China Council for International Cooperation on Environment and Development (CCICED)

Low carbon resilient city development and adaptation to climate change——River Basin Governance in the time of Climate Change

CCICED Special Policy Study Report

CCICED

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Special Policy Study Members

Co-chairs:

- Leader of Chinese Team: Li Xiaojiang, Special Advisor, Members of 5th CCICED, Master of National Engineering Survey and Design, Former President of CAUPD
- Co-leader of International Team: Hans Mommaas, Director-General, PBL Netherlands Environmental Assessment Agency
- Co-leader of International Team: Fernando Miralles-Wilhelm, Lead Scientist, Global Water, The Nature Conservancy

Special Policy Study Members (Core Team Experts):

- Wang Kai, President of China Academy of Urban Planning and Design
- Xue Lan, President of Schwarzman Scholars, Tsinghua University
- Li Yuanyuan, Vice President of General Institute of Water Conservancy and Hydropower Planning and Design, MWR, and Member of Population, Resources and Environment Committee of 13th National Committee of CPPCC
- Pan Jiahua, Member of CASS, former Director of Research Institute for Eco-civilization, CASS
- Zheng Degao, Vice President of China Academy of Urban Planning and Design
- Zhang Jing, Chief Planner of China Academy of Urban Planning and Design
- Zhang Yongbo, Information Center Director of China Academy of Urban Planning and Design
- Lv Xiaobei, Chief planner of Western Branch of China Academy of Urban Planning and Design
- Lv Hongliang, Vice President of Ecological Municipal Engineering Institute of China Academy of Urban Planning and Design
- Liu Kunyi, Deputy Chief Planner of Shanghai Branch of China Academy of Urban Planning and Design
- Yang Bo, The Nature Conservancy
- Kees BONS, Deltares
- Jim Best, University of Illinois
- Renato Paes de Almeida, University of Sao Paulo
- Gerry Galloway, Honorary Professor of Civil and Environmental Engineering, University of Maryland; Chairman of the Institute of Natural Heritage; former Director of Mississippi River Commission
- Marjolijn Haasnoot, Deltares
- Han Meyer, Delft University of Technology
- Xu Xin, The Nature Conservancy
- Wilfried ten Brinke, Blueland Consultancy
- Au Shion Yee, Asian Development Bank

Research Support Team (Consultant and Advisors):

- Zhang Bing, Director of Territorial Planning, Ministry of Natural Resources
- Xu Yisong, Director of Shanghai Municipal Planning and Natural Resources Bureau
- Li Ping, Director of Institute of Quantitative Economics and Technical Economics, CASS
- Zhang Yongsheng, Director of Institute of Ecological Civilization, CASS

- Bao Qifan, Counselor of Shanghai Municipal People's Government, former Deputy Director of Shanghai Port Authority and former Vice President of Shanghai International Port (Group) Co., Ltd.
- Chen Ming, Deputy Director of Academician Studio of China Academy of Urban Planning and Design
- Willem Littvoet, PBL Netherlands Environmental Assessment Agency
- Arjan Harbers, PBL Netherlands Environmental Assessment Agency
- Henk Ovink, Govt of The Netherlands (Water Envoy)
- Martien Beek, IenW
- Howard Bamsey, Global Water Partnership
- LI Lifeng, Food and Agriculture Organization of the United Nations
- MA Chaode, United Nations Development Programme
- Onno van den Heuvel, United Nations Development Programme
- Marcus J. Wishart, World Bank
- Parameswaran Iyer, World Bank
- Gary Spiller, Independent consultant

Coordinators:

- Hu Jingjing Information Center Deputy Director of China Academy of Urban Planning and Design
- Bob Tansey, The Nature Conservancy
- Jan Bakkes, PBL Netherlands Environmental Assessment Agency

** The co-leaders and members of this SPS serve in their personal capacities. The views and opinions expressed in this SPS report are those of the individual experts participating in the SPS Team and do not represent those of their organizations and CCICED.*

Executive Summary

1. Scope and ambition

The subject matter of this SPS is no less than a re-alignment of regional economies to the changing river basins in which they are situated. This cannot happen overnight. But time is short, given climate change, the need for decarbonization and pollution control as well as the opportunities of ongoing economic and demographic shifts. For China, the Yangtze River basin is a key area for the country to address climate change and achieve ecological civilization. The research team has proposed a governance vision of "Yangtze River Basin Life Community" for the critical time target of 2050, with the aim of providing a "Yangtze River example" for international river basin governance. Mutual learning between managers and stakeholders in river basins internationally is key. CCICED should play an active role here, as a rallying point to exchange strategic and practical insights.

2. Research Focus

Building a framework for integrated watershed assessment, in view of the changing 'rules of the game'. Climate change is altering the hydrological cycle of the basin, exacerbating risks and pressures on the basin's water system. Compared to large global river basins, the Yangtze River basin is in a very dynamic stage of development. It faces a higher degree of multiple pressures to achieve decarbonization goals and economic development, with basin security and resilience and optimal use of shoreline resources already prominent issues facing the Yangtze River basin today. The interplay between using the basin for socio-economic development and ensuring a healthy and sustainable water system needs to be redefined. In the face of uncertainties brought about by climate change on watershed governance, eight critical steps for sustainable watershed governance and an integrated assessment framework are proposed with the support of an international team, a watershed resilience paradigm is established, and a framework on disaster risk response is summarized.

Examine the long-term trends of climate change and short-term shocks of disaster risks and propose strategies to enhance the resilience of the basin. This study, among other things, reviews the climate change phenomena in the Yangtze River Basin over the past 50 years, and uses empirical research methods to sort out the type, number, and spatial distribution of climate change-induced disasters in the Yangtze River Basin, forming the spatial distribution of major climate disasters in the Yangtze River Basin, as well as disaster risk analysis in key areas. On this basis, we propose a strategy for building "resilient urban and rural settlements" by integrating classical engineering measures and nature-based solutions (NbS) in four aspects: ecological protection, spatial optimization, facility construction, and emergency management, and specifically propose a safety and security strategy for the upper, middle and lower reaches of the Yangtze River basin, considering the geographic subdivisions and disaster characteristics of the basin. Resilient strategy.

Strengthen empirical studies of river shorelines. Develop localized green, low-carbon and livelihood-oriented shoreline optimization strategies. The lower Yangtze River is a highly dense economic and population area in China, and it is also the area with the most prominent water and land conflicts. Using public satellite image data, we invested a lot of effort to draw the shoreline utilization drawings of the Yangtze River from Nanjing down to the mouth of the sea in 2010 and 2020, sorted out and analyzed the current development and utilization situation, systematically studied and judged the prominent risks and problems of shoreline utilization in the lower Yangtze River, and proposed a green, low-carbon and livelihood-oriented shoreline optimization strategy with reference to international advanced experiences and practices. The SPS also conducted a pre-study on the sustainable development of the delta area at the mouth of the sea with high regional value, high ecological value and high-risk vulnerability.

This SPS argues that special attention should be paid to the safety and social equity of disaster-prone areas such as rural areas, poor areas, remote mountainous areas, and disaster-prone populations such as women, the elderly, and children in watershed governance, and that social and gender equity should be guaranteed as an important goal to enhance the sustainability of watersheds.

3. Policy Recommendations

The experts involved in this first phase of the SPS on River Basins recommend the following steps to be taken by the Chinese government:

Act now on climate change and build a "watershed community of life". China should seize the critical opportunities for adaptation to the expected impacts of climate change that are now fleeting. Set new monitoring focused on the impacts of anthropogenic stresses and climate change, carry out risk assessment focused on a long-term basis (2050-2100), and prepare for more than one scenario.

Improve security in view of extreme events and restore ecosystems. Pro-active strengthening is needed for protection against a wide range of natural hazards. It can be obtained by applying nature-based solutions and rebalancing natural and man-made elements of the river basin landscape.

Build resilient urban and rural settlements to improve Security and Resilience. By making the right choices in the spatial layout of river basins, while combining classical engineering with nature-based solutions, reduce exposure and vulnerability to extreme events, lower disaster risk at the beginning, and increase resilience of urban and rural settlements – including vulnerable groups.

Develop comprehensive planning for key industrial port cities in a low-carbon era, selecting major tributaries and deltas for pilot exploration. The economic planning horizon to 2050 will be heavily influenced by the global transition to a low-carbon future. Given the longevity of the hardware involved, the uncertainty of regional climate projections and the complexity of changing port city economies, it is urgent to start planning and consulting now.

