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Responses of river discharge and sea level rise to climate change and human activity in the Changjiang River Estuary

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Abstract: Climate change and human activity result in the variations in river discharge and sea level rise, both of which are very important for setting the boundary conditions of a numerical model. Thus, to obtain proper boundary conditions, this study presents projected variations in the amounts of Changjiang river discharge and sea level rise caused by climate change and human activity in 2030, 2050, and 2100. Considering the Three Gorges Dam closure in 2003 and utilizing the historical river discharge data at Datong Station from 1865 to 2002, the river discharge variations resulting from the extrapolation of historic data and climate models are almost identical. The mean river discharge in January and February will reach 12 348, 12 683, and 13 522 $m^3 \cdot s^{-1}$ in 2030, 2050, and 2100, respectively, due to climate change. In the past 20 years, the rate of absolute sea level rise was approximately 2.5 $mm \cdot a^{-1}$ in the Changjiang River Estuary. In accordance with the observed tidal data that based on the sea level change over time analysis-based forecasting model, the absolute sea level rise will be 49.1, 148.1, and 395.6 mm in 2030, 2050, and 2100, respectively, compared to the 2012 levels. The saltwater intrusion simulation numerical model for the Changjiang River Estuary must consider the impacts of the Three Gorges Reservoir and South-to-North Water Diversion on the river discharge. The earth crust and land subsidence should also be considered for an accurate determination of the relative sea level rise. These values are presented in this paper for each prediction period.

Key words: Changjiang River Estuary; climate change; human activity; river discharge; sea level rise

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长江河口径流量与海平面上升对气候变化及人类活动的响应

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摘要: 气候变化和人类活动所导致的径流量变化和海平面上升都是数值模式中重要的边界条件. 因此, 为了得到合适的边界条件, 本文给出 2030、2050 和 2100 年气候变化和人类活动影响下长江径流量和海平面上升的变化情况. 考虑到三峡工程于 2003 年坝体合拢, 利用大通站 1865 至 2002 年的历史径流量资料, 发现利用资料外推获得的径流量变化率与气候模型所得结果近似, 得到在 2030、2050 和 2100 年 1、2月平均径流量在气候变化影响下分别为 12 348、12 683 和 13 522 $m^3 \cdot s^{-1}$. 在过去 20 年, 长江河口绝对海平面上升率约为 2.5 $mm \cdot a^{-1}$. 根据海平面变化资料分析预报模型, 2012 年至 2030、2050 和 2100 年绝对海平面分别上升 49.1、148.1 和 395.6 mm. 长江河口的盐水入侵数值模拟需考虑三峡水库和南水北调对入海径流量的影响. 同时, 相对海平面变化需要考虑地壳下沉和地基沉降. 本文给出各个预估时期上述内容的量值.

关键词: 长江河口;　气候变化;　人类活动;　径流量;　海平面上升

0 Introduction

The author's research group recently carried out a study on the influence of climate change on saltwater intrusion in the Changjiang River Estuary, supported by "Responses of saltwater intrusion to climate change and sea level rise"(contract No. 2010CB951201), the first subproject under the National Basic Scientific Research Program of Global Change Research of China "Study on the influence of global changes on typical coastal zone in China and its vulnerability assessment"(contract No. 2010CB951200). The three-dimensional saltwater intrusion numerical model was used as the major study method, in which the open boundaries should be specified first under the constraints of climate change and human activity.

The main factors influencing saltwater intrusion in the Changjiang River Estuary are river discharge and tide[1-5]. Moreover, the wind stress and estuarine morphological evolution are also important[6,7]. The numerical modeling of saltwater intrusion in estuaries requires detailed information on initial and boundary conditions as they vary due to global climate change. It is generally thought that climate change results in local variations in precipitation and sea level rise. In the Changjiang River basin, a change in precipitation can change the river discharge rate, which in turn influences the saltwater intrusion in the estuary. Sea level rise increases the water depth of the entire estuary (estuarine morphology) and influences the tide and tidal current, thereby impacting saltwater intrusion. The impacts of human activity on saltwater intrusion include a change in river discharge due to engineering and projects in the basin as well as the alteration of the local river regime. In particular, the water diversion projects in the river basin can adjust the river discharge downstream and thus directly affect the estuarine region. Therefore, the major projects in the river basin account for some of the most significant boundary factors that alter river discharge.

