Zhijun Dai

Changjiang Riverine and Estuarine Hydro-morphodynamic Processes

In the Context of Anthropocene Era

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Foreword by Dake Chen

The Changjiang River is one of the largest rivers in the world, flowing 6300 km from the Tanggula Mountains of the Qinghai–Tibet Plateau to the East China Sea. Over the long history of Chinese civilization, the Changjiang basin has always been a major cradle of culture, economy, and population. However, modern hydraulic engineering such as dam construction has broken the balance of fluvial water and sediment, river bed evolution, and estuarine morphological variation. As a consequence, the river turns from a naturally evolving system to a strongly human-interfered system, which could have profound impact on biodiversity and sustainable development. Therefore, it is of paramount importance to understand the responses of the water and sediment transports, the channel erosion/accretion, as well as the estuarine hydrology and geomorphology, along the entire Changjiang River.

Previous studies on the Changjiang River have mostly focused on its separate components, and a systematic, updated overview of the whole river system is obviously lacking. This book provides a freshening look at this complex system, including the river basin and estuaries, the river–lake groups, the channel branches entering the sea, and the tidal flat and submerged delta. Field measurements and analytical techniques are used to evaluate the effects of hydraulic engineering on water–sediment transport and morphological erosion/deposition, to explore the influence of extreme flood and storm on the river estuary, and to illustrate the self-adaption of the estuarine shoal–channel system under river–tide interaction. These should help readers to gain a comprehensive understanding of how the Changjiang River responds and adjusts to human and natural interferences.

As demonstrated in the book, hydraulic engineering largely reduces the river flow difference between the flood season and dry season, leading to less sediment transport in the former and more in the latter. Also, in response to human imposed stress, the low water level season occurs earlier in the Dongting Lake and Poyang Lake; the main stream of the Changjiang River gradually shifts from accretion to erosion; the four branches of the Changjiang Estuary show distinct variation patterns; and the coupling between sea level rise, river–tide interaction, extreme flood and typhoon may cause sink and erosion of the Changjiang delta. These findings are alarming and enlightening. In particular, the delayed response of the estuarine morphological erosion/accretion to fluvial water and sediment change may have important implications for the global mega river and estuary evolution.

The author of this book has long been engaged in riverine–estuarine hydrological and morphodynamic research. As a student of Chen Jiyu, a leading geomorphologist and an academician of the Chinese Academy of Engineering, the author extends his late mentor's pioneering work to examine the upstream, midstream, lake, estuary, and submerged delta of the entire Changjiang River from a hydro-geomorphic perspective. This book is a result of the author's tireless research effort and considerable scientific insight on the coupled dynamics of the river–estuary system, especially his longstanding passion for the evolving Changjiang River. It should be useful to the students and researchers in the fields of geography, hydrology, as well as marine sciences.

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Foreword by Hao Wang

Global mega rivers have long been in a natural evolution state, while their estuaries are always in dynamical variation due to the influences of fluvial water and sediment. Mega river basins and their estuarine deltas are the most economically and culturally developed areas. However, intensive human activities along the river, particularly dam and estuarine regulation projects, control the global mega rivers from upstream to estuary, and thus affect their social and economic developments. The restriction is firstly reflected on basic physical parameters, such as river–estuary hydrology, sediment, and channel morphology. Quantification variations of these parameters therefore should be the core issue of global river–estuary research.

The Changjiang River is the longest river in China. The Changjiang Estuary is China's largest estuary. The Changjiang River and associated delta are one of the most developed regions in China. In recent hundred years, over 50,000 dams, including the 2003 Three Gorges Dam, were constructed along the river for flood control, irrigation, and hydroelectric power, which made a significant contribution to population security and economic development. In the meantime, however, dam regulation changed the downstream hydrology in some situations and further affected the estuary. Large-scale tidal flat reclamation, channel dredge, and reservoir construction in the Changjiang Estuary also influenced its morphological change. Although previous research have worked on the water and sediment transport and morphological evolution of the upper, middle, lower Changjiang and the estuary individually, few studies have been carried out to fully analyze the entire 6300-km river from the source to the estuary in view of the researcher's scientific field, understanding level, and the complexity of river change. Lack of such knowledge presents a great obstacle to understanding the response of Changjiang River to natural variation and human activities as well as the development and protection of the water, landform, and navigation resources of the river basin.

