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Assessment of coastal vulnerability to environmental change in Jiangsu coastal plain

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Abstract: Assessment of coastal vulnerability to future environmental change has been emphasized in coastal nations or regions. The Jiangsu coastal plain, located to the north of the Yangtze River Delta in China, is most vulnerable to sea level rise and exacerbating coastal hazards. This paper develops the method of delimiting vulnerable scope and assessing coastal vulnerability through field observations and sampling and by applying remote sensing and GIS, which are suitable for great river delta and coastal plains with large area, relative complex micro-geomorphology and the protection of seawall. Applying this method, the coastal vulnerability of the Jiangsu coastal plain to relative sea level rise (approximately 50 cm up to the year 2050) and exacerbating storm surges have been assessed. The results show that, up to the year 2050, the Jiangsu coastal plain will probably lose 12.8 % of tidal flats (about 5.8?104 hm2) and 7.9 % of cultivated land (about 7.2?104 hm2). Meanwhile, 2.0 % of population, 3.8 % of original value of fixed assets, 3.2% of GDP (Gross Domestic Product), 40.3 % of salt industry and 5.8 % of aquiculture respectively will be affected due to coastal environmental change.

Assessment of coastal vulnerability to environmental change in Jiangsu coastal plain YANG Gui-shan, SHI Ya-feng, ZHANG Chen, LIANG Hai-tang (Nanjing Institute of Geography and Limnology, CAS, Nanjing 210008, China) 1 Introduction Coastal areas, with dense population and high urbanization, are highly sensitive to global environmental change. The impacts of coastal environmental changes, such as sea level rise and related disasters exacerbation on socio-economic development of coastal areas, have become a matter of public concern. To study the vulnerable scope and degree of impacts of sea level rise and related exacerbating coastal hazards can provide a scientific basis for lessening the potential losses through taking measures to restrict over-centralization of population and economy, adjust land use pattern and industrial structure in the vulnerable area of coastal zone. The Intergovernmental Panel on Climate Change (IPCC) called for all coastal countries firstly to implement coastal vulnerability assessment when they evaluate the impacts of climatic change[1,2]. IPCC Working Group III (the Coastal Zone Management Subgroup), based on the suggestions of experts from various countries, put forward and address the common methodology for assessing coastal vulnerability to sea level rise in 1992[3]. In the World Coast Conference (WCC>93) organized by the government of the Netherlands, the representatives exchanged experience and results of coastal vulnerability assessment, and underlined the necessity of assessment, which helped to make out Integrated Coastal Zone Management (ICZM) plan. Meanwhile, the conference stressed that the governments of various coastal states should pay more attention to and finish the assessment as soon as possible, so as to integrate the global coastal vulnerability and make out the aid plan to some developing countries[4,5]. After that, lots of studies of vulnerability assessment were reported[6-9]. However, the Common Methodology ignores the delimitation of vulnerable scope. In the studies reported, the vulnerable scope was delimitated only by comparing the rising sea level with the altitude of land surface. It is obviously unreasonable to the extensive deltaic and coastal plain with complex micro-geomorphologic features and protected by seawall. In fact, due to the limited duration of specific high tides and limited current velocity, the distance of sea-water intrusion is limited even in these areas without protection of the seawall. Therefore, not all lowlands below high tidal level belong to vulnerable scope, so the vulnerable scope by comparing rising sea level with the altitude of land is more than the actual one. But the vulnerable scope merely limited to tidal flats outside seawall is obviously smaller than the actual one, it is because that the lowland inside seawall will be affected by rising phreatic water level and exacerbated stor m surges. To solve this problem, this paper discusses the method of vulnerable scope delimitation and vulnerability assessment to the extensive coastal plains and deltas with complex micro-geomorphologic features and the protection of seawall. Based on this method and the field observation and water-soil sample analysis in typical coastal profile, the vulnerability of Jiangsu coastal plain has been assessed through applying remote sensing and GIS technology (The Jiangsu coastal plain, located to the north of the Yangtze River Delta with a 954-km-long coastline, covering an area of 29.3?103km2, with a population of 19.3million, boasts a GDP of more than RMB 104.1 billion yuan in 1998). 