The impacts of climate change and human activity on saltwater intrusion in the Changjiang River Estuary are mainly reflected in the river discharge variation and sea level rise. To predict

the response of saltwater intrusion to climate change in 2030, 2050, and 2100, it is necessary to determine the values of the river discharge and sea level rise due to climate change since 2012.

1 Change of river discharge

1.1 Response to climate change

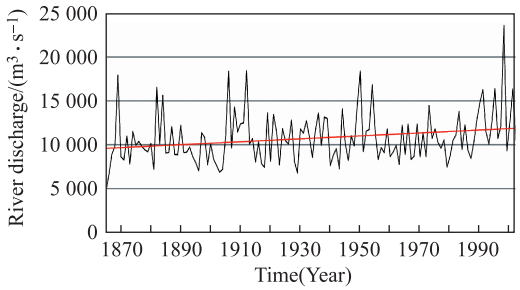
The river discharge is specified at the upstream river open boundary in the saltwater intrusion numerical model of the Changjiang River Estuary. The observed river discharge at Datong Station is directly used for the model boundary condition to consider previous periods. However, there are generally two methods used to ascertain the river discharge for future periods. One is extrapolation based on historical observation data, and the other is prediction from climate change models or statistics models under different greenhouse gas emission scenarios. In this study, we adopted these two methods based on previous studies to more accurately determine the future river discharge at Datong Station.

In the Changjiang River Basin, the river discharge is closely related to the precipitation, with a correlation coefficient of 99%, indicating that changes in the river discharge are mainly controlled by the rainfall[8]. Due to the monsoon season, the precipitation exhibits pronounced annual and monthly variations, which are larger in flood seasons (July and August) and smaller in dry seasons (January and February). Meanwhile, extreme droughts or flooding occur more frequently in warm climates. Based on the Datong Station hydrological records, Shi et al[9] indicated that the mean annual river discharge was 28 859 $m^3 \cdot s^{-1}$ from 1950 to 2000, and it increased to 30 415 $m^3 \cdot s^{-1}$ from 1991 to 2000 with an increase rate of 3.2%. The records of more than 100 years of data from Cuntan Station near Chongqin city, which is near the upper reaches of the Changjiang River, indicate that the mean river discharge was $3\,596 \times 10^8$ $m^3 \cdot a^{-1}$ from 1889 to 1959, which was a wet period, and it decreased to as low as $3\,419 \times 10^8$ $m^3 \cdot a^{-1}$ from 1960 to 1998, which was a dry period. Compared with the annual mean river discharge of $3\,531 \times 10^8$ $m^3 \cdot a^{-1}$, the river variations during wet and dry periods are approximately +2% and −3%, respectively.

Qin et al[10] considered that the river discharge varies with different trends at different reaches of the Changjiang River. The river discharge at Yichang Station, which is at the upper reaches, and Hankou Station, which is in the middle reaches, exhibited a decreasing trend of 918 and 1 108 $m^3 \cdot s^{-1}$ per 100 years, respectively. The river discharge at Datong Station, which is in the lower reaches, had an increasing trend of 1 707 $m^3 \cdot s^{-1}$ per 100 years, which is larger than the trends in the upper and middle reaches. During the 1990 s, the composition of the river discharge exhibited a decreasing volume at the upper reaches and increasing volumes at the middle and lower reaches, especially in the lower reaches. Jiang et al[11] analyzed the spatial distributions of precipitation from June to August during the 1990 s. They noted that the increase of precipitation in the summer mainly occurs in the basins of Dongting Lake, Boyang Lake, and Taihu Lake at the middle and lower reaches of the Changjiang River, which have mean precipitations of more than 100 mm. The precipitation anomalies are negative in the north area of the Jinsha River, Mintuo River, and Jialing River basins in the upper reaches of the