Strengthen integrated water and land management of the basin shoreline. In particular, promote the transformation of selected parts of the downstream industrial port shoreline into an ecological shoreline and a living shoreline. More generally, river shorelines should be managed as long-term resources. In order to ensure future strategic flexibility, shorelines should be maintained in their natural state as much as possible.

Strengthen response capacities to improve the emergency response capabilities of local governments and the public. Invest in monitoring and early warning systems, and in local response capacities. Pay more attention to gender equality and social equity issues in disaster-prone areas and among disaster-affected people. In particular, ensure that efforts to engage stakeholders do indeed empower everyone.

4. Suggestions for a Five-Year Program of work

The five high-level guiding principles laid out in the scoping study for this SPS lead to a five-year programme of work. These principles will play out differently in each individual river area. We will learn more about these principles, and possibly redefine them, as we learn from the analyses of cases, in China and worldwide.

Table 1. Proposal for research foci in 5 subsequent years based on the 5 high-level guiding principles presented in the scoping study Managing River Areas in Times of Climate Change

	Principle/	**Possible research focus#**
2022-2023	Make good on your responsibility stretching from the headwaters to the coastal seas	The mechanism for regional collaboration
2023-2024	Adopt a 100-year perspective and plan your steps	A proactive approach to adapt to projected climate change and increase resilience
2024-2025	Engage everybody who can contribute and develop a shared vision	The organization of collaboration in multi-subjects' interests
2025-2026	Adapt to climate change and other principal river stressors in every aspect of the management of river areas	Dealing with the uncertainty of climate change and other stressors, and of disasters
2026-2027	Continue to strengthen and innovate	Management approaches, knowledge programs, policy tools and forward-looking financing mechanisms, etc.; international exchanges

The order over the years should be fine-tuned in view of opportunities to align with international events

The proposed 5-year programme should take advantage of special occasions in each given year, such as the UN Water Decade Conference in early 2023, as they emerge. The work programme each year would see:

- A stock-taking paper
- A work conference, with field visits if possible (otherwise, good video reports)
- A report to the AGM and the wider community reporting on lessons drawn and, importantly, identifying areas for development

Along this line, it is proposed to co-organize, or align with, the following events in 2022/2023:

- an international seminar considering River basins and Delta areas of the Yangtze, Rhine, and Mississippi, with special focus on the transformational challenges of port city economies – October 2022;
- a side event or similar on water and biodiversity in the context of maintaining river systems, at or around the Biodiversity COP 'Kunming';
- building on the results of the envisaged event at the Biodiversity COP: a side event or similar at or around the UN Water Conference, March 2023.

Contents

Forward

Climate change has posed a host of new challenges to basin management. The impact of climate on the water cycle, the resulting flow patterns, species, ecological processes and other human and natural systems has triggered new situations. Large river basins are vulnerable to various other human and natural stressors (UNEP-DHI and UNEP, 2016; Best, 2019; Su et al., 2020), which brings a range of challenges and opportunities to river basin management due to possible interaction and combination of such stresses. Recognizing the interaction among such stresses and the way to deal with them under climate change has brought unprecedented challenges to future basin management and governance.

For China, large river basins, including the Yangtze River, are key areas to address climate change for ecological civilization. As with the Rhine River in Europe, the Yangtze River Basin plays a significant role in China's regional development paradigm due to its larger area and more complex comprehensive conditions. Preliminary studies of the China Academy of Urban Planning Design (CAUPD) and the Netherlands Environmental Assessment Agency (PBL) shows that the long-term impact and the short-term shock of climate change on the Yangtze River Basin have emerged, greatly affecting water security and water system in a great many aspects, with rapidly increasing impacts and risks.

Experts of CAUPD and the international team in the SPS group fully discussed the issue, reaching a consensus that this work should be committed to promoting the governance action and governance capacity building, including a systematic, synergistic and urgent response to the management of the Yangtze River Basin under climate change, based on the existing work of the *Yangtze River Protection Law of the People’s Republic of China, the Outline of the Development Plan of the Yangtze River Economic Belt*, ecological compensation of the Yangtze River Economic Belt and the SPS on green development system reform, along with other preliminary studies. Considering the complexity of the issue and the limitations of current studies, this SPS should also combine the long-term arrangement on the seventh session of CCICED with the current action strategy.

1. Risks and Challenges of Global Large River Basins Under Climate Change

1.1 Impact of natural and human activities on large river basins

Globally, large river areas hold huge social, ecological and economic importance. As the birthplace of human civilization, large river basins played a central role in human history, culture, religion and society. They form regions that provide critical agricultural productivity and support growing populations, provide natural resources for the development of towns and cities, and have fostered the development of some of the world’s most diverse and important ecosystems.

As key areas of interrelation between humans and nature, river basins are being affected by a host of natural and human factors, which has posed a series of challenges to river basin governance of the present day. The Netherlands PBL study team, in preliminary studies, identified 17 factors affecting river basins, mainly emphasizing two aspects: The first is the impact of natural environment on river basins, including flooding, droughts, high waves, landslides, erosion, wildfires and other disasters. These extreme events become natural hazards when people, buildings, or infrastructure are in harm’s way. The second is the impact from socio-economic development, including both the impact of traditional activities in river basin areas such as dams, water diversions and transfers, sediment mining and fisheries, and the impact from urban settlement and industrial development, such as urbanization and industrialization, port and industrial development, agriculture, and deforestation in the catchment area. These natural and socio-economic impacts interact, correlate and combine with each other, undermining functions and ecological systems of river basins and posing a host of changes, threats and challenges to river basin management.

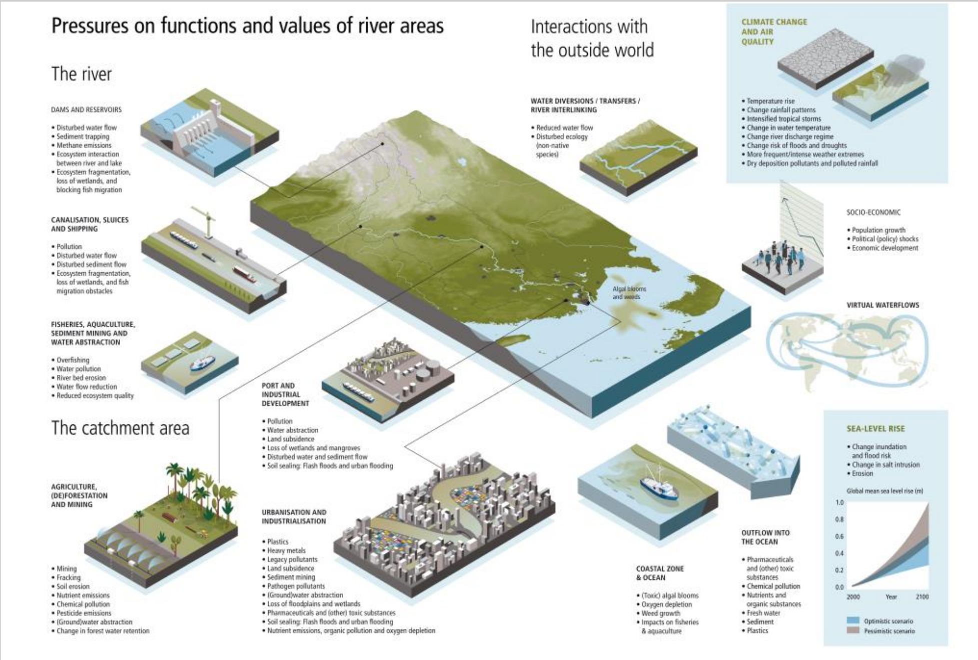


Figure 1-1 Overview of pressures (challenges) in the river and the catchment area, and in relation to interactions with the outside world

1.2 Possible impact of climate change on hydrology of large river basins

Hydrological cycles of river basins are seeing changes due to climate change, altering the distribution, timing, and quantity of water in river basins, with implications for human and natural systems . Therefore, the TNC study team made a special study earlier on the hydrological impact of global large river basins under climate change, reaching the following conclusions:

Possible exacerbated seasonality of flow in large river basins by climate change. For instance, river discharge for rivers such as the Ganges, Yangtze, and Yellow River, influenced by monsoonal precipitation, is projected to increase during the high-flow season[1].

Possible higher water temperature of rivers by climate change. Global mean river water temperatures are projected to increase on average by 0.8 to 1.6 ℃ for 2071–2100 relative to 1971–2000; the largest water temperature increases are projected for the United States, Europe, eastern China, and parts of southern Africa and Australia[2].

