Ocean & Coastal Management 82 (2013) 1–6

Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Opinion paper

Coastal use accelerated the regional sea-level rise

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ARTICLE INFO

Article history:
Available online 4 June 2013

ABSTRACT

Coastal zones are highly threatened by global sea-level rise (SLR), but human-induced change in SLR is often neglected in many studies. Identifying the influences of coastal use on regional SLR and their interactions is helpful to effectively respond to SLR. In this paper, we analyzed the relationship between SLR, coastal use and rising temperature at the provincial level in mainland China since 2000. The results show that there is significant correlation between increasing coastal use and SLR, but that relationship between temperature rising and SLR is not significant. This supports our hypothesis that coastal use can accelerate regional SLR on Chinese coasts, especially in the Bohai Sea. We also discuss the potentially influential mechanism of one important coastal use, reclamation, on SLR in the Bohai Sea and present suggestions for both coastal use management and adaptation to SLR for this region.

1. Introduction

Global sea levels remained nearly stable since about 3000 years ago, but have risen through the 20th century. These rises are expected to accelerate through the 21st century (Nicholls and Cazenave, 2010). For instance, geological and tide-gauge data worldwide indicate that mean sea-level rise (SLR) was 1.7 mm/yr between 1961 and 2008 and 3.26 mm/yr between 1993 and 2008, respectively, suggesting that the SLR is accelerating at a global scale (Ablain et al., 2009; Church et al., 2011). However there is high regional variability and higher rates have been recorded. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, global sea-level will rise by about 60 cm by 2100 (IPCC, 2007).

Global and regional effects of SLR have been well documented (e.g. Cooper and Lemckert, 2012). Regional SLR has increased the risk of damage in low-lying coastal regions, such as densely populated deltas. Direct consequences include submergence, flooding, saltwater intrusion and shoreline retreat, as well as coastal habitat loss (Michener et al., 1997; Pilkey and Cooper, 2004; Hopkinson et al., 2008; Ranasinghe and Stive, 2009). These physical impacts in turn have resulted in significantly negative socioeconomic consequences, such as flooding of urban roadways and coastal lands (Nicholls and Cazenave, 2010).

Heterogenous patterns in SLR mainly result from non-uniform driving factors (Cabanes et al., 2001). In addition to climatic events (e.g. ocean warming and glaciers melting), non-climatic related anthropogenic processes (e.g. land subsidence due to groundwater depletion, or sediment supply reduction caused by hydraulic engineering) increasingly contribute to relative SLR (Ranasinghe and Stive, 2009; Fiedler and Conrad, 2010). Global coastlines are becoming increasingly managed and engineered as a consequence of urbanization over recent decades, and patterns of coastal use have greatly influenced the extent and intensity of human activities on coastal zones (Bulleri and Chapman, 2010).

In recent decades human-induced changes in coastal regions have been rising more rapidly than climate-induced SLR, exacerbating the vulnerability of coastal zones (Nicholls, 2011). According to the estimation of Sahagian et al. (1994), total anthropogenic SLR has been 11.8 mm, with the mean rate of 0.54 mm/yr since 1960. Understanding non-climatic components of SLR is therefore critical to monitoring, assessment and adaptation to SLR effects. However, anthropogenic factors for SLR have long been neglected because of their local features and uncertainty, even though they are widespread (Nicholls and Cazenave, 2010).

Historical tide records show that sea levels around China have risen 90 mm during the past 30 years. This is higher than the global average rate (www.coi.gov.cn). As a result, Chinese coasts have suffered more disturbances, amplifying their vulnerability to SLR. In China, the coastal zone is a major socio-economic region. Spatial patterns of coastal use in China have changed greatly because of the national adjustments and development policies over last decade, with rapid coastal urbanization. For instance, the emerging Bohai

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0964-5691/$ – see front matter
http://dx.doi.org/10.1016/j.ocecoaman.2013.04.012

Economic Rim (BER) is playing an important role in China's economic development. Recently, many nationally important coastal use projects have been implemented in this region. These include the Tianjin New Industry Zone and the Caofeidian Industry Zone.