Changjiang River, especially in the center area of the main river, where the variation is below −100 mm. Xu et al[12] noted that the general trend of precipitation in the Changjiang River basin increases in the winter and summer and decreases in the spring and autumn. Overall, previous studies have indicated that the river discharge at Datong Station, which is located in the lower reaches of the Changjiang River, has exhibited an increasing trend.

Our team collected monthly mean river discharge data at Datong Station from 1950 to 2012. To obtain a longer historical data record, our study adopted the reconstructed monthly mean river discharge from 1865 to 1949 by Yang et al[8], which is based on the correlation between Datong Station and other stations in the middle reaches of the Changjiang River. It was first necessary to remove the impacts of human activities on river discharge to construct the relationship between climate change and river discharge at Datong Station with a time series. The Three Gorges Reservoir, which was built in 2003, has clear seasonal runoff regulation. Therefore, we adopted the river discharge data at Datong Station from 1865 to 2002. Saltwater intrusion in the Changjiang River Estuary is high in January and February, and the monthly mean river discharges were similar in these two months. Hence, we adopted the mean river discharge in January and February as the upper open boundary condition for our saltwater intrusion model. Figure 1 presents the annual variation of the mean river discharge in January and February at Datong Station from 1865 to 2002. The correlation relationship between the river discharge (y) and year (x) was fitted with the following linear relationship: y=16.777(x−1 865)+9 579.3. The mean river discharge in January and February increased with an annual rate of 16.777 $m^3 \cdot s^{-1}$ under the influence of climate change. The monthly mean value was 10 745 $m^3 \cdot s^{-1}$ from 1865 to 2002, and thus, the annual mean increase rate was 0.16%. This result indicated that the mean river discharge in January and February at Datong Station increased slightly over the past hundred years, which is consistent with the conclusions made from previous studies.



Note: The red line is the linear fit function y=16.777(x−1 865)+9 579.3.

Fig. 1　Temporal variation of the mean river discharge in January and February at Datong Station

Ju et al[13] selected 7 general circulation models (GCMs), such as the Bjerknes Center for Climate Research Bergen Climate Model 2.0 (BCCR-BCM 2.0), according to the evaluation of the performance of 22 GCMs that were used in the IPCC Fourth Assessment Report (AR4) to simulate precipitation and temperature in the Changjiang River basin. They utilized the model prediction results for future temperature and precipitation under 3 typical emission scenarios,

A1B, A2, and B1, to predict the trend in the river discharge variation for the Changjiang River basin due to future climate change. The results indicated that the monthly mean river discharge will increase between January and June and decrease between July and December. The rate of increase at Datong Station reached 13.8%, and the rate of decrease was −11.0%. In this study, historical data from 1961 to 2005 were adopted, and the monthly mean river discharge in January and February during this period was approximately 11 500 $m^3 \cdot s^{-1}$. The rate of the river discharge increase from January to February and March to June was found to be nearly steady throughout the 90-year prediction period from 2010 to 2099. Thus, we calculated the annual river discharge increase rate in January and February at Datong Station from 2010 to 2099 to be 13.8%/90=0.15%.

As mentioned above, the future annual increase rate of the river discharge in January and February at Datong Station is 0.16% based on an extrapolation of the historical data and 0.15% based on the precipitation results of the climate models under different emission scenarios. These values are very similar. Therefore, we adopted an annual rate of 0.15% for the river discharge increase in January and February at Datong Station from 2012 to 2100 due to climate change for this study. Using the fitting function between year and monthly mean river discharge, the mean value in January and February of 2012 at Datong Station is found to be $16.777 \times (2012 - 1865) + 9579.3 = 12046$ $m^3 \cdot s^{-1}$. Thus, the river discharge in 2030, 2050, and 2100 will be 12 348, 12 683, and 13 522 $m^3 \cdot s^{-1}$, respectively, due to climate change.