Increasing impact of global climate change on extreme weather in large river basins. Global and regional extreme weather and climate events are increasing, both in frequency and intensity[3] (IPCC, 2021). Addressing climate change and the frequent occurrence of extreme climate-related weather events and arriving at targeted and practical strategies to improve the level of resilience in river basins is a critical need in today's river basin management.

Uncertainty in predicting hydrological changes in specific river basins. There are still significant uncertainties to be resolved in terms of directionality (increases or decreases), magnitudes (relative size of changes) and time scales (seasonality, frequency, short term vs. long term) of climate change impacts, despite the significant progress in understanding the impact and significance of climate change on river basins in the current scientific field.

Column 1-1: Study on the uncertainty of future scenario prediction for river basin water discharge under climate change

TNC conducted a comparative study on the Yangtze River Basin, the Rhine River Basin and the Amazon River Basin, showing an obvious upward trend between the flow of the Rhine River and the climate change, and no statistically significant trend of the Yangtze River and the Amazon River in different RCP scenarios. The fluctuation range between the minimum and maximum values of the Rhine River is less than 1.2 times, while that of the Amazon River is nearly 5 times, that of the Yangtze River is within 3 times. One credible explanation is that the Yangtze River and the Amazon Rivers are larger in scale, with more influencing factors.

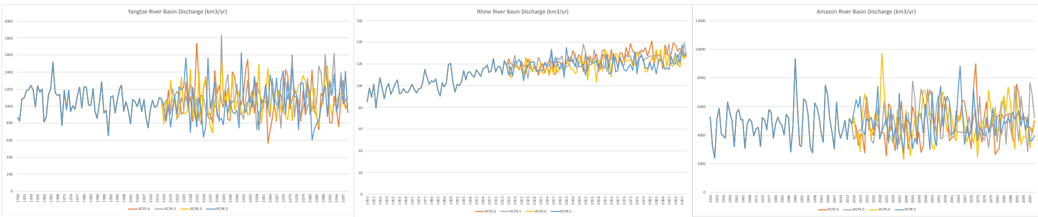


Figure 1-2: Discharge flow under four RCP scenarios in the Yangtze River (left), the Rhine River (middle) and the Amazon River (right)

Results are obtained from the ensemble of CMIP6 models, which have been calibrated to the year 2015, and projected through the year 2100.

1.3 Risks and pressures in large river basins

In the context of climate change, changes in river hydrology will affect the flood control, water resource availability, water quality and biodiversity of large river basins, as well as socio-economic activities including airworthiness conditions, availability for agricultural and food production, energy and mining exploitation, as well as power generation, aggravating water risks of current river basins and the pressure faced by water systems. According to PBL preliminary studies, the risks and challenges of climate change to current global river basins mainly focus on the following aspects:

Risks of heavy rainfall and flood. In general, climate change will increase the intensity of heavy rainfall events because air can retain more water vapor when it heats up. As a result, flash floods and urban flooding may occur more often unless infiltration and water retention capacities in urbanized areas are increased. The past few decades saw a sharp rise in losses due to flood in global rivers, with an upward trend of losses caused by floods: from 2010 to 2050, the global population affected by river and coastal floods is expected to increase from 992 million to 1.3 billion[4]. The frequency of mountain torrents and urban floods will be increased if the infiltration and water retention capacity of urbanized areas remain unimproved. A higher intensity of heavy rainfall events may also increase soil erosion in agricultural areas and nature areas affected by wildfires and may wash down more nutrients to the river[5].

Drought and water shortage. On a global scale, droughts increased in the early half of the twentieth century, decreased in the mid-twentieth century, and increased again starting in the 1980's [6]. Model simulations indicate that by the end of this century, the global land area and population in extreme to exceptional drought could more than double, each increasing from 3% during

1976–2005 to 7% and 8%, respectively. An assessment of global water scarcity by mid-century, based on scenarios of population growth and climate change, has indicated that most of the projected water scarcity is due to climate change[7]. Since the world may face water shortage of 40% by 2030, water mismanagement will exacerbate the impact of climate change on water resources and the whole society.

Hydropower development. Decarbonization development may prompt further development of hydropower potential as renewable energy. The impacts of climate change itself, such as increased flood frequency or intensity, can also lead to increased pressure to build more dams[8].The increasing use of hydropower dams, however, may exert various pressures on river basins, like disturbing water flow and sediment flow, and damaging aquatic biodiversity.

Inland water transport. The functionality of inland waterways can be affected by changes in both high and low flows. High flows can have major impacts such as the suspension of navigation, damage to port facilities due to increased loads on structures, damage of banks and flood protection works, silting, and changes in river morphology. Changes in low water conditions have a higher impact on inland waterway transport, affecting the loading capacity of (mainly) larger freight ships for longer periods of time[9], and on saltwater intrusion in deltas.

River pollution. Usually, river pollution can be seen in populous, industrialized and crop-intensive river basins. Climate change, globally, is expected to worsen water quality like that of the drinking water even treated routinely, posing health risks. These risks stem from rising temperature, increased sediment, nutrients and pollutants caused by rainstorms, reduced pollutant dilution capacity during droughts and interruption of treatment facilities during floods[10]. In addition, increased water temperature reduces oxygen solubility and concentration, and raises the toxicity of pollutants (such as heavy metals and organophosphates) to fish and other freshwater species[11].

1.4 Multiple challenges of river basin governance

High complexity of river basin issues. The complexity of river areas can be seen in two aspects: the first is the complexity of river basins themselves, which is reflected in the linkages among the upper, middle and lower reaches of the river system, the interdependence between all activities and land use types within river basins, and the interaction between river basins and the outside world. The combined action of different pressures often has non-linear results, leading to amplified effects[12 13]. The second is the complexity of multiple impacts of climate change on river basins, and different influencing factors may have cross effects, or act on river basins simultaneously to produce additional effects. This destroys functions and ecosystems of river basins and brings a chain of changes and challenges in managing river basins, which requires us to see river basins as a whole for systematic studies when studying river basin governance.

Uncertainty of risks of short-term shock on river basins by climate change. People have made great progress in understanding the impact and significance of climate change on river basins in the scientific field, believing that the long-term impact of climate change on river basins is relatively certain, such as higher water temperature, increased seasonality of flow and precipitation. However, there is great uncertainty in the short-term prediction of risk shock to river basins due to limited hydrological directionalities, amplitudes and time scales of specific river basins in existing studies, intensifying the difficulty of river basin governance. It is, therefore, necessary to adopt empirical study to analyze specific river basin problems, so as to provide successful schemes and strategic cases for decision makers.

The safe resilience of urban and rural settlements in river basins is the most urgent. The obvious upward trend of frequency and intensity of global and regional extreme climate events[3] also makes river basin management more and more urgent. There exists a large divide in infrastructure construction and vulnerabilities to disasters in urban and rural settlements, due to great gap in development stages of different river basins. With climate change, frequent extreme climate related weather events and better living standards of people, the requirements for the safe resilience of river basins are also greatly increased. As for river basin management, it is imperative for us to work towards resilience-oriented river basin governance, combine hydrology, ecology and social sciences into a new and forward-looking scientific method of river basin resilience, and formulate targeted and practical strategies for better river basin resilience.

Integrity, synergy and coherence of river basin governance. River basin governance policies face multiple challenges due to the complexity of river basin issues. In most cases, natural boundaries of river basins do not match their administrative boundaries, with some river basins even cross-border. What's more, the management of river basins also involves multiple fields, multiple departments and different administrative levels. Therefore, it is likely to show the disadvantages of segmentation, separate policies and repeated construction in governing large river basins. How to cross administrative boundaries at different levels to ensure the consistency, synergy and coherence between cross-border policy objectives and the implementation of cross-sector and cross-level policies is a major challenge. We need to make overall coordination and systematic institutional mechanism design for many fields, departments and places of large river basins in terms of related policies.

The complex interweaving of interest groups in river basin areas. The river basin is complete and complex system, with complicated ecosystem functions, big regional divides in socio-economic development levels, multiple development forms of different degrees, complex relations, diversified interests and needs, which brings numerous challenges to river basin governance in terms of interest selection and interest balance. We should not only coordinate all interest relations of upstream and downstream reaches, left and right banks and different regions, industries and departments, but also center on the risks and challenges brought by climate change to regions with different development levels and groups. In formulating related policies of river basin governance, we should pay attention to all interest relations in the natural, economic, social and cultural systems in river basin areas, comprehensively consider the sustainable development of river basins, make a good choice and balance of interests for fairness, justice and social harmony.