These developments have changed the physical features of tidal flats and offshore zones (Bi et al., 2012). The question arises that these significant changes in coastal use patterns might influence regional variation in SLR. It would seem that little attention has been paid to the potential effects of coastal use changes on regional SLR, and whether these interactions are sensitive to the global changes.

In this context, we presented the hypothesis that increasing coastal use can accelerate the regional SLR on Chinese coasts. The main objective of our study has been to identify the probable influences of coastal use changes on regional SLR, according to quantitative analysis of SLR and coastal use on Chinese coasts. In particular, we compared the differences between the Bohai Sea and the Non-Bohai Sea regions because of its unique geological location and its critical role in the modern Chinese economy. If the data support our hypothesis there will be a need for decision makers to develop appropriate coastal use management options, including mitigation and adaptation measures to take account of future SLR.

2. Study areas

There are 9 administrative provinces and 2 municipalities located in mainland Chinese coasts. They include Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi, Hainan, Shanghai and Tianjin, with the total coastline length of 1.8×10^4 km (Fig. 1). The mean elevation of coast region here is about 2–5 m above sea level and most of coasts are very flat and low-lying land (Yin et al., 2012). Chinese coasts are very fragile, subjected to the frequent morphological changes. Geologically, the coasts of China can be divided into four parts, the Bohai Sea, the Yellow Sea, the East China Sea and the South China Sea (Fig. 1). Coastal regions have also been China's most important economic area, accounting for 42% of the total population and 51% of the gross domestic product (GDP)(Yin et al., 2012).

The Bohai Sea, also known as Bohai Bay, is located in Northern China and includes three provinces, Liaoning, Hebei, Shandong and Tianjin City. Beijing is not considered in this narrative as a typical coastal city although it was included in this region traditionally (Fig. 1). Due to the central government's "reform and opening-up" policy, coastal urbanization has developed rapidly since late 1990s. The Chinese government has made many policies to foster economic development in the Bohai Sea, as a result this region has gone through major changes in urbanization and infrastructure. The Bohai Sea is becoming an economic and cultural hotpot and rivals the Pearl River Delta in the south and the Yangtze River Delta in the east. Increasing human activities have changed the structure and function of coastline and ecosystems, increasing the vulnerability to future SLR (Yin et al., 2012).

3. Data and methods

We used the date from China Oceanic Information Network (www.coi.gov.cn). Since 2000, the official database from State Oceanic Administration released annual data for SLR and coastal use for these 11 coastal provinces and municipalities in mainland China. The SLR data are the relative sea level changes compared with the average sea level value of Chinese coasts from 1975 to 1993 (www.coi.gov.cn). The coastal use data provide information about area, classification and distribution of different coastal uses over the last decade. Using the database, we calculated the rising rate of SLR (mm/yr) and the increasing percentage (%) of authorized coastal use areas (2000–2011) for the 11 administrative units. Since 2009, the information network has released the data for coastal reclamation, an important coastal use in China. We also calculated the total reclaimed areas for each unit since then. The distribution pattern of SLR and coastal uses were conducted by the GIS software Arc map 10.0.

Owing to its great contribution to SLR, the influence of temperature was also considered in our work. We therefore calculated the rate of annual mean temperature rise (°C/yr) on the Chinese coast using data reported by the Chinese Meteorological Administration (www.cma.gov.cn) to determine whether temperature changes in coastal zones are an important driver to short-term SLR in this region. Based on the database, we selected 65 national stations, which are located on the coast of China to calculate the annual mean temperature for the 11 units. Then, Pearson Correlation analysis method was use to explain the relationships between changes in temperature and coastal use with the regional SLR rate for whole Chinese coast, the Bohai Sea and the Non-Bohai Sea, respectively, by the software SPSS 13.0.

4. Results

Our results showed that the mean rate of SLR in China was approximately 1.97 mm/yr from 2000 to 2011. However, the rate of SLR differs greatly between various coastal zones. The Bohai Sea area, including Liaoning (2.97 mm/yr), Hebei (4.99 mm/yr), Tianjin (7.55 mm/yr) and Shandong (2.61 mm/yr), has become a hotspot for accelerated SLR in the past decade. Jiangsu (1.53 mm/yr), Guangdong (1.40 mm/yr) and Guangxi (1.2 mm/yr) have also witnessed a relatively higher SLR rate. Hainan (0.52 mm/yr) and Zhejian (0.25 mm/yr) have relatively lower SLR rate. However, Shanghai (−0.67 mm/yr) and Fujian (−0.64 mm/yr) have negative rates (Fig. 1).