The results of China's National Assessment Report on Climate Change[14] indicated that the precipitation trends were not obvious during the last 50 and 100 years, whereas the inter-annual variations were large. The precipitation decreased in autumn and increased in spring. The regional climate model was applied to predict the precipitation variation. The results indicated that the precipitation increased by 36% in the winter in 2070 compared to 2000 levels in the Changjiang River Basin and by 0.514% annually. In other words, the river discharge at Datong Station was predicted to increase by over 10 000 $m^3 \cdot s^{-1}$ in the next 100 years, which is unrealistic. This has never occurred over the past 100 years, and it would significantly change the saltwater intrusion in the Changjiang River Estuary if it were to occur. This large variation in the river discharge may have been caused either by the clime model in which the contents of greenhouse gases and aerosols were considered but the human activities and trends of climate change were not included or by the numerical errors of the model. Therefore, the results of the report were not adopted in our study.

1.2 Response to human activity

The Changjiang River flows through ten provinces, municipalities, and regions: Qinghai, Tibet, Sichuan, Yunnan, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, and Shanghai. The basin area covers nearly one fifth of China. The river also has one of the most superior navigation conditions among all of the rivers in the world. Shanghai, which is located in the Changjiang River Estuary, is the largest port in China. These large water and navigation resources have been gradually utilized by people with the development of economic construction. Many large reservoirs and water diversion projects have thus been constructed in the river basin. Such engineering, which works by changing and regulating runoff, tends to change the natural balance of the estuarine region, directly affecting the intensity and scope of saltwater intrusion. Thus,

the plans and strategies of large projects should consider the estuary's future saltwater intrusion situation. This report considers the Three Gorges Project and South-to-North Water Diversion Project (Figure 2).

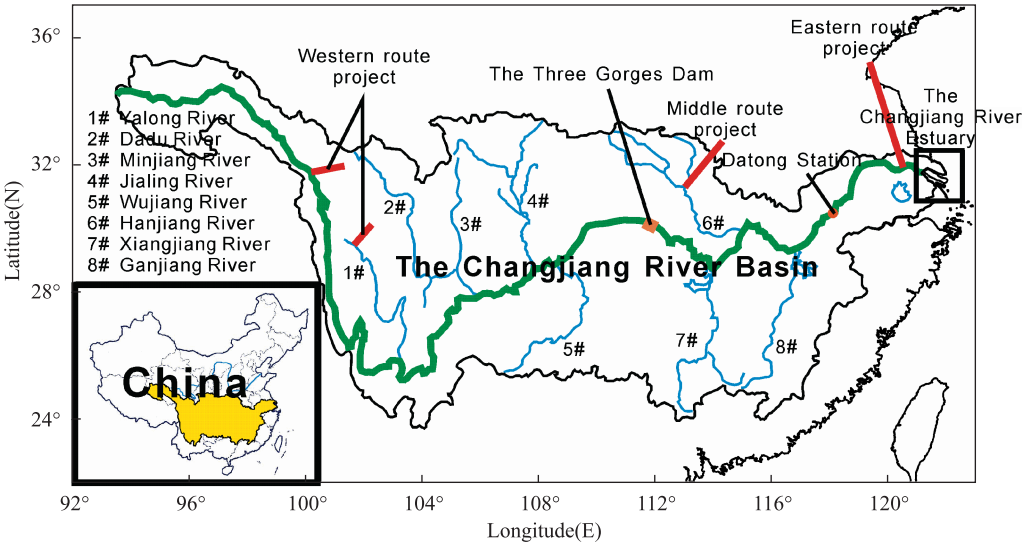


Fig. 2　Sketch of the Three Gorges Project and South-to-North Water Diversion Project