This book covers the upper, middle, and lower Changjiang as well as the Changjiang Estuary, which firstly demonstrates the hydrological and morphological processes along the entire river system during the past hundred years, and clarifies the driving mechanism of hydrological and morphological variations. In particular, the author quantifies the contributions of human activities and climate forcing on fluvial water and sediment changes, brings forward the response patterns of riverine water and sediment transport, channel accretion–deposition, and estuarine geomorphology through statistical technique and model simulation. Hundred years of hydrological and sediment data are combined with over 20 years of field investigation and observation that cover the entire Changjiang support the work. This book has great theoretical significance to fully understand and be aware of the hydrological and morphological behaviors of mega river.

The author breaks the traditional research on individual river reaches, links the geomorphology and sedimentation of lakes in the middle–lower Changjiang to the entire river system through water and sediment, and finally lands in the geomorphology of Changjiang Estuary. The research focuses on field work and starts from the realistic problem along the Changjiang River. For instance, how does the river respond to the upstream dam construction? Why do the two largest freshwater lakes in China enter the dry season 1–2 months earlier? Why does the world's largest navigation project in the North Passage of Changjiang Estuary need a large scale of dredging? A series of new concepts, new laws, and new patterns concerning the practical problems were brought forward in this book, such as the lag effect in response to fluvial water and sediment changes, stress effect of water and sediment exchange between lake and river, self-regulation of estuarine geomorphology, and shift mechanism of the submerged delta depocenter. These ideas are of vital practical significance in solving river–lake relationship, estuary navigation, tidal flat accretion–deposition, etc.

This book focuses on hydrology and geomorphology, exploring the variation of the world-class mega Changjiang River on a century time scale from a morphodynamical viewpoint with question oriented. The work makes up the previous fragmentary understanding on the Changjiang River and lifts systematic research on Changjiang hydrology–morphology to an international level, which greatly promotes global research on mega river system. Meanwhile, the theory and mechanism presented in this book show that river evolution has self-regulation ability, but also a threshold under human and natural interferences. Such knowledge provides new ideas on riverine hydrology and geomorphology research for other global rivers in a similar context. The publishing of this book can promote theoretical and practical research on the entire Changjiang River from source to estuary and enrich the hydro-morphodynamical theoretical system of global rivers.

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Foreword by Marcel J. F. Stive

Ever since humans appeared on earth, humans have lived with and interacted with rivers. As technology developed during the Anthropocene, humans started to exploit resources from the river through projects such as river outlets and intakes, river diversions, river damming, land reclamations, dredging for navigation and sand mining. As a consequence, many rivers have lost their natural connection with the ocean, among others resulting in eroding deltas and estuaries. This book is a contribution and a plea to conduct more innovative systematic research of river hydrology and morphology in response to engineering interventions so as to enable sustainable utilization and management of river and estuary resources.

Changjiang River (modern Chinese), also known as Yangtze River (old Chinese), has played a major role in the history, culture, and economy of China for thousands of years, serving as the cradle of Chinese civilization. This role has continued until today, increasingly supporting the economic and social development of modern China. The prosperous Yangtze River Delta generates as much as 20% of China's GDP.

In 2014, the Chinese government announced it was constructing the Three Gorges Dam on the Changjiang, the largest hydro-electric power station in the world, to create a new economic belt alongside the river. With this dam construction in the upstream region, water diversion and transfer in the middle–lower reach, reservoir regulation in the lake basin region, the deep water channel regulation project, and land reclamation in the river's estuary, the degree of artificial control of Changjiang River is yet uncertain, but comparisons with rivers like the Nile and Mississippi might be realistic. Our current understanding of the Changjiang River is still somewhat fragmentary and localized due to the interdisciplinary and multifaceted issues that need to be addressed. There is a continuing need for more systematic research, e.g., to clarify the response of Changjiang hydrology and morphology to engineering interventions from the upstream to the downstream.

This book analyzes the impact of the above-mentioned projects executed over the recent 50 years, with an emphasis on hydrology and morphology. It clearly exhibits how the river discharge turns from natural to regulated and causing a declining flux of fluvial sediment following engineering constructions. In particular, this book elaborates the coupling process between main stream, tributary, lakes, and estuaries and quantifies the weight of human activity interference. As such it is a vital academic reference for the evolution of the Changjiang River.

A further asset of this book is that it discusses common characteristics between Changjiang and other mega rivers that are affected by dam projects. For instance, dam regulation induced fluvial sediment decline and riverbed erosion on the downstream side along the middle–lower reach. The book also describes how lakes can buffer the mainstream erosion, while displaying an abnormally premature dry season due to water level down cutting in the main stream. Tidal reach adjustment, tidal flat self-organization, morphological differentiation of estuarine branches, and periodic shift of the submerged delta depocenter are also introduced in the book. These novel hydrological and morphological change features on Changjiang River provide a vital reference for the evolution of other rivers.