At the same time, the highest increase in the percentage of coastal use also occurred in the Bohai Sea (Liaoning, 2.17%; Hebei, 10.24%; Tianjin, 20.56% and Shandong, 0.80%), followed by the Yellow Sea (Jiangsu, 6.45% and Shanghai, 7.59%), the East China Sea (Zhejiang, 3.16% and Fujian, 2.66%) and the South China Sea (Guangxi, 2.88%; Guangdong, 0.88% and Hainan, 0.77%), respectively (Fig. 1).

There are no obviously trends of rising temperatures in coastal zone over the last ten years. On the contrary, the temperature data showed that annual mean temperatures in 11 units have all decreased since 2000, except for Guangxi Province. Furthermore, correlation analysis results showed that the rate of SLR in both whole Chinese coast ($P = 0.009$) and the Bohai Sea ($P < 0.0001$) were significantly related to the increase in the percentage of coastal use, while that in the Non-Bohai Sea areas were not significantly related to coastal use increase ($P = 0.6$) (Fig. 2a). However, the rate of SLR in whole coast ($P = 0.96$), the Bohai Sea ($P = 0.52$) and the Non-Bohai Sea ($P = 0.57$) were all insignificantly related to the rate of temperature rise from 2000 to 2011 (Fig. 2b). We therefore conclude that a rise in coastal use is likely to have contributed more to short-term SLR in China coasts than temperature change, particularly in the Bohai Sea.

In China, coastal uses are mainly classified for aquaculture, industry, transformation, tourism, seafloor engineering, as well as reclamation (www.coi.gov.cn). Among the coastal uses, we have focused on coastal reclamation. Cases in European estuaries have shown that reclamation can directly change the surface area of estuaries, which can alter the flow patterns of water, the tidal characteristics and the patterns of sediment deposition and erosion (e.g. Talke and Swart, 2006). Therefore, we summed the total reclamation areas (from 2009 to 2011) in the Bohai Sea, approximately accounting for 0.72%, 2.44%, 10.20% and 0.25% of 5 km