2 Research methods 2.1 Classified data and basic maps acquisition based on remote sensing and GIS Accurate and quantitative local data are necessary to coastal vulnerability assessment to environmental change. Most of these data can>t be collected directly or obtained merely by simple analysis. For meeting the demand of assessment, most of data must have spatial attributes. Therefore, this vulnerability assessment study needs to make use of remote sensing and GIS. The study process is outlined by the framework as follows (see Figure 1). Landsat TM imageries obtained in the winter of 1995 including Shanghai (118-38), Yancheng (119-37) and Lianyungang (118-36) are selected as information sources of land use and land cover. By interpreting these imageries, the land use and land cover map of study area at 1:250000 scale can be produced. The base maps, including political map and digital contour map, are obtained by digitizing the Jiangsu topographic map1 of 1: 250,000 scale using ARC/INFO software. In ARC/INFO environment these maps are transferred to the ones at the same scale to do superposition with land use and land cover map. Then the maps in ARC/INFO format are transferred into the maps of MAPINFO environment by map conversion function to realize all kinds of analysis, relocation, statistic and special subject map acquisition. The background databases are related to coastal natural environment, socio-economic conditions and coastal environmental change and its impacts. These data are saved in attribute database of political map for producing special subject map and realizing other analysis. 2.2 Delimitation of vulnerable scope The delimitation of vulnerable scope is the basis for the vulnerable assessment. Narrow terrace or bay plain with simple feature was selected as the study area in some study results[6], so the methods of comparing high tidal level with the land altitude is reasonable. However, it is difficult to delimit the vulnerable scope of the extensive deltaic and coastal plain with the protection of seawall. Figure 1 Chart of applying Landsat TM imagery and GIS for coastal vulnerability assessment to future environmental change To these areas, the vulnerable scope should include inundated area due to sea level rise, potential scope adversely affected by rising phreatic water level and range influenced by intensified storm surges. Undoubtedly, the areas directly inundated are the most vulnerable parts. The slightly higher part of lowlands will not be permanently inundated, but soil salinization and waterlogging disaster will appear an exacerbate trend owing to the rising phreatic water level and backwater at downstreams of unenclosed river with sea level rise. Therefore, these areas also belong to vulnerable areas, especially, these impacts are very severe on some land use types, such as cultivation. In addition, the rising sea level will intensify storm surges, which will destroy seawall and lead to insufficiency of seawall standard to sea level rise. These will extend potential risk of lowland, so these lowland should belong to vulnerable scope. The Jiangsu coastal plain is low-flat and totally protected by seawall. The elevation of the coastal plain ranges 2-3 m (Datum of the abandoned Yellow River). To delineate the vulnerable scope due to the rising phreatic water level, a typical profile of tidal flat, located on the centre of Yancheng National Nature Reserve, was monitored, including observing phreatic water level and gathering and analyzing water and soil sample, the period lasted one year from 1996 to 1997. The result of observation and analysis demonstrated that salt contents of surface and sub-surface soil are correlated with the phreatic water level. If the depth of phreatic water is deeper than 1.0 m (from surface), salt contents of surface and sub-surface soil would be lower than that of the deep level, indicating the occurrence of desalinization process in the soil. However, if the depth of phreatic water is less than 1.0 m, salt contents of surface soil increase obviously, showing an upward seepage of saltwater into the surface soil, leading to salinization (Figure 2). Figure 3 Chart of surface elevation, relationship between the depth of phreatic water and sea level rise of typical section in Jiangsu coastal plain According to observed slope of tidal flat and gradient of phreatic water level, the depth of phreatic water of different points inland from seawall along the typical profile can be calculated. The result shows that the depth of phreatic water of lowland inside the seawalls is more than 1 m currently, soil salinization will not occur provided cultivation methods are suitable. The change of phreatic water level at different points along the typical profile caused by a 50-cm rising in future sea level can be counted (Figure 3). Based on the extrapolated phreatic depth after 50 cm rising in sea level, the future phreatic depth might be lower than 1m in the area of 9.6 km wide from dikes to inland, with surface elevation lower than 3 m. So salinization in this area will occur and the productivity of land will degrade. The vulnerable scope resulting from intensified storm surges, i.e. maximal invasion distance, can be delimitated by the product of duration