The Three Gorges Reservoir, which is known as the largest water conservancy and hydropower project in China, started operating in 2003. The dam is located in Yichang and ranges approximately 1 800 km from the estuary. The total capacity of the reservoir is 39.3 km^3, and its adjustment capacity is 22.15 km^3. The reservoir stores water from September to October, and its highest water level since 2010 was 175 m. The river discharge is regulated seasonally. The water level is controlled at a level of 145 m during June to prevent flooding, and the reservoir is filled with water from September to November to ensure the power supply and navigation capacity by maintaining a water level of 175 m. The highest level is maintained until January of the following year, and the reservoir begins to release the freshwater to meet the demands downstream until May. The river discharge is increased to approximately 1 700 $m^3 \cdot s^{-1}$ during the reservoir drain from January to May of the following year[15]. Qiu and Zhu[16] concluded that river discharge from January to February increased to 1 709 $m^3 \cdot s^{-1}$, according to the water level variation in the Three Gorges Reservoir over the course of the most recent three years, which was a similar result to that obtained by Chen[15]. In this study, the value of 1 709 $m^3 \cdot s^{-1}$ has thus been adopted as the river discharge regulation by the Three Gorges Reservoir in January and February.

The South-to-North Water Diversion Project, the water volume and distance of which make it the world's largest water conservancy project, involves the Changjiang River, Huaihe River, Yellow River, and Haihe River Basins. The purpose of this project is to supply the water resources of the Changjiang River to the north and northwest regions of China, where it is relatively dry. The South-to-North Water Diversion Project is an inter-basin diversion water project aimed at decreasing the river discharge entering into the East China Sea[1].

There are three diversion routes. The Eastern Route Project employs the existing canal river and surrounding lakes, pumping runoff to Shandong, Tianjin, and other locations with brake control. This project began in November 2013. The first phase plans to pump freshwater with a flux of 500 $m^3 \cdot s^{-1}$, and the flux will be increased to 800 $m^3 \cdot s^{-1}$ in the future. The Middle Route Project supplies water from the Danjiangkou Reservoir, which is located upstream of the Hanjiang River. The principal part of the project has been completed, and operation is expected to begin in 2014. The volume of water abstraction for this project is similar to that of the Eastern Route Project. The purpose of the Western Route Project is to solve the drought and water shortage in northern China by diverting runoff from the upper Changjiang River into the Yellow River. The feasibility study for this project is still underway, as the project is located in the Qinghai-Tibet plateau, where the engineering technology is complex due to the high altitude, complex geological structure, and strong earthquake intensity. Therefore, we mainly focus on the Eastern and Middle Route Projects, and due to these projects, the river discharge may decrease by 1 000 $m^3 \cdot s^{-1}$ in 2030 and by 1 600 $m^3 \cdot s^{-1}$ in both 2050 and 2100 compared to the 2012 levels.

Therefore, considering the combined impacts of climate change together with the Three Gorges Project and South-to-North Water Diversion Project, the river discharge at Datong Station in January and February is expected to be 13 057, 12 792, and 13 631 $m^3 \cdot s^{-1}$ in 2030, 2050, and 2100, respectively, based on a rate of 13 755 $m^3 \cdot s^{-1}$ in 2012.

2 Response of sea level rise

Sea level rise caused by ice melt or thermal expansion by sea temperature rise due to climate change is termed absolute sea level rise. Relative sea level rise is typically considered in studies of the influence of sea level rise on saltwater intrusion in estuaries, which means that the effects due to subsidence of land and earth crust should be added to the absolute sea level rise. In the physical sense, absolute sea level rise is reflected in the water level, i.e., it is added to the initial water level and the open sea boundary in the numerical model. Moreover, the land and crust subsidence deepen the water depth and are thus added to the static water depth in the numerical model. In the following section, we first introduce the absolute sea level rise in the Changjiang River Estuary for the past and future and then introduce the land and crust subsidence for the future.