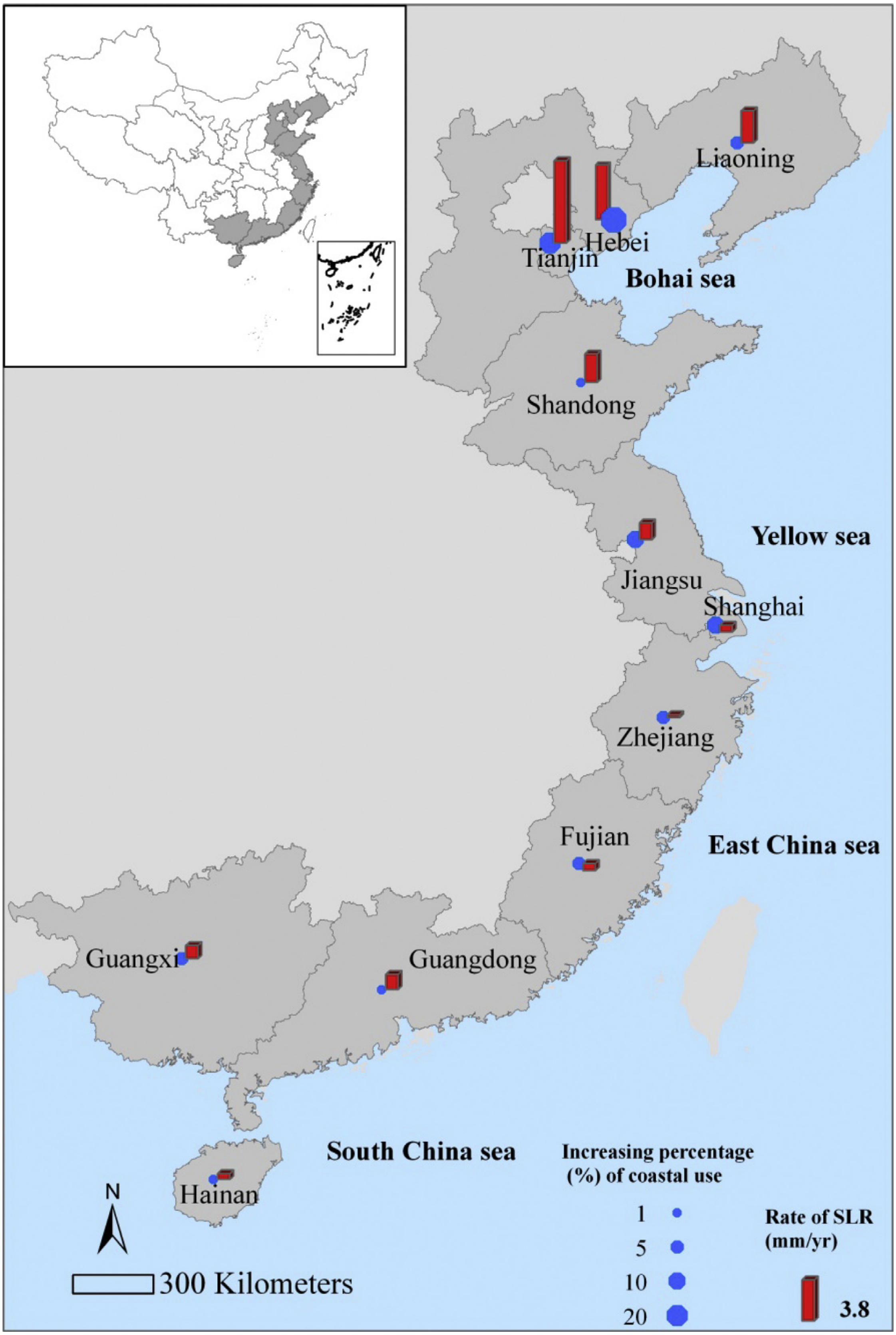

Fig. 1. Distribution of rate of SLR (mm/yr) and increase in the percentage (%) of coastal use in China coast.

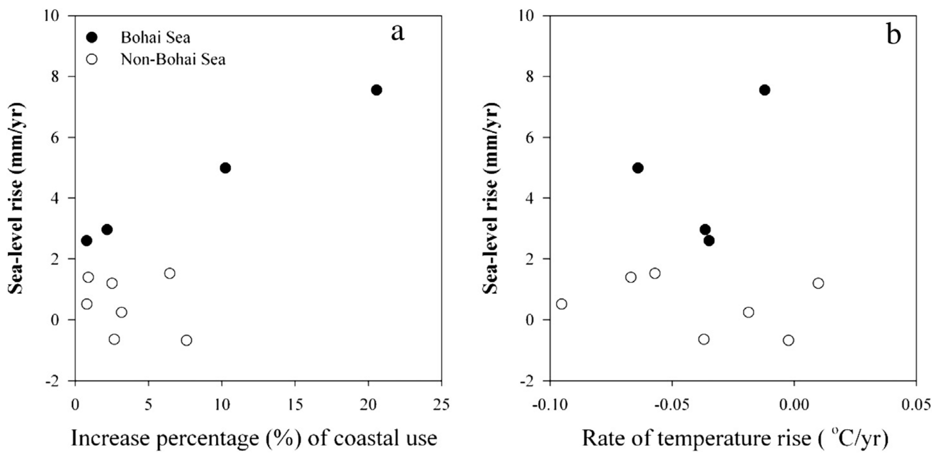

Fig. 2. Relationship between SLR and changes in coastal use and temperature a: rate of SLR (mm/yr) and increase percentage (%)of coastal use; b: rate of SLR (mm/yr) and rate of temperature rise (°C/yr).

coastal zones in Liaoning, Hebei, Tianjin and Shandong, respectively (Fig. 3).