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Foreword by Stephen Darby

The world's rivers have long been the subject of strong scientific and broader societal interest, reflecting their importance in affecting the lives and livelihoods of the billions of people that inhabit river floodplains. However, in recent years the world's rivers have increasingly come under environmental stress, with many major rivers being subjected to major changes in flow regime, sharp declines in sediment loads, and degradation of aquatic environments. The estuarine and delta regions located at the termini of major rivers have been notably impacted, with many of these low-lying regions shrinking and sinking into the sea.

The common thread in linking these critically important issues is the intense human activity that characterizes the human age, the Anthropocene. Sand mining, dam construction, dike building, and lake filling are seen to affect rivers around the world. With such intense anthropogenic pressures being exerted on the world's rivers, we urgently need to know how these stressors will affect rivers. The key question is: What will happen in the future?

This new volume *Changjiang Riverine and Estuarine Hydro-morphodynamic Processes* provides a comprehensive overview of the hydrological and morphological processes, and their variations along the 6300-km Changjiang River, one of the world's most important river systems and also one most heavily impacted by human activity. I am delighted to see this book published because until now there has been no systematic overview of the riverine–estuarine hydrology and geomorphology of this iconic river system. We know that the main stem of the river is dominated by undirectional discharge, whereas the Changjiang Estuary is dominated by the river–tide interactions as well as being affected by waves. However, rivers are interlinked, coherent systems. Any change in the upstream reaches has the potential to propagate to the middle and lower reaches of the river, and its estuary will have response. Without recognition of this system coherence, there is the potential for river and estuary managers to make uninformed decisions about the necessary responses to floods, droughts, and/or incidences of water pollution. The publication of this book represents a recognition of the need for systematic research on global rivers from source to sink, from upstream to estuary.

The book seeks to present answers to a series of interesting questions concerning the Changjiang River. For instance, following the construction of Three Gorges Dam, there has been no significant change in the total annual discharge, but seasonal variations have been dramatically impacted; moreover, there has been dramatic decline in sediment transmission to downstream reaches. The associated river responses to these major alterations have been complex. In the reach directly downstream of the dam channel erosion has been intense, but further downstream there has been far less erosion due to compensating increases in sediment supply from major lakes attached to the main channel. Meanwhile, the tidal reach still retains a normal pattern of morphological variation due to the coupling effect of discharge and tide. While the Mississippi and the Nile Rivers have seen major delta erosion due to declines in sediment supply associated with upstream damming, the tidal flats of the Changjiang Estuary continue to exhibit siltation and self-organization. This reinforces how each river system is unique, with response following the immutable laws of physics but conditioned by the local boundary conditions. In short, this book firstly quantifies the hydrological variations along the Changjiang River, channel erosion, and spatial morphological differentiation characteristics of the Changjiang Estuary before providing a comprehensive scientific explanation of these phenomena based on detailed field measurements and years of painstaking investigation.

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Contents

About the Author

Zhijun Dai, Ph.D. Professor in State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai. Dr. Dai is interested in riverine, estuarine, and coastal system risk analysis; coastal and ocean resources management, riverine estuarine and coastal morphodynamics, wetland hydrological process and has gained excellent achievements. He has published over 70 research papers in international journals and 5 monographs. He has been the leader of over 10 national natural science foundations of China, including the national key programs. Prof. Dai has obtained a number of national or provincial awards. He has won the program for New Century Excellent Talents in Chinese University. Dr. Dai has been a visit researcher in the Netherlands and America and developed a long coopertaion with America, Britain, and the Netherlands. Meanwhile, he serves as editorial board member of Geomorphology, Ocean and Coastal Management and associate editor of Frontiers of Earth Science. He has also supervised 4 postdoctoral fellows, 10 Ph.D. students, and more than 15 master studens.

Chapter 1
Changjiang River Basin Overview

1.1 Brief Introduction to the Changjiang River Basin

1.1.1 Physical Geography of the Changjiang River Basin

The Changjiang River, as the largest river in China and the longest river in Eurasia, stretches 6300 km from the Qinghai–Tibet Plateau to the East China Sea and covers a catchment area of 1.8×10^6 km^2 (Dai et al., 2010). Locating between 24° 30′–35° 45′ N, 90° 33′–122° 25′ E, Changjiang River basin is obviously long and narrow. Its abound natural resources have nurtured Chinese ancient civilization. The catchment is of vital significance on China's social and economic development.