1.5 The urgency of China's river basin issues and the importance of the Yangtze River

More and higher pressures of China's river basins compared with other global river basins. In preliminary studies of the Netherlands PBL team, 16 major international rivers, including the Rhine, and 20 major rivers in China were selected for qualitative comparisons for pressures in 17 aspects. According to the studies, it is expected that by 2050, all large river basins will face more pressures, with China's large river basins facing more pressures and bigger impact. These pressures bring problems and risks not only in dams, wetlands and glacier melting in upper reaches of rivers, but also in fisheries, aquaculture, floodplain and wetland loss, as well as in catchment area pollution, deltaic land subsidence, groundwater exploitation, soil erosion and other problems and risks.

The next 50 years will be a key time window for China's river basin management. Compared with the development of large global river basins in developed regions, China's river basins will face more complex challenges in the next 50 years. The study team compared the Rhine River in Europe with the Yangtze River in China, showing that various problems caused by industry and pollution had been solved in the Rhine River as early as the 1950s. Today, people pay more attention to frontier issues like biodiversity and energy decarbonization in governing the Rhine River. While the development of China's river basin economy is much later, as China didn’t see the beginning of rapid industrialization and urbanization until the 1980s. However, in today's large river basins in China, in addition to solving water pollution prevention and control, water shortage, ecological environment restoration and flood control brought about by urbanization and industrialization, people also put forward issues such as energy decarbonization and biodiversity protection to achieve the strategic goal of "peak carbon in 2030 and carbon neutralization in 2060". Therefore, the development of China's large river basins will face more complex challenges in the next 50 years.

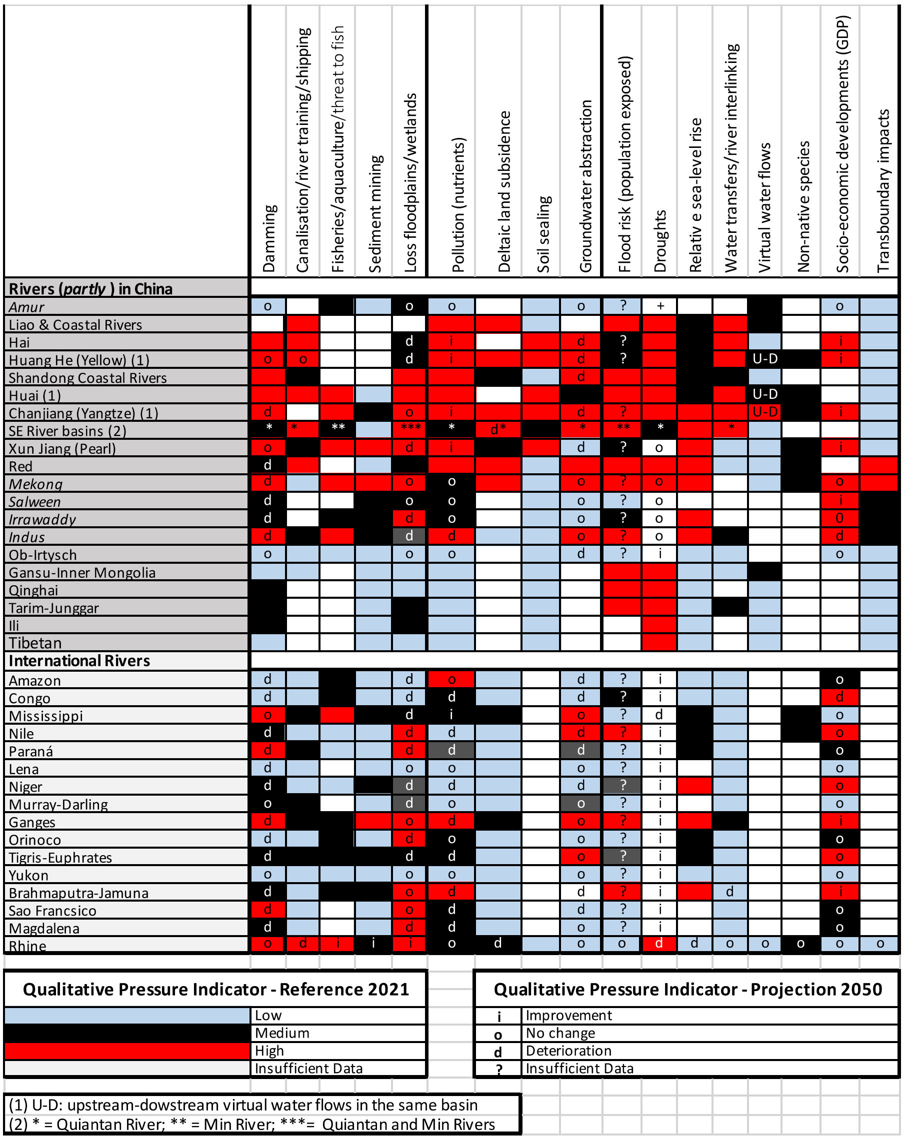


Figure 1-3 Impacts of pressures on rivers now and in the future: An example of indicative fingerprinting using qualitative scores (CCICED, 2021).

Note: In the table, a qualitative low, medium, and high impact label is suggested to characterize the pressures on the rivers in their current situation. In addition, where possible, an i, 0, or d is included to indicate whether an improvement (i), deterioration (d) or no change (0) is projected by 2050.

The Yangtze River Basin is the most important support for China's development and has the most vitality and potential for the socio-economic development of the country. Covering a total area of 1.8

million square kilometers, the Yangtze River basin, rich in natural resources, accounts for 18.8% of China's land area, with the total population and economy exceeding 40% of the country. The Yangtze River Basin, since ancient times, has always faced natural pressures such as floods, droughts and extreme weathers; After the reform and opening up, it faces a series of challenges brought by the rapid socio-economic development. Today, people have adopted a series of major strategies, such as *the Yangtze River Protection Law of the People's Republic of China*, *the Outline of the Development Plan of the Yangtze River Economic Belt*, and the overall policy of eco-priority and green development is taking shape. Understanding complex pressures of the Yangtze River Basin under climate change, the way of addressing climate change and solutions to sustainable development of the basin are not only of great significance to China's ecological civilization, but also of key reference value and demonstration to the governance of other river basins in the country.

Column 1-2: Comparison of the development stages between the Yangtze River Basin and the Rhine River Basin

The countries along the Rhine River Basin have entered the post-industrial development stage, the urban population has witnessed lower growth, so pollutant emissions have peaked after the 1980s, and environmental pollution problems have been basically under control; in recent years, the total carbon emissions and per capita carbon emissions of the coastal countries have begun to decline as low-carbon development were accelerated in response to climate change.

In the next 15 years, economic scale and urban population of the Yangtze River Basin will also maintain rapid growth, and outstanding pressure still emerges when controlling the total amount of pollutants and carbon emissions. At present, the total emissions of major pollutants of the Yangtze River Basin began to decline after 2015; However, the total carbon emissions and per capita carbon emissions are still continuing to increase.

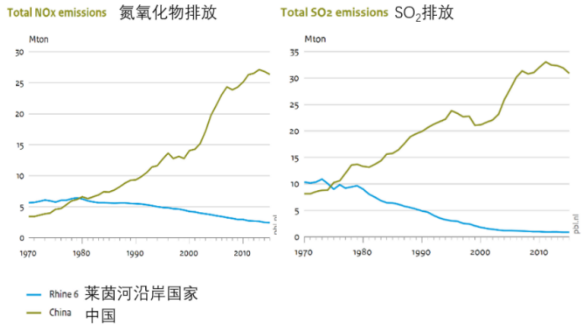


Figure 1-4 NO_x emission (left) and SO_2 emission (right) in the Yangtze River Basin and the Rhine River Basin during 1970-2012

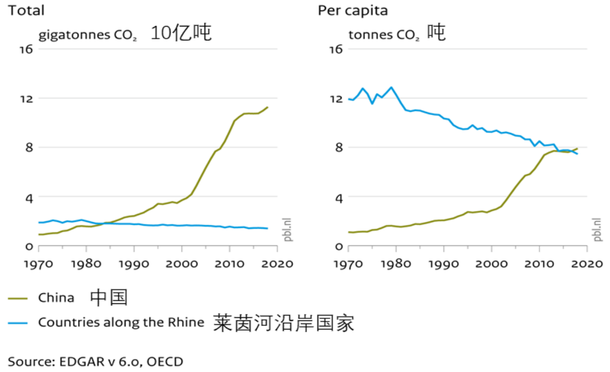


Figure 1-5 Carbon emission (Left) and per capita GDP (Right) of China and countries along the Rhine River during 1970-2020

2. New Path Forward and International Experience Reference in Governance of River Basin

2.1 Eight Critical Steps and Framework for River Basin Management Assessment

The prospect of climate change and the need for ambitious decarbonization of our economies both exacerbate the challenges and open opportunities. We need to redefine the interaction between the use of rivers for socioeconomic development and securing healthy, sustainable water systems. This calls for a transformation towards sustainable river management that addresses both human interventions and the consequences of climate change. This transformation will not happen overnight. The world is complex, and rivers are not stand-alone silos that can be managed in isolation. Agriculture pollutes the river with nutrients, hydropower is an important part of decarbonization that fragments river ecology and disturbs the continuity of water and sediment flow, and the high demand for sand for construction leads to illegal sand mining, to name a few aspects of this complexity (Figure 2-1).