5. Discussion

Sea-level changes reflect the complex interaction between land and ocean processes, which may vary at different scales (Cooper et al., 2008). Patterns of SLR on Chinese coasts are consistent with previous studies which were based on long-term tide-gauge measures and remote sense data (Yin et al., 2012). Both the significant relationship between coastal use changes and SLR and non-significant relationship between temperature changes and SLR support our hypothesis that short-term SLR is potentially accelerated by coastal use rather than temperature on Chinese coasts. In particular, our results suggest that the high rate of SLR in the Bohai Sea is closely associated with land reclamation from sea. The results provide a new insight into the mechanisms of regional SLR and are new to regional coastal management and planning in China. Our analysis suggests that the interactions between SLR and coastal uses should be recognized within adaptation scenarios for SLR, since current researches mainly focus on the impacts of SLR on coasts.

Since the 1970s, coastal use changes in the Bohai Sea have undergone several stages: salt production, aquaculture and development of the port industry. At present, the construction of two new ports and their related industries, Tianjin Port and Caofeidian Port (Hebei Province), on the northwest coast of the Bohai Sea has made this region the biggest artificial coast in China (Zhu and Xu, 2012).

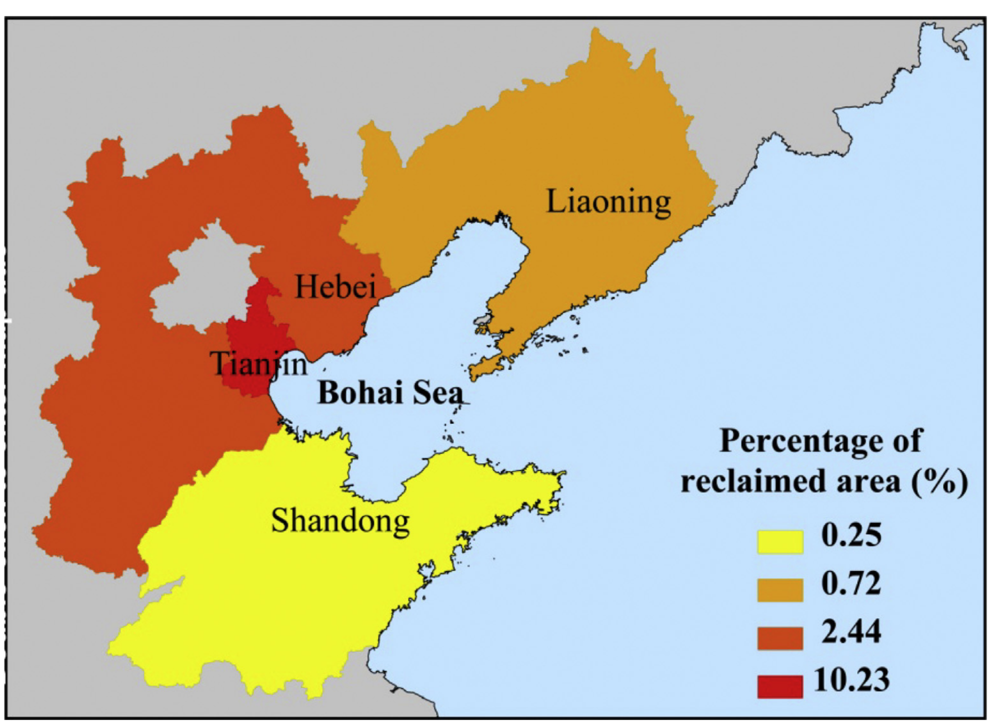

Fig. 3. Percentage (%) of coastal reclamation in 5 km coastal zone in Bohai Sea from 2009 to 2011.

Coastal reclamation has played essentially important role during the development of new coastal uses. Remote sense data show that reclaimed land from the sea in Tianjin and Hebei Province has increased by approximately 901.7 km^2 between 1974 and 2010. This has caused the coastline to move about 4.0 km seaward. Under the government's development planning, another 300 km^2 of inertial flat and offshore will be reclaimed in the next 10 years (Zhu and Xu, 2012).

The low elevation and long coastline radian in the Bohai Sea have made possible coastal reclamation activities in this region (Zhu and Xu, 2012). On the one hand, the reclamation projects today have reached deeper coastal water by filling in coastal water body or intertidal wetland using civil materials and hydraulic technologies, which lead to the seaward movement of the coastal line. According to the equation (1), decreasing S may lead to an increasing H, given a constant V.

$$V = S \times H \quad (1)$$

Here, V = Volume, S = area, H = height.