of high tide above an specific tidal level and current velocity of relevant rising tid al current. The Jiangsu coastal plain has been cultivated for a long time, the chief seawall near the sea is the main defence to prevent the storm surges. Once the chief seawall is destroyed, the lowland protected directly will be endangered. Although the scope inundated by storm surges might surpass the width of lowland protected by the chief seawall, the further submerge will be prevented by secondary seawalls. So vulnerable scope submerged by future intensified storm surges is confined to the area protected directly by the primary seawalls. Its width is about 1.7-6.1 km (average 3.6 km) from the primary seawalls to inland. According to the above studies, the vulnerable scope of Jiangsu coastal plain can be classified into three types: the tidal flat area outside the chief seawall submerged directly by future sea level rise; the lowlands of soil salinization caused by rising phreatic water, about 9.6 km wide from the primary seawall to inland, with mean elevation lower than 3 m; the area affected by intensified storm surges, which is protected directly by the primary seawall, with a width of about 3.6 km from the primary seawall to inland (Figure 4). 2.3 Vulnerability division and integrated vulnerability assessment To the extensive coastal plain and delta, because various coastal sections differ in features of natural environment, socio-economic development and environmental change, their types and degree of vulnerability also very. Therefore, to assess the vulnerability of the whole region can not meet the demand of practical activity. So it is necessary to assess and define the integrated coastal vulnerability degree (CVD) of the different coastal sections. CVD can be divided into five classes: highest, high, medium, low, lowest. Because the percentage of the highest and lowest of CVD is low and the result should be comparable effectively, this study transfers the absolute loss of vulnerable type to relative value by percentage of total value of this type, it then divides it into five classes with symmetric and unequal interval. The value of grading is shown as follows: highest 1.0; high 0.8; medium 0.5; low 0.2; lowest 0. Finally, the integrated CVD of coastal sections can be expressed by accumulating the class value of vulnerable type of different sections. Figure 4 The vulnerable scope and type to future coastal environmental change in Jiangsu coastal plain According to the features of physical, socio-economic and environmental changes of different coastal sections, the Jiangsu coastal plain can be divided into five sections including area north of the Guanhe River Mouth, abandoned Yellow River Delta, northern part of middle coastal plain, southern part of middle coastal plain and area south of Dongzhaogang. Considering the comparability of assessment among different areas and the regional features, eight vulnerable factors for assessing integrated CVD are considered, including tidal flats loss, people at risk, fixed assets at risk, GDP loss, cultivation loss, salt industry loss, aquiculture loss and additional cost of protective projects. Their class criteria is shown in Table1. Table 1 Primary factors and their class criteria used to assess coastal vulnerability degree(CVD) 3 Conclusions and discussion 3.1 Vulnerable type and degree 3.1.1 Loss of tidal flats and wetlands The Jiangsu coastal plain possesses the most extensive and diversified mud-flats in China, and even the mid-latitude areas of the world, with important ecological function and economic value. Nowadays, only about 525?103 hm2 of tidal flats and coastal wetland remain in this plain, being 1/4 of the whole tidal flat and coastal wetlands in China. Due to sea level rise, the tidal flats are severely affected by inundation, intensified erosion and decrease in the rate of accretion, falling into the category of the most vulnerable type. It is estimated that 67?103 hm2 of tidal flats might be lost, given a 50-cm rise in sea level. The rate of loss is about 12.8 %. The tidal flats loss is different from place to place. The area north of the Guanhe River Mouth is about 9?103 hm2, the rate of loss about 12.8 %; the abandoned Yellow River Delta is about 12?103 hm2, rate of loss about 25.5 %; the northern part of middle coastal plain is about 23?103 hm2, rate of loss about 12.9 %; the southern part of middle coastal plain is about 17?103 hm2, rate of loss about 9.3 %; and the area south of Dongzhaogang is about 6?103 hm2, rate of loss about 13.3 %[10]. 