Coombes et al[17] indicated that global warming resulted in a 0.5 °C increase of mean air temperature in the past one hundred years throughout the world, and absolute sea level rose 10 to 20 cm. Cornell et al[18] reported that the global mean sea level rose at a rate of 1 to 2 $mm \cdot a^{-1}$ over the past century. Sterr et al[19] believed that the rate of global mean sea level was 1 to 2.5 $mm \cdot a^{-1}$ over the past one hundred years. Ding[20] noted that the rate of global sea level rise was 1 to 2 $mm \cdot a^{-1}$ over the past one hundred years, whereas sea level generally increased along the Chinese coasts during the past 50 years with a rate of 2.5 $mm \cdot a^{-1}$, with a rate of approximately 3.1 $mm \cdot a^{-1}$ in the Changjiang River Delta. According to the "China Sea Level Communique" in 2007, which was published by the State Oceanic Administration of China (http://www.soa.gov.cn/zwgk/hygb/zghpmgb/), the absolute sea level along the Chinese coasts increased at a rate of 2.5 $mm \cdot a^{-1}$, which was slightly higher than the rate of global sea

level rise. Over the past thirty years, the sea level increased 115 mm with a rate of 3.8 mm·a^{-1} in Shanghai. The "China Sea Level Communique" in 2012 indicated that the rate of sea level rise was 2.9 mm·a^{-1} along the Chinese coasts, which was higher than the global mean rate. In the Changjiang River Estuary, Chen et al[21] adopted the 19-year moving average method to eliminate various oscillations using tidal data from Wusong Station for the 1951—1987 period and found that absolute sea level increased at a rate of 2.4 mm·a^{-1}. Qin and Li[22] estimated that the increase in absolute sea level in Shanghai in 2010 would be 5 cm relative to that in 1990 with a rate of 2.5 mm·a^{-1}. Li et al[23] adopted a statistical superposition model of a time-series, multivariate stepwise regression technique and a periodic analysis method to study the interannual variability of the absolute sea level at Wusong Station and predicted the varying trends in sea level rise. They suggested that the rate of increase was 0.9 mm·a^{-1} before the 1960 s, whereas it reached 2.0 mm·a^{-1} after the early 1960 s and has been accelerating since then. Based on this discussion, the rate of the absolute sea level rise in the Changjiang River Estuary was considered to be approximately 2.5 mm·a^{-1}over the past twenty years.

The estimate by the IPCC[24] suggested that the absolute sea level rise caused by climate change would increase by 20 to 86 cm in 2100 with a rate of 1.90 to 8.19 mm·a^{-1}, with a best estimate of 49 cm (including aerosol cooling effect). Qin and Li[22] predicted that the absolute sea level would rise by 11 cm in 2030 compared to 1990 levels in Shanghai, with a rate of 2.75 mm·a^{-1}. Based on the historical tide records at seven tide gauge stations in the Shanghai region, Li et al[23] established a sea level rise prediction model with a time-series analysis method to predict the variation trends of sea level rise over the next 50 years, and they assessed the rationality and reliability of the predicted values in detail. Compared to 1990 levels, the absolute sea level would rise by 4, 9, and 18 cm in 2010, 2030, and 2050, respectively. The calculated interannual variations in the absolute sea level rise rates were 2.0 mm·a^{-1} from 1991 to 2010, 2.5 mm·a^{-1} from 2011 to 2030, and 5.0 mm·a^{-1} from 2031 to 2050.