As a semi-enclosed sea, the area of the Bohai Sea (approximately 78,000 km^2), has decreased as a result of increasingly invasive projects (Fig. 4). On the other hand, the infrastructures in reclaimed areas, such as seawalls, dykes, roads as well as buildings, can compact the muddy or sandy substrate, which can lead to land subsidence and indirectly increase the relative rate of SLR (www.coi.gov.cn). The cases in the UK have also shown that use of seawalls and embankments can exacerbate the steepening process of coasts by halting the landward movement of high tide, which has resulted in an intertidal squeeze and ultimately the changes in beach profiles would accelerate the tidal range (Taylor et al., 2004; Jackson and McIlvenny, 2011). In addition, the possible funneling effects in confined spaces in the Bohai Sea due to excessive groundwater depletion may also lead to loss of accommodation space in unhardened coastlines (Taniguchi et al., 2008). The combination of coastal uses can therefore explain the accelerated SLR in the Bohai Sea.

In this context, the Bohai Sea become more sensitive to SLR combined with its geomorphology and intense levels of land reclamations. Recognition of the interactions between coastal use and SLR is especially important for coastal management when considering adaptation strategies to address SLR. Impacts and responses of coastal use changes at different levels, e.g. national or provincial scale, to regional SLR should be carefully considered during coastal management and planning. National development plans need to address the growing risks of coastal occupancy. A long-term and detailed coastal use and management database should be constructed, including SLR monitoring systems. For instance, the distance to sea, density, height, weight and spatial distribution of urban infrastructure in reclaimed areas should be included in coastal use database.

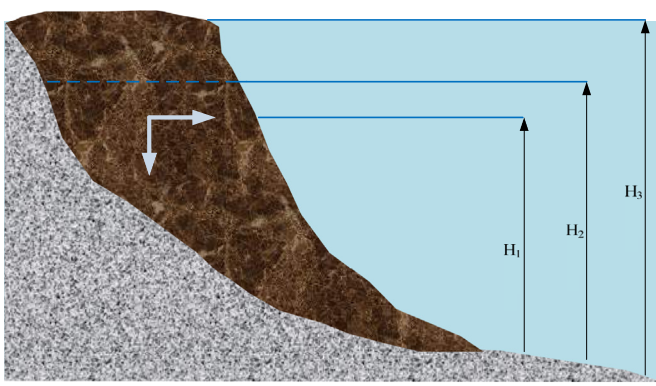

Fig. 4. Potential influences of coastal reclamation on SLR in Bohai Sea H_1: the original sea level; H_2: Sea level under global climate changes; H_3: Sea level influenced by coastal reclamation and global climate changes; The arrows represented potential physical forces from coastal reclamation activities (right: directly decrease the area of Bohai Sea; down: the compaction effect may lead to land subsidence).

Assessment of potential and cumulative consequences of coastal use changes in the Bohai Sea, especially in the Tianjin New industry zone and the Caofeidian industry zone, is urgently needed. For example, our understanding of how coastal reclamation activities can lead to land subsidence remains extremely limited. Accurate physical experiments and model simulation are therefore needed to quantify their interrelationships. In addition, the potential risk of coastal use within the vicious circle of SLR and its adverse drivers, such as groundwater depletion and coastline retreatment, the two main environmental issues related the SLR in North China (Liu et al., 2001; Wada et al., 2012), should be also addressed. Monitoring spatial patterns and dynamic processes of dominant drivers under those changes are required. Since long-term coastal use data are limited, spatial information technology can provide alterative options, such as geographic information system and remote sensing.