Changjiang River basin stretches across the three major economic zones in the southwest, central, and eastern of China. The main stream runs through 11 provincial regions, including Qinghai, Tibet, Yunnan, Sichuan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, and Shanghai and flows to the East China Sea in Shanghai. The basin consists of diverse geography, with landscape ranges from mountain to hill, basin, plateau, and plain. Mountain, hill and plateau landscapes comprise 84.7% of Changjiang's total area. High mountain plain is distributed in the western region, middle mountain is in the middle, and low mountain is mainly in the middle–lower region of Changjiang River (Fig. 1.1). Changjiang River is mainly composed of Jinsha River, Jialing River, Hanjiang River, Dongting Lake, and Poyang Lake, with the water area of lake accounting for 4% of the total territory of the basin (Fig. 1.1).

The average elevation of the Changjiang River basin is 1650 m, with high terrain to the west but low elevation to the east. The highest elevation 7556 m is located in Sichuan Province, while the lowest elevation 0 m is in the estuarine area of Wusong in Shanghai. Jinshajiang River and Qingjiang River are middle–high mountainous area. Their mean elevation is 3000 m and 2600 m, respectively. Jialingjiang River and Wujiang River have a mean elevation of 1200 m and are middle mountainous area. Hanjiang has a mean elevation of 800 m. Dongting Lake and Poyang Lake are hilly area, with the mean height in a range of 300–500 m. The average elevation of the lower Changjiang River is less than 100 m.

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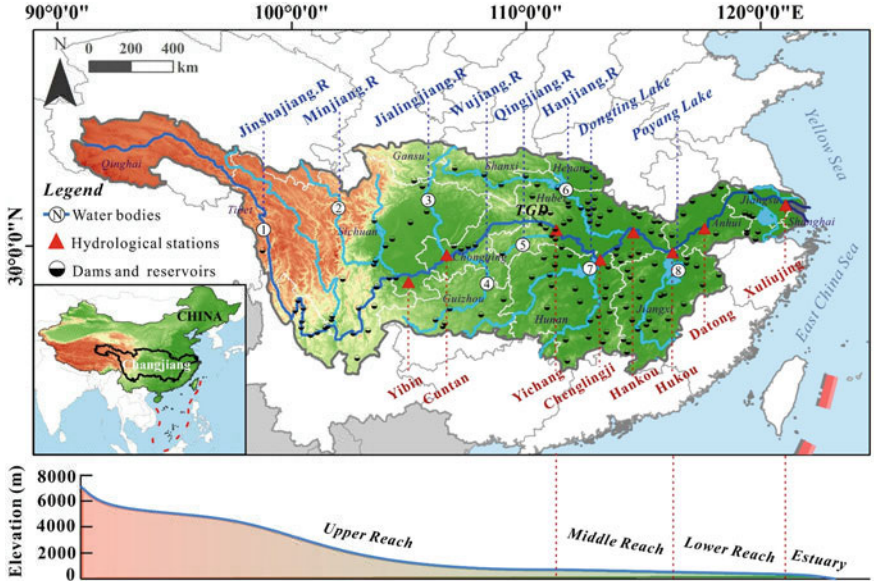

Fig. 1.1 Research area and associated hydrological stations

The bed's slope decreases along the river course, with the highest value occurring in the upstream area from Cuntan to Yichang (0.18‰), followed by 0.026‰ from Yichang to the estuary; the estuarine region is the flattest area, with a slope of 0.005‰ (Fig. 1.1).

1.1.2 Regional Division of the Changjiang River Basin

The upper Changjiang River originates from the river source to Yichang in Hubei Provinces and has a length of 4500 km and a catchment area of 1 million km^2. The reach between source and Yibin is Jinshajiang River, with a length of 1030 km, while the reach from Yibin to Yichang is 1030 km, commonly known as Chuanjiang River. The lower Chuanjiang River is the famous Three Gorges reach. The middle Changjiang River stretches from Yichang to Hukou in Hunan Province and has a length of 950 km and a catchment area of 0.68 million km^2. Changjiang River enters to alluvial plain in the middle region and gets water and sediment from the tributaries of Hanjiang River, Dongting Lake, and Poyang Lake. The lower Changjiang River from Hukou to the estuary has a length of 930 km and covers an area of 0.12 million km^2. The area downstream of Xuliujing is Changjiang Estuary. Generally, the upper reach of the Changjiang River ends at Yichang; thereafter, the middle reach extends from Yichang to Hukou, while the lower reach stretches from Hukou to the river mouth (Dai & Liu, 2013). Yichang, Hankou, and Datong were selected to reflect the hydrological characteristics of the upper, middle, and lower reaches of the Changjiang River, respectively (Fig. 1.1). The landward limit of the tidal current is around Datong (Fig. 1.1) (Dai et al., 2016).

