 104km since the 1980s[16].

The conclusion which sea level rise will aggravate coastal erosion has been confirmed by more and more researchers, Bruun et al. even obtained quantitative relations between the range of sea level rise and the distance of coast retreat

through a large number of field and experimental researches[17]. In China, sea level rise not only accelerates coastline retreat but also causes vertical erosion and retards accretion of tidal flat in some sections where retreat has been limited by dykes. Wang et al. (1993) estimate that a 50cm rise in relative sea level could reduce 12 to 49m retreat of coastline in China's major seaside tourism zones[17]. In China, sea level rise not only accelerates coastline retreat but also causes vertical erosion and retards accretion of tidal flat in some sections where retreat has been limited by dykes. Wang et al. (1993) have analysed impacts of rising sea level on coastal erosion in the Chinagjiang Delta and its adjacent areas, they conclude that 1cm rise in relative sea level could cause 8.3 to 9.1 m retreat of coastline assuming without the protection of defense projects in the northern coast of the delta. At present, the proportion of sea level rise in all factors of aggravating erosion of tidal flat is 9% to 10%, if future relative sea level rises 50cm, this proportion could increase by approximately 35%[19].

Table 2 Change in the reoccurence periods of storm surge caused by relative sea level rise (Yellow Sea datum plane, m)

Affected area	Relative sea level rise (cm)	Storm surge level of various reoccurence periods					
		5	10	20	50	100	1000
West bank of Bohai Bay	0*	2.58	2.83	2.96	3.18	3.33	
	0.5	3.08	3.33	3.46	3.68	3.83	
	0.8	3.38	3.63	3.76	3.98	4.13	
Changjiang estuary area	0**	3.04	3.21	3.32	3.55	3.72	4.23
	0.5	3.54	3.71	3.82	4.05	4.22	4.73
	0.8	3.84	4.01	4.12	4.35	4.52	5.03
Zhujiang esturary area	0***		2.76	2.99	3.26	3.47	4.11
	0.5		3.26	3.49	3.76	3.97	4.01
	0.8		3.56	3.79	4.06	4.27	4.91

* Tanggu tidal gauge[13]

* * Huangpu Park tidal gauge

* * * Guangzhou tidal gauge[14]

2.3 *Coastal flooding and waterlogging*

As above mentioned, China's coastal plains are low and flat, the considerable part of habitable land lies at local mean high tidal level or less. Sea level rise not

only would marked increase the inundated risk due to increase in storm surge level or flood level of tidal river, but also would exacerbate flooding and waterlogging disasters through decrease in drainage ability of various water conservancy projects. This problem could be very serious in some great river deltaic plains. For example, in the Changjiang deltaic plain, a 40cm rise in relative sea level would decrease 20% to 25% of natural drainage ability of Lixiahe and east Taihu lowlands, the total inundated area would be more than 4, 860 km^2 under the condition of present water conservancy projects supposing reoccurence of the flood of the 1991-or 1954-type, in which the area increased by relative sea level rise exceeds 486 km^2, making up approximately 10% of the total inundated area[20]. In the Zhujiang Delta, Fan (1994) estimates that at least increase in 15% to 20% of capacity of power drainage can prevent present draining waterlogged standards of lowlands to decline supposing that future relative sea level rises 50cm.[21]

2.4 *Salt water intrusion*

Salt water intrusion, both into estuaries and aquiers, is also a kind of natural disaster not to be ignored in the coastal area of China. For example, in the Changjiang estuary, a serious salt water intrusion disaster during the winter in 1978 to the spring in 1979 caused the difficulty of urban water supply in Shanghai, and resulted in 14 million RMB yuan of direct industrial loss; in the coastal area of Shandong Province, salt water intrusion into aquiers has reduced 300 mulillion RMB yuan a year of mean industrial loss and 450 km^2 of farmland suffering salinization in recent 10 years.