The appropriate response to SLR is to adapt to it (Nicholls and Cazenave, 2010). Adaptation involves both technical and socio-political issues (Naylor et al., 2012), which should be substantially integrated into wider coastal management and development planning. In Europe, many analytical and numerical models have been applied to estuary areas, e.g. the Ems, Schelde, Elbe and Seine estuaries, to estimate tidal range, storm surges and mixing and dispersion processes and evaluate the effects of coastal use (Frouin et al., 2007; Lebbe et al., 2008; Ducrotoy, 2010; Tessier et al., 2012). The Ems, for example, is a relatively well studied estuary and the relative research projects are focusing on tidal dynamics and affects of dredging in the high turbidity zone (Talke and Swart, 2006). In addition, optimal planning measures are also provided at national level in Europe. An example of such planning is demonstrated by the Netherlands, which is planning to provide higher levels of protection against SLR by beach nourishment. The plan stresses the interaction between the adaptation to SLR and coastal management. It also stated that the adaptation would continue for a long term (Nicholls and Cazenave, 2010). In the Uk, SLR has formed a central tenet of planning guidance for design of new flood defences (e.g. http://www.defra.gov.uk/environ/fcd/pubs/pagn/default.htm)

Although it is widely recognized the possible impacts of SLR, there is limited policy and regulation that explicitly incorporates accelerating SLR into the coastal management process in a world context yet (Moser et al., 2012). Coastal management must consider the cumulative, synergistic and mounting stresses arising from SLR and coastal use changes. The key issues for policy makers are to identify how, where and when to adapt to the changes resulting from SLR and to justify the current approaches to reflect the increasing vulnerabilities (Willis and Church, 2012). Since previous attention has mainly been paid to the impacts of SLR, the theory and technologies of adaptation to the regional SLR are still big challenges for our society.

6. Conclusions

Data for SLR and coastal use at the provincial level confirm that our hypothesis that the regional SLR may be accelerated by coastal use rise on Chinese coasts. In particular, the rate of SLR is closely related to coastal use changes in the Bohai Sea. Among those coastal uses, more attention should be paid to the potential influences of coastal reclamation. Understanding the interactions between coastal use and the regional SLR is helpful to both coastal management and adaptation to SLR. Coastal management and national development planning should carefully consider the possible mechanism and consequences of SLR.

Acknowledgments

This manuscript benefited from the critical comments and helpful suggestions of two anonymous referees. The work is funded by the 2020-Planning Project of Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (No. Y254021031) and the National Natural Science Foundation of China (No. 31270510 and No. 31000197).

