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Assessment of socio-economic vulnerability under sea level rise coupled with storm surge in the Chongming County, Shanghai

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ABSTRACT

The sea level rise (SLR) caused by global climate change will have a great impact on the coastal areas. This will affect significantly the socio-economic development in the region. The study of the responses of coastal systems to climate change, assessment of the effects of climate change on the coastal systems, and proposal of feasible mitigation strategies are important prerequisites for the sustainable socio-economic development. In this study, the possible impact of the SLR coupled with storm surge caused by climate change on the socio-economic development in the region was analyzed by the Source-Pathway-Receptor-Consequence (SPRC) model using the Chongming County in the municipality of Shanghai as a case study. An index system for vulnerability assessment was developed, in which the flooding depth, population density, GDP per capita, GDP per land unit, rate of flood damage, and fiscal revenue were selected as the key indicators. A quantitative spatial assessment method based on the GIS platform was established by quantifying each indicator and calculating and grading the vulnerability index. The vulnerability assessment was performed under the scenario of the SLR coupled with storm surge and assuming the present infrastructure for three periods: 2030, 2050, and 2100. The projected vulnerability assessment for 2030 shows that the SLR coupled with storm surge will have little impact on the socio-economic development as 98.3% of the areas show no vulnerability. By 2050, the areas with moderate and high vulnerabilities will account for 1.6% and 1.2%, respectively of the total area, while by 2100, 15.1%, 7.9%, and 3.9% of the area will be low, moderately, and highly vulnerable, respectively. The SPRC model and the methodology for vulnerability assessment developed in this study can objectively and quantitatively assess the vulnerability of the socio-economic development in the Chongming County under the impact of the SLR coupled with storm surge caused by climate change. The results from this study indicate that mitigation measures should be considered in the future for securing the socio-economic development in the region.

1. Introduction

The Fifth Report of the Intergovernmental Panel on Climate Change (IPCC) shows that the global warming has been an undoubted fact in recent 100 years [1]. The global warming has accelerated melting of glaciers and rising of sea water temperature, which finally result in global sea level rise (SLR) [2]. The prospect of climate change, in particular sea-level rise (SLR) caused by climate change and its impacts on low lying coastal areas, have generated worldwide attention among scientists, governments and managers of coastal regions [1,3]. The coastal areas, as vital hubs in terms of settlement, national economy and social development, are particularly sensitive to SLR [4]. SLR, at the estimated rate, will pose a significant threat to coastal areas, as a higher sea level provides a higher base for storm surges to build upon. Thus, storm events occurring in conditions of higher mean sea levels will enable inundation and damaging waves to penetrate further inland, increasing flood events and the subsequent impacts on the socio-economic development of the coastal region [5]. According to the statistical data, the flooding caused by SLR coupled with storm surges in the Chinese coastal regions is showing a rising trend, which caused the direct socio-economic losses amounting to hundreds of billions RMB in the last 20 years [6].

Since the First Report of IPCC, many studies have been carried out to assess the socio-economic vulnerability of coastal region to SLR coupled with storm surges. In this context, Kleinosky et al. applied a SLOSH model to assess the socio-economic vulnerability in the metropolitan area of Hampton Roads along Atlantic coast, southeast Virginia, USA [7]. Based on the scenarios of SLR coupled with storm surges, exposure and flooding risk maps were drawn, and the socio-economic vulnerability was assessed under the projections of population growth and its distribution. A vulnerability index system in terms of society and economy was developed to assess vulnerability of urban infrastructure under SLR coupled with storm surges for Cairns in Australia [8]. In China, few studies on the assessment of socio-economic vulnerability for the coastal region under climate change have been carried out, e.g. a vulnerability

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assessment on the coastal plain in Jiangsu Province under the combined impacts of tide current, seawall protection and underground water level [9]. On the whole, the present studies on the socio-economic vulnerability to SLR for the coastal regions were mainly carried out by applying models or developing an index system. However, to assess the socio-economic vulnerability to SLR coupled with storm surge in the coastal regions is a difficult task, as the complexity of the interface among climate change, society and economy [5,10].

To assess the socio-economic vulnerability to climate change is an important prerequisite for the formulation of feasible mitigation strategies to secure sustainable development of the coastal region. In this context, an assessment of socio-economic vulnerability of a Chinese coastal area to SLR coupled with storm surge was carried out, taking the Chongming County in the municipality of Shanghai as a case study. The main objectives of this work were to: 1) develop a methodology for assessing vulnerability; 2) assess quantitatively the socio-economic vulnerability of the Chongming County to scenarios of SLR coupled with storm surge risks, and 3) propose feasible mitigation measures, based on the results.

2. Study area

The Chongming County in the municipality of Shanghai is located at the mouth of Yangtze River (121°10′–122°10′E, 31°18′–31°50′N). The county consists of three islands, i.e. Chongming, Hengsha, and Changxing, with a total land area of 1411 km^2 (Fig. 1). The Chongming County is surrounded by the Yangtze River, the East China Sea to east, the mainland of the municipality of Shanghai to south, Haimen and Qidong of Jiangsu Province to north. The Chongming Island covers 1267 km^2, with an east–west length of 80 km and north–south width of 13–18 km. The whole island is flat and 90% of the land elevation is between 3.21 and 4.20 m (the local Wusong bathymetric benchmark). The Changxing Island is located south to Chongming Island, covering a land area of 88 km^2 and with an east–west length of 26.8 km and north–south width of 2–4 km. The Hengsha Island is located at the eastmost area of the Yangtze Estuary, covering a land area of 56 km^2 and with an east–west length of 8 km and north–south width of 12 km. The average elevation of this island is about 2.8 m.