3.1.2 Loss of agriculture Loss of agriculture was resulted from soil salinization due to phreatic water level rise. The phreatic water level of coast is correlated closely to sea level in hydrodynamic feature. The salt content and physical-chemical feature of surface soil may be affected by rising phreatic water level due to future sea level rise, resulting in damage to cultivation in the coastal lowlands in certain width apart from coastline, whether defense engineering was built or not. According to the vulnerable scope to rising phreatic water level delimitated in Figure 4, if a 50-cm rise in sea level, the cultivated area at risk would be 82?103 hm2, about 7.7 % of the total cultivated area, mainly distributing in northern part of middle coastal plain with low elevation, being about 31?103 hm2. Based on the grain output (per unit area yield) and output value of grain of coastal villages and towns in 1995[11], it is assessed that grain loss per year is 263?106 kg and loss of output value from farming is RMB 4.8?108 yuan, a population of 1.64?105, or about 1.3 % of the total population in this region would be affected (see Table 2). Table 2 Loss of agriculture and vulnerable area under cultivation caused by a 50-cm rise in sea level in Jiangsu coastal plain 3.1.3 Integrated socio-economic loss The tidal flats and agricultural production of coastal lowland will be affected by sea level rise. In addition, sea level rise will cause heavy socio-economic loss by intensifying significantly the frequency and intensity of storm surge disasters. Prese ntly, a 985-km long seawall protecting about 197?103 hm2 of coastal lowland has been built in the study area. Of which 74?103 hm2 are occupied by saltern, 23?103 hm2 by fish and pawn farm, 58?103 hm2 by plowland, and 42?103 hm2 by land devoting to housing, transportation, forest and grass and others. The total population directly protected reaches 46?104. According to the latest seawall surveys conducted by water conservancy department of coastal cities covering 1995-1996, the chief seawall of this area has a protection capacity to storm surges with the frequency of 1/50-1/100 years only in view of seawall height. However, because the seawall is made of earth and lacks slope defense measures, the overall capacity of protection is lower than the level mentioned above. Once the highest tidal level exceeds the seawall height, a burst of the seawall will be easily resulted, causing inundation of the whole area protected. It is predicted that the highest tidal level will increase by 0.4-0.44 m, given 50 cm rising in sea level. The storm surges with the frequency of 1/100 years will become that of 1/50-1/20 years; the storm surges with 1/50 years will become that of 1/10 years[12]. When a 50-cm rise in sea level meets the storm surges with the frequency of 1/50 years, the seawall which might be damaged (storm surge overtopping seawall) will be about 437.7 km in length and rate of loss is about 44.3 %. Of the damaged seawall, the area on northern part of the Guanhe River Mouth is about 227 km, rate of loss being about 89.4 %; the abandoned Yellow River Delta is 60.7 km, rate of loss about 69.8 %; the northern part of middle coastal plain is 27 km, rate of loss about 13.3 %; the southern part of middle coastal plain is 82 km, rate of loss about 38.3 %; and the area on southern Dongzhaogang is about 39 km, rate of loss about 40.0 %[13]. According to the situation of socio-economic development, land use pattern and the length of seawall which might be damaged, assumed the increasing rate of future main socio-economic index in area protected directly by seawall is the same as that of the whole coastal plain, potential integrated socio-economic loss resulting from a 50-cm rise in sea level meeting the storm surges with the frequency of 1/50 years is assessed (see Table 3). Table 3 Socio-economic loss caused by a 50-cm rise in sea level meeting storm surges with the frequency of 1/50 years in Jiangsu coastal plain (percentage) 3.1.4 Additional costs of seawall The rise of the highest tidal level of storm surges due to sea level rise can not only increase the frequency of submerging seawall and reduce the level of protection capacity of seawall, but also intensify erosion of tidal flats and dike base and body, especially the earthen seawall, which can be immediately destroyed. According to the existing design standard of excessive height of seawall, width of seawall top and seawall slope, the cost for maintaining the current level of protection against storm surges of 1/50-1/100 years is evaluated. If a 50-cm sea level rises, anticipated, at least about 4.09?107 m3 of earthwork and 1.5?106 m3 of stonework are needed, or about an additional RMB 5?108 yuan investment in current price standard. This investment makes up 0.88 % of GDP of the whole coastal plain in 1995, in which, the area on northern part of the Guanhe River Mouth accounts for 2.10 %, abandoned Yellow River Delta 4.62 %, the northern part of middle coastal plain 0.26 %, the southern part of middle coastal plain 0.56 % and the area on southern part of Dongzhaogang 0.43 %. 