Sea level rise will alter the balance between fresh water and sea water, increase the area of ground water level lower than mean sea level and exacerbate salt water intrusion disaster. In the Zhujiang estuary, Li (1994) estimates that 40cm of relative sea level rise might increase 2 to 3km of the distance of salt water intrusion (the isohaline of 0.3‰)[22]. In the Changjiang estuary, a 50cm rise in future relative sea level could increase 6.5km and 5.3km of the intrusion distance of the isohalines of 1‰ and 5‰ respectively in dry season, if future relative sea level rises 80cm, these distances would lengthen approximately 10km and 8km respectively[23]. In the North China coastal plain suffering serious harm from salt water intrusion into aquiers, salt water intursion into aquiers today is mainly reduced by groundwater overpumping, vertical increase in relative sea level would undoubtedly exacerbate this hazard due to expanding the area with groundwater level lower than mean sea level, even though overpumping groundwater could be strictly controlled and groundwater level would not continue to decline.

3. Endangering Natural Rseources

3.1 *Land resources*

Relative sea level rise would influence both quantity and quality of land resources in the coastal areas, owing to inundation, aggravating erosion and retrading accretion of tidal flat and wetlands without the protection, and exacerbating soil salinization of farmland respectively. At present, there are approximately 17, 500 km^2 of tidal flat and 3, 200 km^2 of coastal wetlands in China. These lands are the most valuable resource in the coastal areas with too many people but little habitable land. If relative sea level rises 50cm, the total loss (including inundation, aggravating erosion and retrading accretion) of tidal flat and coastal wetlands could reach 11% and 20% respectively in the Changjiang Delta and its adjacent areas, a 100cm rise could cause these losses to be more than 20% and 28% respectively[20]. On these grounds, 50cm and 100cm rise in relative sea level would cause 2, 565 km^2 and 4, 396 km^2 of land resources outside dykes to be lost in the whole China (Table 3).

Table 3 The rough estimates of the loss of land resources outside dykes caused by sea level rise in China (km^2)

Area		Changjiang Delta and its adjacent areas*			China		
		Total	Tidal flat	Wetlands	Total	Tidal flat	Wetlands
Current area		5280	4030	1260	20700	17500	3200
Loss area	50cm	796	550	246	2565	1925	640
	100cm	1398	1054	344	4396	3500	896

* according to Zhu et al., 1994.

Decline in the quality of land resources reduced by sea level rise is owing to water with high salinity permeating some lowlands from estuaries and aquiers. Besides that the area of salinizated land would further expand along with relative sea level rise in the North China coastal area (where has been suffering serious harm from salt water intrusion into coastal aquiers), this problem would also appear in some deltaic plains. For example, Mao (1992) estimated that a 80cm rise in relative sea level could increase approximately 400 km^2 of salinizated land in the eastern Taihu lowland, due to exacerbated salt water intrusion into the Changjiang estuary[23].

3. 2 *Water resources*

Impacts of relative sea level rise on water resources are mainly deterioration of water quality due to salt water intrusion aggravating and drainage of urban polluted water being impeded. In the southern area from the Changjiang estuary, many important cities, such as Shanghai, Hangzhou, Fuzhou and Guangzhou, are located at the estuarine areas, so higher estuarine salt levels and polluted loads caused by relative sead level rise would contaminate urban surface water suppiles. For example, 50cm of relative sea level rise could cause the probability of hourly chlorinity over drinking water standard (CL<250mg/kg) to double in dry season at Wusong water intake of Shanghai, in the dry season of dry year, this probability would increase from 32% today to 70% in the future[22]. Meanwhile, polluted water drained into the Huangpu River from Shanghai City is impeded by tidal current and can't smoothly flow into the sea, it has resulted in serious water pollution, this problem will more serious along with relative sea level rise due to inhancement of tidal current. The same problem would also appear in the other estuarine areas, such as the Minjiang estuary and the Zhujiang estuary.

In the northern areas from the Changjiang estuary, water supply to great extent depends on groundwater, the quality of groundwater of some areas (including Dalian, Qinhuangdao, Yantai and Qingdao areas etc.) has been polluted by salt water. As above metioned, groundwater pollution will also exacerbate due to rise in relative sea level, thus aggravating the contradictory of water supply and demand of the coastal areas.