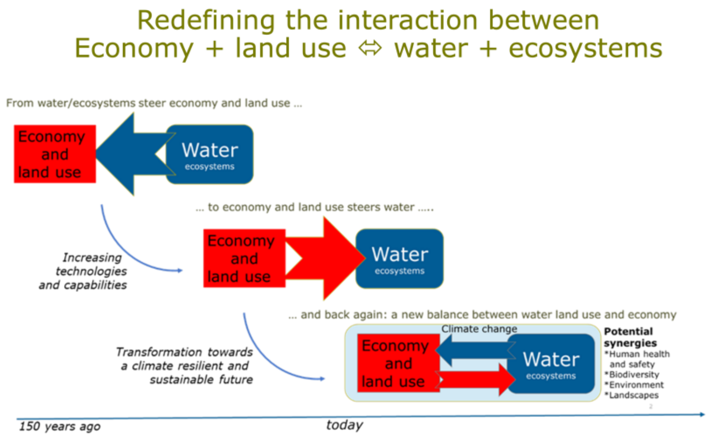


Figure 2-1 The shift of water steering economy and land use to economy and land use steering water, calling for the redefinition of the interaction between the two. z

There is no 'golden bullet' to solve all problems. Bending the trend towards climate resilient and sustainable rivers requires a machinery of eight steps to shift the outcome of policy and investment strategies in the intended direction (Figure 2-2).

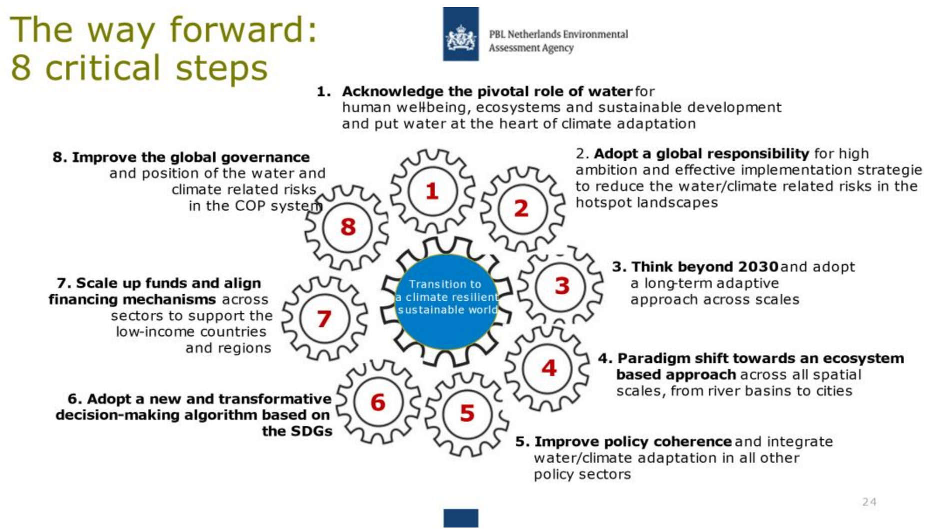


Figure 2-2 Eight critical steps of the 'machinery' to bend societal trends towards climate resilient and sustainable rivers.

This will require – amongst other things – a leap in ambitions, thinking beyond 2030, requiring policy integration and coherence across sectors, new transformative algorithms for decision making, integrated spatial development, and speeding up and scaling up efforts and investments, especially in low-income countries and high-risk regions in order to prevent structural loss of human habitats.

A framework is presented that helps us to investigate river basins and river basin management under climate change by comparing cases and drawing lessons from practices around the globe. Focus is on current and future developments in river basins due to socioeconomic developments, land use and climate change, on river basin resilience and adaptability, and on river basin management and governance. The investigative framework distinguishes the basin characteristics that define the possibilities in the river basin, stresses that act on the basin, and the response of the river system that leads to outcomes in terms of changes in risk and resilience, prosperity and decarbonization, security of the supply of water, food and energy, and progress in achieving the SDGs. The stresses acting on the river basin are climate change, socio-economic development, and internal strategies and policies (Figure 2-3). (Figure 1-3 shows one application of this assessment framework)

The investigative framework aims at providing evidence-based recommendations building on experiences from case studies in the Rhine and Yangtze basis and from river basins around the world. Each case needs to be analysed following a structured approach to identify as good as possible the drivers, the enabling environment, the hurdles, thresholds, catalysts, deciding measures and actors.

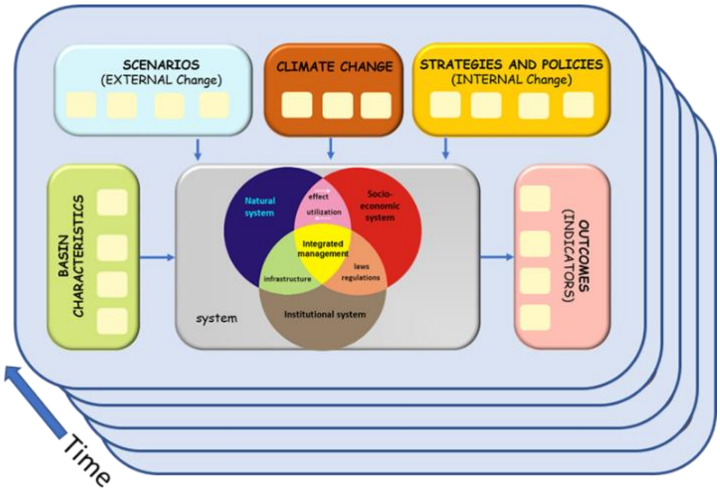


Figure 2-3 Components of a conceptual Framework for River Basin Management Assessment.

2.2 The Changing Game：Understanding and Building Resilience in River Basin

Climate change, its interaction with a wide range of anthropogenic and natural stressors, and the challenge of decarbonization are altering all aspects of river basins, especially the use of land and water resources within the basin, as well as the corresponding ecosystem services provided by river basins. This is the ‘Changing Game’ of river basin management we are facing now. The changing game is largely about dealing with uncertainties that pose important challenges in the governance and management of river basins that need to be met. Decisions need to be made, planning needs to proceed, operations need to continue in areas such as water allocation, storage management, infrastructure, and provision of ecosystem services in general. This calls for understanding and building resilience.

Historically, from an ecology perspective, the concept of resilience focused on bouncing back to previous functions, species, and ecosystem services; resilience in this sense involves resistance to change and recovery from change, or ‘persistence’. In addition, two complementary concepts in resilience, particularly applicable to river basins, have emerged: adjusting in the face of change (‘adaptation’) and transition to new ecological states (‘transformation’). These concepts are illustrated in Figure 6. Persistence, adaptation, and transformation can be thought of as modes that apply to the various dimensions of resilience, e.g., hydrological, ecological, social, institutional/governance, cultural, engineering/infrastructure, among others.