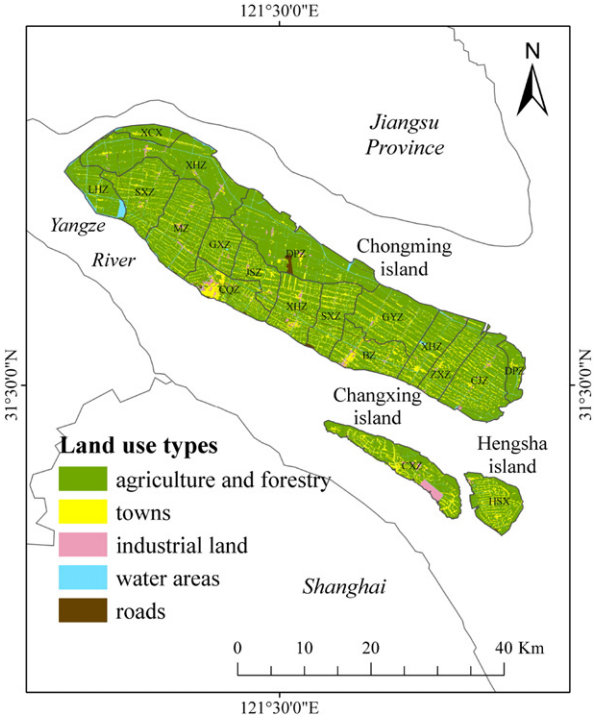

Fig. 1. The location and the land-use types (2007) of the Chongming County, Shanghai.

The Chongming County has an eastern Asian monsoon climate with an average annual temperature of 15.3 °C. The warmest month is from July to August, with an average temperature of 26.8 °C–26.9 °C. The coldest month is from January to February, with an average temperature of 3.0 °C–3.9 °C. The annual frost-free period is about 320 days and the average humidity is 82%. Average annual precipitation is approximately 1022 mm, with 60% of rainfall occurring during May–September and few typhoons during summer and autumn. It has a semidiurnal tide and the tidal amplitude of the estuary system ranges from 2.4 to 4.6 m and averages 2.6 m and the existing seawalls and flood-control levees are constructed in excess of 6 m in order to prevent flooding [11]. Adjacent to the Yangtze River and the sea, typhoons and associated storm surges are some of the most devastating natural disasters affecting the region. The flood disasters caused by storm surges and high tide level, such as during "Typhoon No. 9711", "Typhoon No. 0509" and "Typhoon No. 0515", had led to severe social and economic loss in the region. It was estimated that such disasters in the last 20 years had caused a direct socio-economic loss of RMB 2.47 billion to the municipality of Shanghai [12].

The Chongming County includes 16 towns and 2 villages. The registered population has increased from 633,000 to 688,000 during the period 2004 to 2013 with a growth rate of 8.7%. The population density reached 487 person/km^2 in 2013. In the recent decade, the economy of the Chongming County has been increasing at a stable rate. The annual GDP reached RMB 25.24 billion in 2013, with an annual growth rate of 12.3% for the period of 2004–2013. In 2013, the primary industry amounted to RMB 2.33 billion, the secondary industry to RMB 12.46 billion and the tertiary industry to RMB 10.45 billion, with a structural ratio of 9.2:49.4:41.4. The GDP per capita of the whole county reached RMB 36,700 in 2013. The fiscal revenue of the county reached RMB 4.06 billion and the fixed asset investment reached RMB 13.51 billion in 2013 [13].

3. Methodology for socio-economic vulnerability assessment

3.1. The conceptual model for vulnerability assessment

The Pressure-State-Response (PSR) model has been widely applied in the assessment of socio-economic vulnerability under climate change [4]. The PSR model has a causal relationship to develop an indicator system for vulnerability assessment, i.e. the pressure of human activities or climate change on the systems and the response of the systems to the pressures [14]. Based on the PSR model, a conceptual model of SPRC (Source-Pathway-Receptor-Consequence) model was proposed by the European THESEUS project to assess the impact of SLR coupled with storm surge on the socio-economic vulnerability for the coastal regions [15].

In this context, a SPRC model was developed for the assessment of socio-economic vulnerability in Chongming County under sea level rise coupled with storm surge (Fig. 2). In the SPRC model, the SLR coupled with storm surge caused by climate changes is the source (S) of impacting directly the socio-economic system of the coastal region. Pathways (P) are the routes between the source and the receptors, including seawall defenses, land subsidence and land elevation (DEM). If storm events occur in conditions of higher sea levels, it may overflow the existing seawalls and result in flood events and the subsequent consequences (C) of impacts on the socio-economic development of the region. The land elevation would determine the severity of flooding damages, while land subsidence could increase the rate of SLR and further exacerbate the impacts. Receptors (R) are the coastal systems that would be impacted by the flood events within the case study boundaries. In this study, five categories of receptors have been classified for the Chongming County, i.e. the land for agriculture and