3. 3 *Tourism resources*

The coastal area is a hot spot of tourism in the world, the income from seaside tourism has occuried approximately two-thirds of the total ones. In China, coastal cities have built over 300 tourism places, including seashore park, bathing beach and seashore convalescent home etc. and the tourists received by these cities in a year have made up 60% of the total ones of the whole country. Relative sea level rise would first cause sandy beaches, the most valuable resort place of the coastal area, to suffer a heavy loss through inundation and erosion. Although China possesses a long coastline, sandy beaches which can be exploited as resort place are not abundant, the length of tourism beaches is only 256km. Wang et al. (1993) have estimated the impacts of a 50cm rise in relative sea level on tourism beaches in the cities of Dalian, Qinhuangdao, Qingdao, Beihai and Sanya, they conclude that tourism beaches of these cities would retreat 31—366m under 50cm of relative sea level rise, mean loss rate of beach area exceeds 24%, Beidaihe, the most famous

resort place of China's coastal area, could lose 60% of tourism beaches[18].

Table 4 The estimates of the loss of sandy beaches of major seaside cities caused by 50cm rise in relative sea level in China

City	Current area ($\times 10^3$ m^2)	50cm rise in relative sea level		
		Retreat (m)	Loss area ($\times 10^3$ m^2)	Loss rate (%)
Dalian	687	34-103	248	36.0
Qinhuangdao	2991	31-204	1390	46.5
Qingdao	1284	75-84	321	25.0
Beihai	11344	37-366	2301	20.3
Sanya	11504	40-114	2387	20.8
Total	27810	31-366	6647	23.9

In addition, many characteristic tourism resources of the coastal area, such as some geomorphologic landscape, the protection areas of valuable animals, plant and wetlands, as well as some tourism islands, would also suffer impacts of relative sea level rise to varying degrees.

3.4 *Biological resources*

The coastal area, located in the junction of land and ocean, has higher output of living things than that of inland area. Due to the loss of tidal flat and coastal wetlands, living resources lived in there would also suffer harm correspondingly. According to the data of resources investigation of the coastal zone, mean output of living things in China's tidal flat is over 249.5 g/m^2, the total output exceeds 5.4 million tons in a year. If future relative sea level rises 50cm, approximately 452 thousand tons of living things in a year would be lost, about 2,000 km^2 of aquatics ponds might be to varying degrees damaged by rise in mean sea level. Meanwhile, the loss of coastal wetlands would decrease growth area and output of some resource plant, such as reed, mangrove and *Spartina anglica*, a rough estimate, based on the typical research on the loss of wetlands in the Changjiang Delta and its adjacent area, shows that 50cm rise in relative sea level could cause at least 260 km^2 of reed and 100 km^2 of *Spartina anglica* to be lost in the whole China.

IV. SUMMARIES AND SUGGESTIONS

Sea level rise is a certain result caused by global warming, unreasonable economic actions, such as groundwater overpumping and building dykes in

estuarine areas, would accelerate regional relative rise in sea level. Due to existing many indefinite factors and lacking sufficient test data, the estimates of future sea level rise diverge with different authors. According to the inferences from present studies, 20 to 30cm rise in global sea level in 2050 is reliable. In China's coastal plains, relative sea level rise could be at least 2 to 3 times over global mean value during the first half part of the 21st century, due to rapid land subsidence caused by overpumping groundwater etc., so stirctly controlling man-made land subsidence in China's coast can effectively decrease the range of relative sea level rise.

Main environment and resource effects caused by sea level rise in China include the following three aspects: (1) permanent inundating a large unmber of tidal flat (including coastal wetlands) outside dykes and increasing inundated risk of coastal low-lying habitable land; (2) aggravating storm surge, coastal erosion, flood and salt water intrusion into both estuaries and aquiers disasters; (3) endangering land, water, tourism and biological resources and their utilization.

In the face of accelerated relative sea level rise and its environment and resource effects, passive drawing back is unrealistic in the densely populated and well developed coastal areas. Sea wall, or dyke, is the most effective means to holding back the sea, according to the range of relative sea level rise and the characteristics of natural environment and socio-economic development in different regions, formulating rationable defense standards and reinforcing current sea wall can greatly mitigate the harm from vertical increase in relative sea level. Meanwhile, explictly considering the factor of relative sea level rise in the processes of economic construction in the coastal areas, such as heightening the foundation of various building, avoiding high dense construction in vulnerable lowlands and readjusting the structure of land use, could also lighten avoidable losses.

There are a long coastline, complex natural and socio-economic situations in China's coastal area, so the range of relative sea level rise and its affecting way and extent diverge are greatly different in different regions. Due to the complex nature of the objects of study themselves and lacking series of observed data, the results obtained by this paper are considerable rough, this problem still remains further to study on the basis of long-term data accumulation.

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