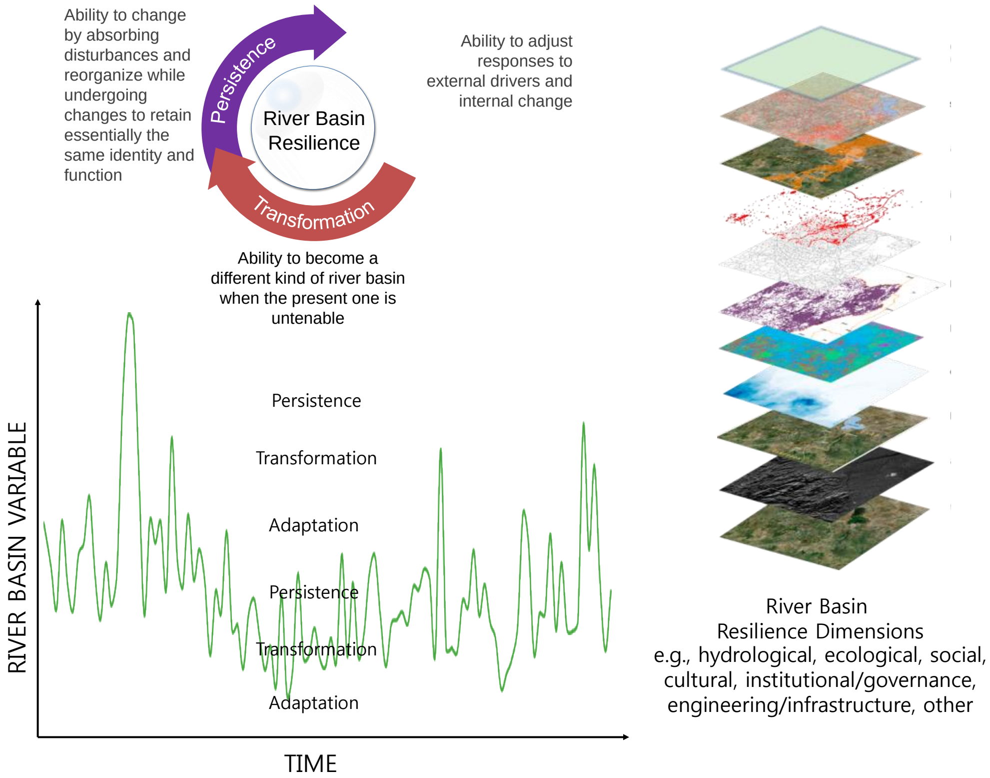


Figure 2-4 Conceptual framework to define and characterize river basin resilience. The upper left panel shows the persistence-adaptation-transformation cycle. The right panel shows various resilience dimensions (layers). Each layer is characterized by several variables. The lower left panel shows a time series of a hypothetical river basin variable (e.g., flow, land cover, population, water demand), illustrating the transitions between resilience modes.

Managing river basins under a resilience paradigm suggests a more dynamic, interactive form of engagement, whereby basins may be managed for desired conditions and services (either persistence or adaptation), but potentially with physical and biological characteristics that exhibit limited resemblance to their recent historical state (transformation). The development of holistic management strategies from headwaters to floodplain to groundwater may be necessary as single system approaches are not sufficient14. This represents a new frontier for hydrologists, ecologists and social scientists and will inevitably require novel and more intensive forms of stakeholder engagement and collaborative decision-making to define watershed objectives and management actions. The science of river basin resilience will need to combine insights from these disciplines into a new, forward-looking framework that is only beginning to emerge operationally.

2.3 Framework for disaster risk assessment

Globally, climate change will affect the number and intensity of extreme events, but the extent to which is uncertain. Pro-active strengthening is needed of protection against a wide range of natural hazards, including floods, droughts, wildfires, and landslides. Future predictions of global risk must also integrate climate change with socio-economic factors. Disaster risks are rapidly increasing around the world; many regions are experiencing greater damage and higher losses than in the past. Increasing exposure to flooding and increasing damage sensitivity are the main causes of the steeply rising trend in global river flood losses over the past decades. The IPCC (2012) [15] has high confidence that "increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters.”.

In 2015, the Third World Conference on Disaster Risk Reduction, held in Sendai, Japan, approved 2015-2030 Sendai Framework for Disaster Risk Reduction and confirmed four priorities for action including global disaster prevention and reduction, and called on countries around the world to increase investment in disaster reduction, strengthen resilience construction, and reduce losses caused by natural disasters. The four priorities for action are: understanding disaster hazards, strengthening disaster reduction management, increasing investment in disaster reduction, and disaster prevention and recovery and reconstruction. The Sendai Framework for Disaster Risk Reduction also put forward 6 key dimensions and 10 specific elements to enhance resilience against disasters **Error! Bookmark not defined.** (Figure2-5).

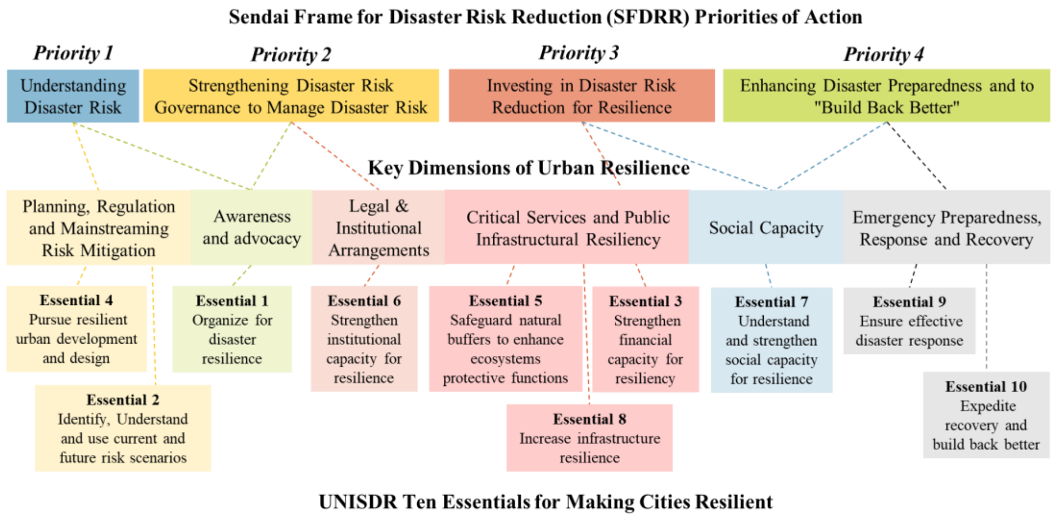


Figure 2-5 Priorities for action key dimensions and specific elements of resilience of *Sendai Framework for Disaster Risk Reduction* (sorted according to the data of UNDRR[16])

It should also be recognized that restoring ecosystems can enhance protection against disasters and risks to some extent, and thus rebalancing natural and man-made elements of the river basin landscape. Focus should be on co-management of water and land, for instance by using the opportunities of more wind and solar on land to reduce the adverse effects of hydropower on river systems. A shift to regenerative agriculture can bolster lands resilience, while renewables should be sited on lands less suitable for other uses.

2.4 Nature-Based Solutions (NbS)

In theory, NbS can address multiple dimensions and modes of river basin resilience while providing co-benefits to communities, businesses, and nature[17][18] . Although some functions of NbS can be fulfilled by built infrastructure, the high flexibility and adaptive capacity of NbS, highly relevant in the context of uncertain future change, are specific advantages.

Uncertainties created by climate change and an unpredictable future render static solutions with high sunk costs and low adaptive capacity, such as large reservoirs and similar gray infrastructure, increasingly risky investments. NbS are often smaller, more affordable, more flexible, and more multipurpose than conventional interventions[1920]. For example, single NbS interventions can mitigate effects of floods and droughts both, which is rarely found in engineered interventions, or can address water quality through interventions that also improve habitat, capture additional carbon dioxide, and can improve health and well-being of communities. As such, NbS are more compatible with the type of adaptive solutions and no-regret strategies that are advocated in the context of uncertain future change.

Column 2-1: Nature-Based Solutions (NbS)

An umbrella-type approach concept to achieve the UN Sustainable Development Goals (SDGs) by actively using ecosystem services, encompassing many ecosystem-based solutions for various sustainable development issues, such as solutions for ecosystem-based adaptation, ecosystem-based disaster risk reduction, natural infrastructure, green infrastructure, and nature-based climate change. The IUCN defines NbS as actions that effectively and adaptively address societal challenges and bring benefits to human well-being and biodiversity through the protection, sustainable management, and restoration of natural or man-made ecosystems[21]. Eggermont et al. (2015) [22]used two gradients to classify NbS types involving the extent of NbS intervention on ecosystem/biodiversity diversity, and the magnitude of ecosystem service enhancement resulting from the implementation of NbS.