Furtherly, the middle reach of Changjiang from Yichang to Hukou covers three important water systems, including Hanjiang, Dongting Lake, and Poyang Lake (Figs. 1.2 and 1.3) (Wang et al., 2011). The Hanjiang River, which is the largest tributary in the middle reach, annually contributed 475.2×10^8 m^3 of discharge and 0.72×10^8 t of SSD to the Changjiang River during 1956–2010 (Fig. 1.1) (BCRS, 2010). Dongting Lake, which used to be the largest freshwater lake in China, is currently the second largest lake after significant shrinkage from approximately 6000 km^2 to less than 3000 km^2 (Yin et al., 2007). The lake consists of the East Dongting Lake, South Dongting Lake, and West Dongting Lake (WDL). Dongting Lake spans approximately 28° 30′–30° 20′ N, 111° 40′–113° 10′ E, with most of the region located in Hunan Province. The northern portion of the lake is fed by the Changjiang River through the Three Outlets in the Jing River section, which comprises the Songzi River, Hudu River, and Ouchi River. The southern portion of the lake is fed by four main tributaries, namely the Four Waters, including the

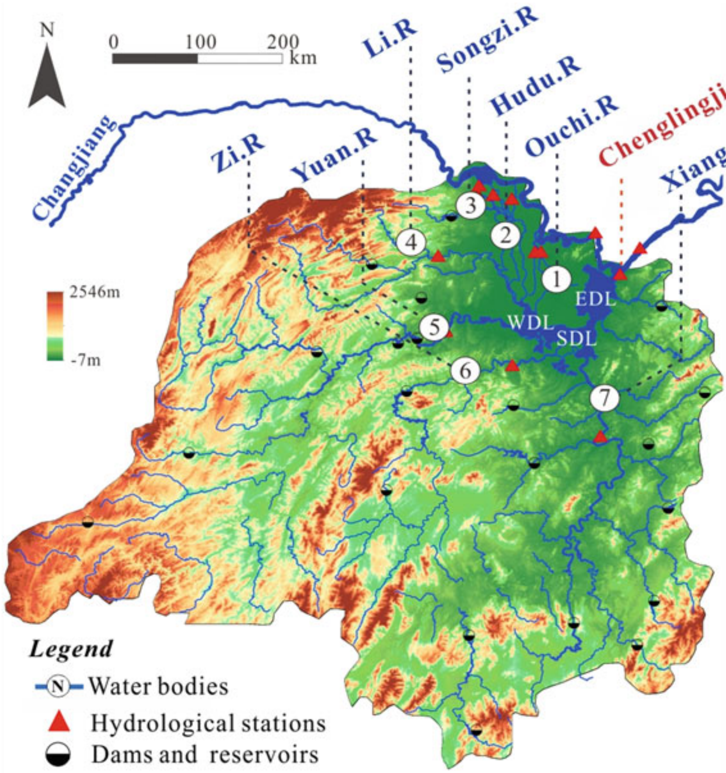

Fig. 1.2 Dongting Lake basin and associated hydrological stations

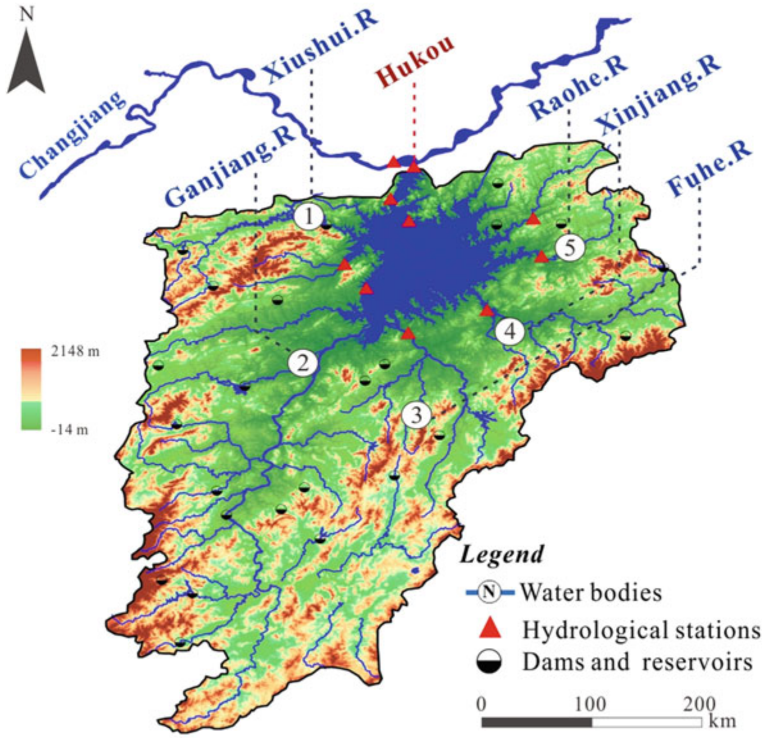

Fig. 1.3 Poyang Lake basin and associated hydrological stations

Xiang River, Zi River, Yuan River, and Li River. Dongting Lake finally flows into the Changjiang River via Chenglingji, the only outlet from the lake into Changjiang River (Fig. 1.2). Therefore, Dongting Lake is both a temporal storage site for water and sediment from the upper Changjiang River and a water and sediment provider to the lower Changjiang River.