The 2007 "China Sea Level Communique", published by the State Oceanic Administration of China, forecasted that the sea level would rise by 38 mm with a rate of 3.8 mm·a^{-1} in the Shanghai region in the next 10 years. The 2011 "China Sea Level Communique" noted that it would rise by 145 to 200 mm until 2050 in the same region. In the report, the average sea level from 1975 to 1993 was defined as the annual mean sea level, and the year 1984 was recognized as the mean year. Therefore, the rate of increase in the sea level in the Shanghai region could be estimated as 2.2 to 3.0 mm·a^{-1} until 2050. The 2012 "China Sea Level Communique" estimated that sea level would rise by 64 to 135 mm in the next 30 years in Shanghai with a rate of 1.4 to 2.9 mm·a^{-1}. The IPCC[25] reported that by the end of the 21st century (2090—2099), the absolute sea level will rise by 0.18 to 0.38 m in scenario B1, 0.21 to 0.48 m in scenario A1B, and 0.23 to 0.51 m in scenario A2. The mean absolute sea level rise is 0.21 to 0.46 m in different scenarios, and the mean rising rate is 2.1 to 4.6 mm·a^{-1}.

Wang et al[26] collected sea level rise data in the Changjiang River Estuary, including the "China Sea Level Communique", published by the State Oceanic Administration of China, historical annual mean tide records, and published literature, particularly the paper of Li et al[23]. They considered the work of Li et al[23] to be the most systematic study of the sea level rise in Shanghai until now, and thus, they reconstructed that study. By extending the annual

mean tidal level from 1993 to 2009, they discovered that the absolute sea level would rise by 86.6, 185.6, and 433.1 mm in 2030, 2050, and 2100, respectively, compared to 1997 levels, and the corresponding rising rates were 2.62, 3.50, and 4.20 mm·a^{-1}, respectively.

Different studies obtained similar sea level rising rates in the Changjiang River Estuary. For instance, the rising rate of 2.62 mm·a^{-1} in 2030 given by Wang et al[26] is close to the value of 2.9 mm·a^{-1} given by the "China Sea Level Communique" in 2012; the rising rate of 3.5 mm·a^{-1} in 2050 given by Wang et al[26] is close to the value of 3.0 mm·a^{-1} given by "China Sea Level Communique" in 2011; and the rising rate of 4.2 mm·a^{-1} in 2100 given by Wang et al[26] is close to the value of 4.6 mm·a^{-1} given by IPCC[25]. Therefore, we adopted the conclusions given by Wang et al[26] as the rates of sea level rise for the future. Because our study periods are from 2012 to 2030, 2050, and 2100, the initial time needed to be reset. As noted previously, the rising rate of absolute sea level was approximately 2.5 mm·a^{-1} in the Changjiang River Estuary over the most recent twenty years, and hence, 37.5 mm should be deducted from the sea level in 2012 from the results in 1997 by Wang et al[26]. Therefore, the absolute sea level in the Changjiang River Estuary will rise by 49.1, 148.1, and 395.6 mm in 2030, 2050, and 2100, respectively, compared to the 2012 levels.

The earth crust near the Changjiang River Delta exhibited a gradual rise during the Miocene, whereas it transitioned into a phase of slow subsidence following the Pliocene. Using long-term measurements by laser ranging and global positioning system technology, Ye[27] estimated that the average rate of neotectonic subsidence was 1.5 mm·a^{-1} in the Changjiang River Delta and adjacent areas. We adopted this result here.

Previous studies have seldom focused on the land subsidence in the Changjiang River Estuary, except near the Dongtan east of Chongming Island and other portions of the coastlines in Shanghai. Wang et al[26] concluded that the land subsidence was approximately 2.0 mm·a^{-1} near the coastlines, such as Changxing Island. Liu and Gong[28] estimated that the long-term land subsidence in Shanghai would be 10 to 37 cm with a rate of 1.82 to 6.73 mm·a^{-1} from 1995 to 2050. A Poisson cycle mathematical model was developed to predict the land subsidence based on long-term empirical predictions. The land subsidence within or near water was generally smaller than that in the urban regions due to construction projects and groundwater extraction. Referring to the above research results, it is reasonable to assume that the rate of land subsidence is 2 mm·a^{-1} in the Changjiang River Estuary.