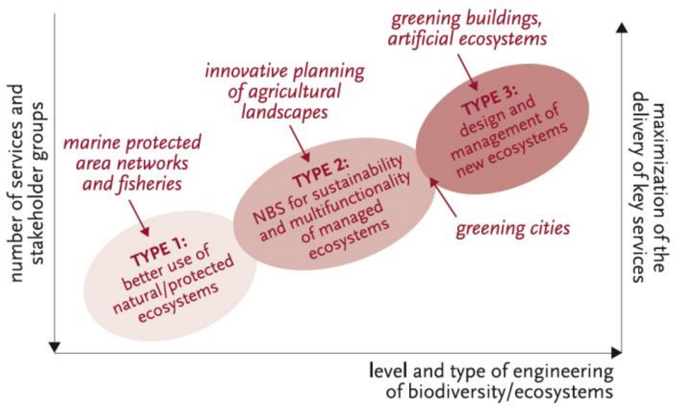


Figure2-6 Different types of NbS (Eggermont et al., 2015[22])

2.5 Learn from other river basins, globally

The river Rhine in Europe is an example of a river that already in the 1980s made a turnaround to tackle pollution when a chemical disaster caused extensive ecological damage stretching from Switzerland to the North Sea. The turnaround proved successful. It was exemplified by the – symbolic – return of salmon in the river. The transformation is still ongoing and includes other river characteristics as well. Examples are the increase of discharge capacity by the Room for the River Program in the Netherlands and measures to restore ecological qualities of the floodplains. In the coming years, measures to reduce the adverse impacts of droughts under climate change will be a focal point for river managers in the area. And all these elements of the transformation of the Rhine have been – and will be – designed with the continuation of river functions for society in mind.

The example of the Rhine – and many examples of rivers throughout the world – illustrate that we do not have to reinvent the wheel. We can learn how to take the eight critical steps of the transformation towards a sustainable future by learning from other rivers, globally.

2.5.1 The Rhine River: The Room for the River, and recover its natural appearance

Since the mid-20th century, the Rhine River has faced increasing problems of river pollution and flooding, and the focus of governance has gradually expanded from pollution control to flood control and biodiversity restoration. A major disaster (fire in Basel, Switzerland) in 1986 caused unprecedented, large-scale pollution of the Rhine. This has led to a governance shift of more strict and transboundary pollution control and ecological restoration of the river. Peak river discharges occurred in 1993 and 1995. The one in 1995 almost caused dike failure (and flooding) of one of the branches of the Dutch Rhine River system. This initiated the program (with 39 measures) to give more 'Room for the River'. This program was a governance shift: before the 90s river flood protection policy was all about high and strong dikes; since the near-floodings of the 90s policy is about combining strong and high dikes with increasing the discharge capacity of the river (and hence 'more room for the river').

Column 2-2: The Netherlands "Room for the River": Nijmegen Practice Project

The floods of 1993 and 1995 in the Netherlands cast doubts on the old approach to flood prevention strategies: that land reclamation and building dikes were positive approaches to water management. Thus, Room for the River as a newer approach was considered-- rather than restricting water, the area around the river could accommodate fluctuating tides. This is done through a series of over 30 measures, in which the area will have been "...lowered and broadened [the] floodplain and created river diversions and temporary water storage areas." Marshy riverine landscapes have also been restored to protect biodiversity and aesthetic value.

One of the *Room for the River* measures exemplifying environmental adaptation is the 'Room for the Waal' project in Nijmegen. This measure moved the dike at Lent (on the north side of the city of Nijmegen), inwards and dredged an ancillary channel in the floodplain in order to help drain the river during high water. The project of moving of the dike had a double goal of protecting the city from floods and improving the urban spatial quality. Building the channel created an island along the Waal, which forms a city park for Nijmegen with urban development possibilities (https://www.ruimtevoorderivier.nl/room-for-the-waal/).

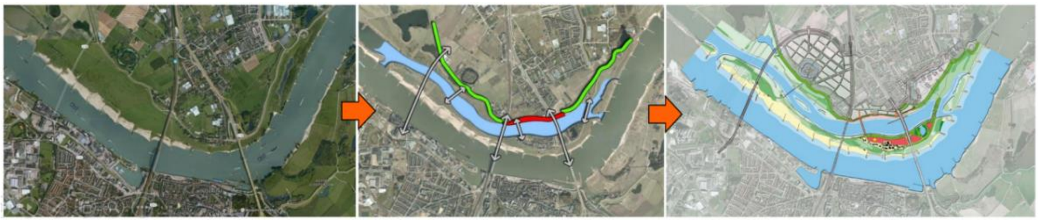


Figure 4-8 Comparison of Nijmegen pictures before and after the construction of Nijmegen "Returning Land to River" project

2.5.2 The Danube River: Climate Change Adaptation Measures Toolbox

From the 19th century to the mid-20th century, the core issues of early governance of the Danube River basin were navigation and hydro-energy development. After the 1980s, it centered on water pollution prevention and ecological protection problems. In 1994, the 11 countries along the Danube established the International Commission for the Protection of the Danube River (ICPDR) to coordinate water pollution prevention and control, flood control and disaster reduction, and other governance work.

After 2010, the International Commission for the Protection of the Danube River began to attach importance to the impact of climate change on the Danube River Basin, and formulated two editions of the *Strategy on Adaptation to Climate Change* in 2012 and 2018 respectively. For the impacts and challenges of climate change on the Danube River, a series of Climate Change Adaptation Measures Toolbox are proposed from the aspects such as climate change and basin vulnerability analysis, water resources and water environment management, flood risk management and response, and drought management[23].

Column 2-3: Climate Change Adaptation Measures Toolbox

ICPDR formulated a set of Climate Change Adaptation Measures Toolbox for the Danube River basin, which provides comprehensive and easy-to-use governance measures from governance fields, types of measures, time scales, and other different dimensions. The governance fields involve agriculture, ecosystem, biodiversity, navigation, hydropower, flood, and so on; The types of measures include basic preparation measures, ecosystem-based measures, technical measures, action and management measures, and policy measures; The time scales include long-, medium-, and short-term. The toolbox can be inquired on the website: http://www.icpdr.org/main/climate-changeadaptation.

2.5.3 The Mississippi River: ecological restoration of the lower reaches and the estuarine delta

From the 19th century to the mid-20th century, the governance focus of the Mississippi River was navigation and flood control, and a series of relevant projects were implemented along the river, causing some damage to the ecological environment of the Mississippi River. By the 1980s, 67% of the wetlands along the main stem had disappeared. Since the 1950s, increasing attention has been paid to restoration of the ecological system. Since the 1980s, basin ecology restoration plans such as the "Plan for Restoring the Upper Mississippi River" and "Plan for Restoring America's Greatest Rivers" have been implemented in the Mississippi River[24]. In particular, after 2006, comprehensive ecological restoration work was carried out in the lower reaches and the delta coastline, which specifically included restoration of wetlands and woodlands on both sides of the shoreline and on the river island, as well as shoreline restoration and protection measures for the estuarine delta[25].

Column 2-4: Ecological restoration measures for the lower reaches of the Mississippi River ("Plan for Restoring America's Greatest Rivers")

After 2006, comprehensive ecological restoration work was carried out in the lower reaches of the Mississippi River and the delta coastline, coordinating with 6 state governments along the shoreline for more than 200 implementation projects. Among which 3 aspects were advanced in response to climate change. Firstly, the dikes were trenched to restore tributary flow and aquatic habitat; currently 30% of the downstream dikes have been trenched. Secondly, frequently flooded land in the floodplain were restored to wetlands and woodlands, with approximate 110 km^2 (27,000 acres) of land already subscribed for restoration to ecological space[26].Thirdly, measures such as sediment transfer and shoreline restoration were implemented in the estuarine delta to mitigate shoreline erosion and flood caused by storms and rising sea level. Two "diversion" projects are planned in Louisiana at the estuary of the river, so as to make more river sediments retransfer from cities into the estuarine delta.

3. Governance Vision, Guidelines and Actions of the Yangtze River Basin for 2050

2050 is a key time node, which is not only the most critical decade from China's grand development goal of the "Second century" towards "Carbon neutrality" in 2060, but also the key node for the "2050 strategic long-term vision" of EU and the "2050 net zero emission long-term strategy" of the U.S. For the grand goal, we should not only formulate a shared vision and goals in various fields and regions, but also focus on the present to form guidelines and key areas for current actions.

3.1 Vision and guidelines for the governance of the Yangtze River Basin

3.1.1 Vision of river basin governance

We should deeply analyze the changing characteristics of water resources in the Yangtze River under climate change and the coordination between socio-economic development and biodiversity protection in river basins, adhere to "Step up conservation of the Yangtze River and stop its over development", build the Yangtze River Basin into a greener, low carbon, more coordinated and balanced, safer and more resilient, more inclusive, more open and co-governed "river basin life community" to provide a "Yangtze River example" for the governance of global river basins.