Poyang Lake (28° 22′–29° 45′ N and 115° 47′–116° 45′ E), which is currently China's largest freshwater lake, is located in the middle of the Changjiang River basin and is naturally connected to the Changjiang River at Hukou (Fig. 1.3). The lake covers an area of approximately 4000 km^2, which can be further divided into two sections: The southern portion is relatively broad and shallow, while the northern area is narrow and long, which joins the Changjiang River through a deepwater channel. As a typical throughput lake, Poyang Lake mainly receives water from Ganjiang, Fuhe, Xinjiang, Xiushui, and Raohe and discharges water to Changjiang at Hukou. The 766-km-long Ganjiang River is the largest tributary in the Poyang Lake catchment in terms of sediment load and discharge, followed by Xinjiang and Fuhe. Poyang Lake annually supplies 17 and 2% of the total water and SSD into the East China Sea (Mei et al., 2016).

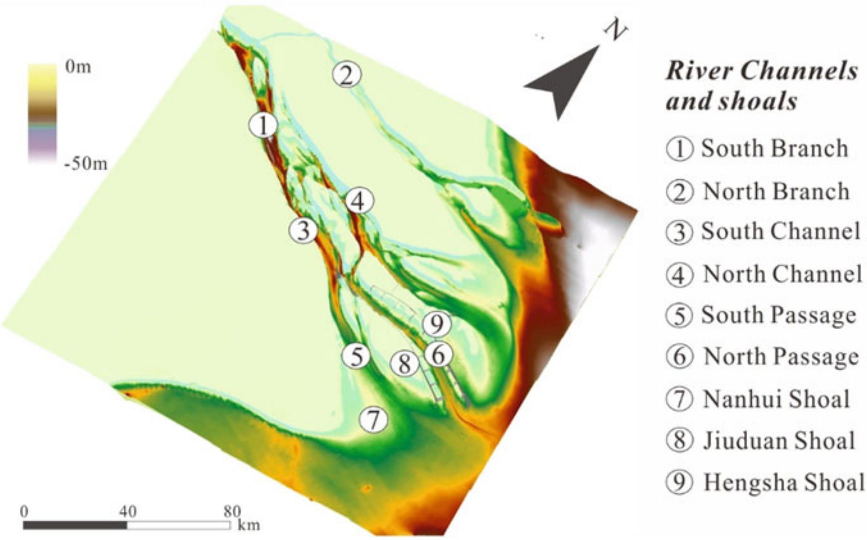

Fig. 1.4 River channels and shoals of the Changjiang Estuary

The Changjiang Estuary is a typical bifurcated mesotidal estuary with abundant water and sediment (Fig. 1.4) (Chen, 2007). The river mouth is almost 100 km wide, and the river channel bifurcates at four islands, namely the Chongming, Hengsha, Changxing, and the Jiuduan Shoals (Fig. 1.4), forming a three-tiered branching delta with four distributary mouths that debouch in the East China Sea, namely the North Branch (NB), North Channel (NC), North Passage (NP), and South Passage (SP) (Fig. 1.4). The mean tidal range in the Changjiang Estuary is approximately 2.67 m, and the peak tidal current is 1 m/s (Dai et al., 2016). The four bifurcated estuaries indicate a distinct hydrological regime because of various topographical conditions and dynamic effects. Specifically, the NB is funnel-shaped, leading to the deformation of the semi-diurnal tidal wave during its propagation inland (Fig. 1.4) (Dai et al., 2016). The NB has a spring tidal range of 4 ~ 6 m and is a tide-dominated estuary according to Davis's classification (Davis, 1964). The NC is a second-order bifurcation. The annual tidal range along the upper NC reach is 2.45 m, with maximum and minimum average values of 2.61 m and 2.33 m, respectively. The NC is a typical ebb-dominated channel: The ebb tidal volume is greater than the flood tidal volume, with a tidal volume ratio between ebb and flood tides during spring tide around 2.1 (Mei et al., 2018). The NP was gradually dredged from an average water depth below 7 m before 1998 to the current level of 12.5 m because of the deepwater navigation channel project, one of the world's largest hydraulic engineering projects. Similar to the NC, the SP is also an ebb-dominated estuary (Dai et al., 2015). As the major conduit for water and sediment in the Changjiang River (Milliman et al., 1985), the SP has been less affected by direct human activities (Dai et al., 2015).