Based on the above discussion, the relative sea level is predicted to rise by 112.1, 281.1, and 703.6 mm in 2030, 2050, and 2100, respectively, compared to the 2012 levels.

3 Conclusions

The responses of saltwater intrusion to climate change and human activity in the Changjiang River Estuary are mainly reflected by variations in river discharge and sea level rise. To predict the saltwater intrusion and its responses in 2030, 2050, and 2100, it is necessary to ascertain the variation values in the river discharge and sea level rise due to climate change and human activity.

Previous studies have indicated that the river discharge at Datong Station exhibited an increasing trend in the winter. The mean river discharge in January and February from 1865

to 2002 indicated that the annual variation was pronounced. The correlation relationship between the river discharge (y) and year (x) was fitted with the following linear function: y=16.777(x−1 865)+9 579.3. In other words, the increase in river discharge caused by climate change was 16.777 $m^3 \cdot s^{-1}$ per year, i.e., with a rate of approximately 0.16%. This conclusion is consistent with that of previous studies. Using the river discharge fitting function for the years from 1865 to 2002, the mean river discharge in January and February in 2012 was calculated to be 12 046 $m^3 \cdot s^{-1}$. Then, the discharge at Datong Station was calculated to be 12 348, 12 683, and 13 522 $m^3 \cdot s^{-1}$ in 2030, 2050, and 2100, respectively, due to climate change. Human activities can also change the river discharge. The Three Gorges Reservoir stores fresh water from the beginning of September to the end of October, resulting in increase in river discharge of 1 709 $m^3 \cdot s^{-1}$ in January and February due to water release. The Eastern and Middle Route Projects of the South-to-North Water Diversion Project transfer fresh water from the Changjiang River, resulting in a total decrease in river discharge of 1 000 $m^3 \cdot s^{-1}$ in 2030 and of 1 600 $m^3 \cdot s^{-1}$ in 2050 and 2100. Overall, the mean river discharge of the Changjiang River in January and February was 13 755 $m^3 \cdot s^{-1}$ in 2012 and changed to 13 057, 12 792, and 13 631 $m^3 \cdot s^{-1}$ in 2030, 2050, and 2100, respectively.

However, the water regulation schemes of the Three Gorges Reservoir and the South-to-North Water Diversion Project may be adjusted considering to climate change. Because of the increasing trend of river discharge, the projects can transfer more fresh water to the water-shortage regions as well as water conservancy, so that river discharge at the Datong Station may probably keep a stable value. Therefore, it may be reasonable to assign a relatively stable boundary condition of river discharge for future scenarios in the numerical model.

Based on the observed historic tidal data in Shanghai, Li et al[23] established a prediction model of sea level rise with a time-series analysis method. Wang et al[26] extended the tidal data from 1993 to 2009 based on the work of Li et al[23] and found that the absolute sea level rise would be 86.6, 185.6, and 433.1 mm in 2030, 2050, and 2100, respectively, compared to 2007 levels, respectively. This study adopted the results of Wang et al[26]. A rate of increase of 2.5 $mm \cdot a^{-1}$ over the past twenty years was considered. Therefore, the absolute sea level rise in the Changjiang River Estuary is predicted to be 49.1, 148.1, and 395.6 mm in 2030, 2050, and 2100, respectively, compared to the 2012 levels. Generally, the impact of the relative sea level rise is considered for saltwater intrusion in estuaries. Near the Changjiang River Estuary, the rates of crust and land subsidence were 1.5 and 2.0 $mm \cdot a^{-1}$, respectively; thus, the relative sea level rise in the Changjiang River Estuary is predicted to be 112.1, 281.1, and 703.6 mm in 2030, 2050, and 2100, respectively, compared to the 2012 levels.

[References]

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