3.2 CVD assessment of different sections In order to assess coastal vulnerable degree (CVD) of different sections comparable, the main vulnerable types are standardized in the same scale according to the grading standard of Table 1. In view of the whole area, we can conclude that vulnerable degree of the Jiangsu coastal plain belongs to medium grade. Except the higher vulnerable degree of salt industry, all the others, including tidal flats loss, people at risk, fixed assets at risk, GDP loss, cultivation loss and aquiculture loss belong to medium grade. Additional cost of coast defenses maintaining current designing standard account for low proportion of GDP. In view of different sections, vulnerable degree of the area on northern part of Guanhe River Mouth belongs to the highest grade. The CVD reaches to 0.80, the coastline of this section stretches 180 km, about 18.9 % of that of the study area. This section is densely populated with higher economic density and most centralized distribution of saltern in the study area, the area of saltern exceeds 34.4?103 hm2, making up about 1/2 of that of the study area. Meanwhile, the standard of coastal defenses is on the low side, about 78 % of which is lower than the defense standard to prevent the storm surges with a frequency of 1/50 years. Therefore CVD of most of the vulnerable types in this section belongs to the highest grade except cultivation loss and tidal flats loss. The vulnerable degree of abandoned Yellow River Delta belongs to high grade with CVD amounting to 0.63. The coastline of this section stretches 87 km, about 9.1 % of that of the study area. The standard of coastal defenses is on the low side (69 % of which can not prevent the storm surge with 1/50 years). Coast erodes severely, the average erosion rate of tidal flats amounts for 2.1 cm/a. Concentrated salterns make up about 35.5 % of that of the study area. Consequently, vulnerable degree of tidal flats at risk, GDP loss and salt industry loss are quite high, the other types belong to medium grade in this section. The CVD of the northern part of middle coastal plain and the area south of Dongzhaogang is lower than the mean level of the study area, being about 0.45 and 0.46. The coastlines of the two sections are 369 km in length, about 38.7 % of the study area. In the northern part of middle coastal plain, the length of coastline is 291 km, 90 % of the seawall exceed the defense standard in preventing storm surge of 1/50 year s, higher than the other sections. There are the most centralized distribution of pawn farm and plowland in the study area, about 9.5?103 hm2 and 34.2?103 hm2 respectively, or 41.9 % and 34.2 % of the study area. Therefore, except that vulnerable degree of cultivation and aquiculture belong to high grade, the other types belong to low grade. In the area on southern Dongzhaogang, the length of coastline is 78 km, the vulnerable degree of cultivation and salt industry are relative high due to low relief, the others belong to medium and low due to relativey high standard of coastal defense (over 2/3 of seawall exceeds the standard of 1/50 years). Table 4 Coastal vulnerable degree (CVD) of different sections in Jiangsu coastal plain The CVD of the southern part of middle coastal plain belongs to the lowest grade, about 0.31. The coastline of this section stretches 318 km, amounting for 33.3 % of the study area. There are the most extensive tidal flats, about 182?103 hm2 in area. In addition, the rate of coast accretion is quick and the seawall standard is high. So only vulnerable degree of salt industry is relatively high, the other types belong to low grade. 3.3 Discussion 1) Coastal vulnerability means the degree of incapability to cope with the consequences of climate change and accelerated sea level rise. To assess the integrated coastal vulnerability resulting from environmental change is to assess the general destructive degree of coast by impacts of various environmental changes. It lies on not only the sensitivity of natural system and fragility of socio-economic system to coastal environmental change, but also the protective level of coastal natural and socio-economic system. 2) The delimitation of vulnerable scope is the base of the vulnerable assessment. To the extensive coastal plains and deltas, the methods of defining the vulnerable scope by comparing high tidal level with land altitude is unreasonable. The vulnerable scope should include inundated area caused by sea level rise, potential scope adversely affected by rising phreatic water level and the area directly harmed by exacerbating storm surges resulting from sea level rise. 3) It is just a primary study to assess vulnerability by taking land use map of 1:250000 scale as a base map, which are mapped by extracting information from Landsat TM imageries. It may be feasible to probe into this method, but the accuracy is inadequate for practical purpose. In addition, to the calculation of the vulnerable scope of rising phreatic water level due to sea level rise is undertaken provided that the gradient ratio of phreatic water level is constant regardless of sea level change. In fact, the rising sea level will increase hydraulic pressure, which will decrease gradient of phreatic water level. Therefore, the estimated scope of rising phreatic water level due to sea level rise is relatively higher than actual value. The more accurate result must be based on the relationship of dynamic model between sea level change and phreatic water level fluctuation through long period of field observation. References

关键词： coastal vulnerability assessment; vulnerable scope; coastal environmental change; Jiangsu coastal plain