1.2 Meteorological and Hydrological Characteristics of the Changjiang River Basin

1.2.1 Temperature Characteristics

Situated in the subtropics, a majority of the Changjiang River lies on the East Asian monsoon belt because of sea–land climate contrast and seasonal variation in atmospheric circulation. The weather on the Changjiang River features four distinct seasons, with southerly winds prevailing in summer while northerly winds reigning in winter. The average temperature over the river basin is about 15°–70° (Fig. 1.5). In summer, there is often high temperature in July and August due to the West Pacific subtropical high and continental tropical depression. Summer temperature over most of the basin is above 25° except the source region. In winter, Polar cold weather hit the basin under the high atmospheres pressure from Mongolia with the yearly lowest temperature of 2–4° occurring in January. The spring and summer start from south to north and east to west along the river, while the autumn and winter start in the opposite direction. The river has long winter and summer and short spring and autumn with March and April being spring, May to August being summer, September and October being autumn, and December to February being winter. General atmospheric circulation and seasonal alteration directly affect the water and sediment of the Changjiang River.

In the past 30 years, the global temperature has increased by ~0.2 °C due to global climate change (Hansen et al., 2006). The temperature over the Changjiang basin showed similar changes (Zhang et al., 2005). At the three control stations of Yichang, Hankou, and Datong, temperature records between 1952 and 2010s all showed a noticeable increase compared to those in the 1950s (Dai et al., 2014). The rise of annual mean temperature at Yichang was 0.78 °C, at Hankou 0.77 °C and at Datong 0.77 °C. Meanwhile, the yearly, flood season and dry season mean temperature all indicated upward tendency by passing the Mann–Kendall trend test,

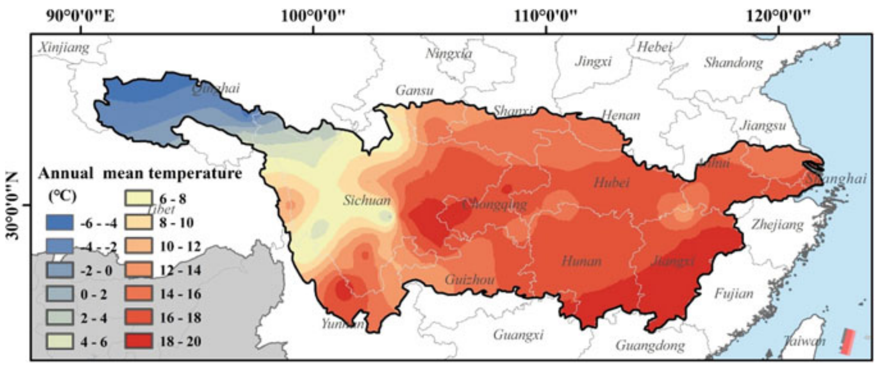

Fig. 1.5 Average temperature over Changjiang River basin

showing a potential increasing in the yearly mean temperature over the Changjiang River basin.

1.2.2 Precipitation Characteristics

Rainfall is abundant in the Changjiang River basin and primarily from the Bay of Bengal, the South China Sea, and the Western Pacific. The annual average precipitation over the catchment is around 1100 mm (Fig. 1.6), concentrated mostly in summer and autumn when the flood season from May to October contributes 70–90% of the total. Regional distribution of precipitation in Changjiang River is inequality and decreases from southeast to northwest, with mountain larger than plateaus and windward side larger than leeward side. Specifically, annual mean rainfall in the source region is less than 400 mm, in Jinshajiang region is 800 mm, Jialingjiang region is around 954 mm, Wujiang region is 1100 mm, and Dongting Lake and Poyang Lake is 1400 mm and 1600 mm, respectively.

Like temperature, precipitation in Changjiang River has distinct seasonal nature. It generally first appears over the Dongting Lake and Poyang Lake in April and then generates plum-rain season over the middle–lower river in mid-June and early July. The rain belt covers the entire river catchment during July to September and ends in October. The time of rain season over the upper and mid-lower river is staggered during a normal year and will not generate flood. However, the abnormality atmospheric circulation El Nino can make the rain season of different reaches meet and thus cause local and even regional floods that attack the entire river, like the recent 2020 flood.