References

Ablain, M., Cazenave, A., Valladeau, G., Guinehut, S., 2009. A new assessment of the error budget of global mean sea level rate estimated by satellite altimetry over 1993-2008. Ocean Science 5, 193–201.
Bi, X., Liu, F., Pan, X., 2012. Coastal projects in China: from reclamation to restoration. Environmental Science & Technology 46, 4691–4692.
Bulleri, F., Chapman, M.G., 2010. The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology 47, 26–35.
Cabanes, C., Cazenave, A., Le Provost, C., 2001. Sea level rise during past 40 years determined from satellite and in situ observations. Science 294, 840–842.
Church, J.A., White, N.J., Konikow, L.F., Domingues, C.M., Cogley, J.G., Rignot, E., Gregory, J.M., van den Broeke, M.R., Monaghan, A.J., Velicogna, I., 2011. Revisiting the Earth's sea-level and energy budgets from 1961 to 2008. Geophysical Research Letters 38.
Cooper, J.A.G., Lemckert, C., 2012. Extreme sea-level rise and adaptation options for coastal resort cities: a qualitative assessment from the Gold Coast, Australia. Ocean & Coastal Management 64, 1–14.
Cooper, M.J.P., Beevers, M.D., Oppenheimer, M., 2008. The potential impacts of sea level rise on the coastal region of New Jersey, USA. Climatic Change 90, 475–492.
Ducrotoy, J.P., 2010. Ecological restoration of tidal estuaries in North Western Europe: an adaptive strategy to multi-scale changes. Plankton & Benthos Research 5, 174–184.
Fiedler, J.W., Conrad, C.P., 2010. Spatial variability of sea level rise due to water impoundment behind dams. Geophysical Research Letters 37.
Frouin, M., Sebag, D., Durand, A., Laignel, B., Saliege, J.F., Mahler, B.J., Fauchard, C., 2007. Influence of paleotopography, base level and sedimentation rate on estuarine system response to the Holocene sea-level rise: the example of the Marais Vernier, Seine estuary, France. Sedimentary Geology 200, 15–29.
Hopkinson, C.S., Lugo, A.E., Alber, M., Covich, A.P., Van Bloem, S.J., 2008. Forecasting effects of sea-level rise and windstorms on coastal and inland ecosystems. Frontiers in Ecology and the Environment 6, 255–263.
IPCC, 2007. Climate change 2007: the physical Science Basis. In: Solomon, S., et al. (Eds.), Contribution of Working Group I the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
Jackson, A.C., McIlvenny, J., 2011. Coastal squeeze on rocky shores in northern Scotland and some possible ecological impacts. Journal of Experimental Marine Biology and Ecology 400, 314–321.
Lebbe, L., Meir, N.V., Viaene, P., 2008. Potential implications of sea-level rise for Belgium. Journal of Coastal Research 24, 358–366.
Liu, C.M., Yu, J.J., Kendy, E., 2001. Groundwater exploitation and its impact on the environment in the North China Plain. Water International 26, 265–272.
Michener, W.K., Blood, E.R., Bildstein, K.L., Brinson, M.M., Gardner, L.R., 1997. Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. Ecological Applications 7, 770–801.
Moser, S.C., Williams, S.J., Boesch, D.F., 2012. Wicked challenges at land's end: managing coastal vulnerability under climate change. Annual Review of Environment and Resources 37, 51.
Naylor, L.A., Coombes, M.A., Venn, O., Roast, S.D., Thompson, R.C., 2012. Facilitating ecological enhancement of coastal infrastructure: the role of policy, people and planning. Environmental Science & Policy 22, 36–46.
Nicholls, R.J., 2011. Planning for the impacts of sea level rise. Oceanography 24, 144–157.
Nicholls, R.J., Cazenave, A., 2010. Sea-level rise and its impact on coastal zones. Science 328, 1517–1520.
Pilkey, O.H., Cooper, J.A.G., 2004. Society and sea level rise. Science 303, 1781–1782.
Ranasinghe, R., Stive, M.J.F., 2009. Rising seas and retreating coastlines. Climatic Change 97, 465–468.
Sahagian, D.L., Schwartz, F.W., Jacobs, D.K., 1994. Direct anthropogenic contribution to sea-level rise in the 20th-century. Nature 367, 54–57.
Talke, S.A., Swart, H.E., 2006. Hydrodynamics and Morphology in the Ems/Dollard Estuary: Review of Models, Measurements, Scientific Literature, and the Effects of Changing Conditions. Institute for Marine and Atmospheric Research Utrecht (IMAU), University of Utrecht. IMAU report #R06-01. http://depts.washington.edu/uwefm/publications/TalkedeSwart_Ems_Review.pdf.
Taniguchi, M., Ishitobi, T., Chen, J., Onodera, S.-i., Miyaoka, K., Burnett, W.C., Peterson, R., Liu, G., Fukushima, Y., 2008. Submarine groundwater discharge from the Yellow River Delta to the Bohai Sea, China. Journal of Geophysical Research-Oceans 113.
Taylor, J.A., Murdock, A.P., Pontee, N.I., 2004. A macroscale analysis of coastal steepening around the coast of England and Wales. Geographical Journal 170, 179–188.
Tessier, B., Billeaud, I., Sorrel, P., Delsinne, N., Lesueur, P., 2012. Infilling stratigraphy of macrotidal tide-dominated estuaries. Controlling mechanisms: sea-level fluctuations, bedrock morphology, sediment supply and climate changes (The examples of the Seine estuary and the Mont-Saint-Michel Bay, English Channel, NW France). Sedimentary Geology 279, 62–73.
Wada, Y., van Beek, L.P.H., Weiland, F.C.S., Chao, B.F., Wu, Y.H., Bierkens, M.F.P., 2012. Past and future contribution of global groundwater depletion to sea-level rise. Geophysical Research Letters 39.
Willis, J.K., Church, J.A., 2012. Regional sea-level projection. Science 336, 550–551.
Yin, J., Yin, Z., Wang, J., Xu, S., 2012. National assessment of coastal vulnerability to sea-level rise for the Chinese coast. Journal of Coastal Conservation 16, 123–133.
Zhu, G.R., Xu, X.G., 2012. Annual processes of land reclamation from sea along the Northwest coast of the Bohai Bay during 1974 to 2010. SCIENTIA GEOGRAPHICA SINICA 31, 45–51. (Chinese with English abstract).