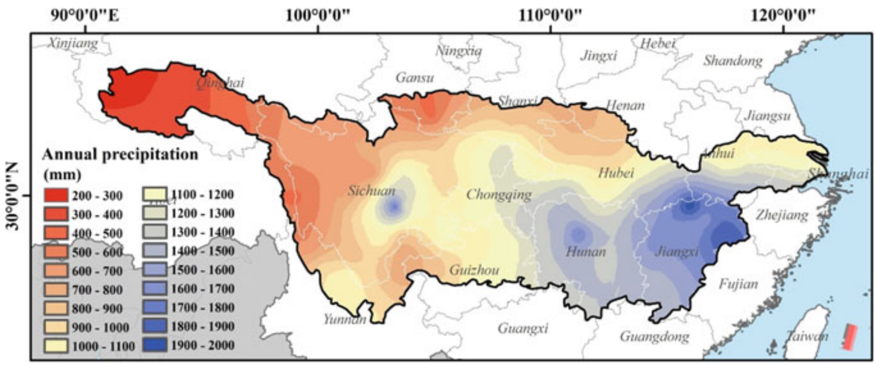

Fig. 1.6 Average precipitation over Changjiang River basin

1.2.3 Runoff Characteristics

Runoff over the Changjiang River basin shows high consistence with the rainfall and decreases gradually from southeast to northwest. Specifically, Dongting Lake and Poyang Lake suggest a high runoff depth larger than 1200 m (Fig. 1.6), the source region exhibits the smallest runoff depth less than 50 mm, while the middle–lower reach indicates a runoff depth of 800–1200 mm.

The runoff characteristics along the Changjiang River are further analyzed through the control station of Yichang, Hankou, and Datong. Based on the data between 1950s and 2006, annual mean discharge through Yichang at the upper Changjiang River is 433 billion m^3, contributing approximately 50% of discharge entering to the sea, with Jinshajiang, Minjiang, Jialingjiang, and Wujiang, respectively, accounting for 33%, 20%, 15%, and 11%, while the rest is from interval catchment. Annual discharge through Hankou is 710 billion m^3, with the upstream accounting for 68%, Dongting Lake water system accounting for 24%, and Hanjiang River accounting for 7%. Annual discharge through Datong is 899.2 billion m^3, among which 80% comes from the upper-middle reach, 17% comes from Poyang Lake system, and the rest is from interval catchment.

Similar to rainfall, runoff over the Changjiang River basin has a typical seasonal pattern, with most discharge in summer. November to April of the following year is the river's dry season, when runoff replenishment mainly comes from groundwater. The river's dry season begins from southeast and then gradually moves to northwest, with the Poyang Lake first entering low water season, following by Dongting Lake and then the upper-reach rivers like Wujiang and Jialingjiang.

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Chapter 2
Hydrological Processes of the Changjiang River

Abstract Hydrological processes of the Changjiang River have experienced significant changes in recent decades due to the coupling of environmental factors and intensive anthropogenic activities. In this chapter, based on long-term time series of daily suspended sediment discharge, water discharge, water level, and meteorological data along the Changjiang River, the holistic hydrological processes with possible impacted factors were explored. The main results indicate that streamflow along the Changjiang consists of a trend and four intrinsic components. Stage–discharge relationships at the upper, middle, and lower reach present substantial shifts since the Gezhouba Dam and Three Gorges Dam operation. Trend component in streamflow has obvious downward change, which could be mainly attributed to dam construction. In addition, increasing snowmelt caused by a warming climate leads to more water discharging into the upper reach. While, suspended sediment discharge over the mainstream exhibits dramatic decline, suspended sediment concentration delivering into the sea in the period 1956–2013 can be divided into three phases: (i) high SSC (0.69 kg/m^3) in the wet season and low SSC (0.2 kg/m^3) in the dry season from 1956 to 1970; (ii) relative high SSC (0.58 kg/m^3) in the wet season and low SSC (0.15 kg/m^3) in the dry season from 1971 to 2002; and (iii) low SSC (0.19 kg/m^3) in the wet season and very low SSC (0.09 kg/m^3) in the dry season after 2002. The variations in water and suspended sediment between 1950s and 2010s can be induced by anthropogenic influence, especially dam regulation, precipitation, and atmosphere fluctuation, which present different weights in the water and sediment processes changes in different eras. Our conclusions can be well applied to assessment of riverine discharging to the ocean of other rivers that subject to similar human activities and natural forcings.

2.1 Runoff Changes in the Changjiang River

The availability of water resources is a globally important issue for human development. However, water discharges have been influenced by climate change, which could further impact water availability for humans. In recent decades, intensive human activities (e.g., irrigation, dam construction, etc.) have had major impacts

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