3.1.2 Eight governance principles

Principle 1: Shared vision and co-governed river basins. We must pay attention to synergies among central and local governments, departments and industries, regions, governments and market society, and to the synergies among the trunk stream and tributaries, upstream and downstream areas, urban and rural intensive areas and marginal areas, villages and cities. Additionally, we must form a long-term vision based on common understandings of issues and values, as the basis for multi-party policies and concerted actions, and formulate policies and action programs crossing department authorities, administrative levels and regional boundaries; Also, we must give full play to the power of the market and society and combine top-down policies with bottom-up actions for real sustainable river basin governance.

Principle 2: Shared responsibilities from sources to coastal areas. Taking river basins as a whole, we should not transfer problems from upstream to downstream areas, nor transfer them through time. We must adopt a river basin-based comprehensive approach, recognize key roles of water in river basin development for human-nature coordination, combine climate change with socio-economic development, fulfill overall responsibilities from sources to estuaries of different regions, departments and groups. Furthermore, we must make use of overall functions of river basins to establish an integrated and coordinated governance system for the adaptation and mitigation of climate change.

Principle 3: Blueprint based on 100 years. In terms of river basin governance, we must have long-term goals and value orientation, pay attention to longer-term interests, comprehensively consider major issues related to the survival and development of human civilization such as carbon neutrality and biodiversity, and incorporate river basin governance into key actions of the *United Nations Convention on Biological Diversity* and the *Convention on Climate Change*.

Principle 4: Focus on and respond to uncertainty. For river basin development, we should confront the long-term pressure brought by climate change, and deal with the short-term impact and uncertainty of disaster risks. Also, we should systematically understand long-term roles of river basins on economy, population, nature, water areas and oceans, and form multi-scenario prediction through long-term monitoring, comprehensive modeling and real-time data analysis to deal with the complexity of river basin problems and the uncertainty of climate change.

Principle 5: Controlling the relation between river basins and settlements. We should not only respect and control macro integrity of river basins, but also respect and understand their divides between medium and micro zoning, especially in urban and rural settlements with highly dense population and economy. We must pay attention to the vulnerability of such highly exposed areas and formulate zoning and classified governance strategies based on urban and rural settlements from aspects of ecological protection, space optimization, facility construction, collaborative response and so on.

Principle 6: Controlling the relation between regional development and social equity. In terms of river basin development, we should improve resident well-being in the whole river basins and pay close attention to imbalance of river basin development, not only focusing on marginal and disaster-prone areas such as villages, small towns, flood storage and detention areas and ecological protection areas, but also on vulnerable groups such as women, the elderly population and left-behind children. We should also pay attention to vulnerabilities of such areas and groups, and strengthen the construction of regional equity, social equity and gender equity mechanisms and the security of vulnerable groups in disaster-prone areas.

Principle 7: Controlling the relation between artificial measures and nature-based solutions. As for river basin governance in response to climate change, we should be people-oriented, respect nature and fully understand system operation modes and ecological service functions of river basins, not only centering on underlying roles of systematic defense projects in improving river basin safety, but also on the advantages of nature-based solutions in alleviating pressures of water security, maintaining the integrity, flexibility and adaptability of the ecosystem for better overall integration to effectively enhance the resilience of river basins to resist disaster risks.

Principle 8: Innovative exploration and strengthened actions. We should continue to strengthen innovative exploration in management methods, knowledge plans, policy tools, forward-looking financing mechanisms, the relevant knowledge of sustainable development under climate change, global exchange and share, in order to further transform the knowledge into joint global actions.

3.2 Key areas requiring continuous attention and actions

Improving the resilience of urban and rural settlements in river basins. With climate change and socio-economic development, dealing with disaster risks and reducing vulnerabilities are the most urgent in the Yangtze River Basin. Therefore, we must firmly abide by the bottom line of water security, attach great importance to urban and rural settlements along river basins, and adopt classified and zoning response strategies to improve the adaptability to climate change.

Comprehensive governance of river basins and coastlines. Catchment areas are main stressors of river basins, which will have a large-scale and long-term impact on other systems, highlighted by the pressure brought by the utilization of shoreline spaces to river basins. Therefore, strengthened comprehensive assessment of shorelines and optimized shorelines governance are critical to deal with pollution in densely populated urban and rural areas of river basins, which should be paid special attention.

More attention to deltas and other key areas. Contradictions between the protection and development of large river basins are prominent in deltas, one of the most sensitive areas to the impact of climate change in the future. Therefore, in addition to urban and rural settlements and river shorelines, we should also pay close attention to key areas such as estuary deltas, flood storage and detention areas and important agricultural natural ecological zones, speed up the identification of all risks in key areas and strengthen the risk response under climate change.

More attention to disaster-prone areas, groups and fields. We should fully consider the differences of the impact of climate change on spaces and factors of river basins, monitor and identify disaster-prone areas, groups and fields in river basins that are seriously affected by climate change. Targeted and diversified measures shall be taken for disaster-prone areas and fields and vulnerable groups to ensure that different regions and groups have equal disaster prevention capacities and the right to equitable development when facing disaster risks brought by climate change.

Optimized ideas and methods of river basin planning and design. In river basin-related planning, facilities and architectural design, we should fully consider the impact of climate change, put forward comprehensive solution systems integrating engineering measures and non-engineering measures, so as to foster the sustainable development capacities of river basins. Also, we should, with holistic and systematic thinking, coordinate river basin development planning, land space planning, ecological protection, resource utilization, disaster prevention and other special plans, and make multiple subjects be part of the planning preparation for better joint implementation mechanisms.

A mechanism for long-term monitoring of pressures of the Yangtze River Basin by climate change. We should strengthen monitoring, establish a monitoring and evaluation information network throughout the whole river basins, and timely understand the long-term trend and short-term risks of climate change in river basins. Additionally, we should realize early warning through combined modeling scenarios and data analysis, scientifically and pragmatically formulate adaptation paths and measures, and make timely adjustments based on uncertain factors.

Advocating and promoting nature-based solutions. We should take NbS as important tools to alleviate water pressure and protect ecological security in river basins, combine NbS with traditional system engineering solutions, and maintain integral ecosystem while reducing floods and other disaster risks. Using NbS, we should also improve the flexibility and adaptability of river basin governance, and dynamically adapt to the uncertain impact of climate change on river basin governance in view of complex geographical conditions and socio-economic spatial differences of the Yangtze River Basin.

4. Climate Change and Disaster Risk Analysis of the Yangtze River Basin

Disaster risk is currently the primary and urgent issue in the Yangtze River basin in the face of climate change, which is mainly affected by four major climate change factors: heavy precipitation, warming, drought and extreme weather. By retracing the frequency, impact scale, loss and spatial distribution of disasters in history, we combine the distribution of population, towns and economic industries in the basin in order to study the exposure of disaster impacts and further study the spatial characteristics of disaster risks in the Yangtze River basin under the influence of climate change.

4.1 Basic characteristics of the Yangtze River Basin

The Yangtze River is the largest river in China and the third largest river in the world, with a total length of 6,300 kilometers and an area of about 1.8 million square kilometers; From west to east, it flows through 11 provinces, autonomous regions and cities, then into the East China Sea.

Geographical characteristics. The Yangtze River Basin crosses China's three-level topographic ladder, with great differences in the physical and geographical characteristics of the upper, middle and lower reaches. The terrain of the Basin is high in the west and low in the east, with the total drop from the river source to the estuary of about 5,400 meters. Its upper reach is dominated by plateaus, mountains and canyon terrains, with a big riverbed gradient and rapid flow. Its middle reach is with alternatively distributed plains, hills and mountains; rivers herein are tortuous and wide, with various tributaries. Its lower reach is dominated by plains, with deep and wide water and short tributaries.

Climatic characteristics. Most parts of the Yangtze River Basin are in the subtropical monsoon region, with big regional climate differences due to its terrain. Cold winter and hot summer, obvious dry and wet seasons represent basic characteristics of the climate, with an average annual precipitation of

1,067 mm for years. It sees uneven temporal and spatial distributions of annual precipitations and rainstorms, which is greatly subject to extreme climate events.

Hydrological characteristics. The Yangtze River Basin is rich in water resources, but with uneven distributions in its upper, middle and lower reaches. Its average water resources for years are 995.9 billion cubic meters, accounting for about 36% of China's total water resources, and its water resources per unit land area is 59,5000 m^3/km^2, about twice China’s average. Its middle reach sees the most surface water resources, while its upper and lower reaches see less.

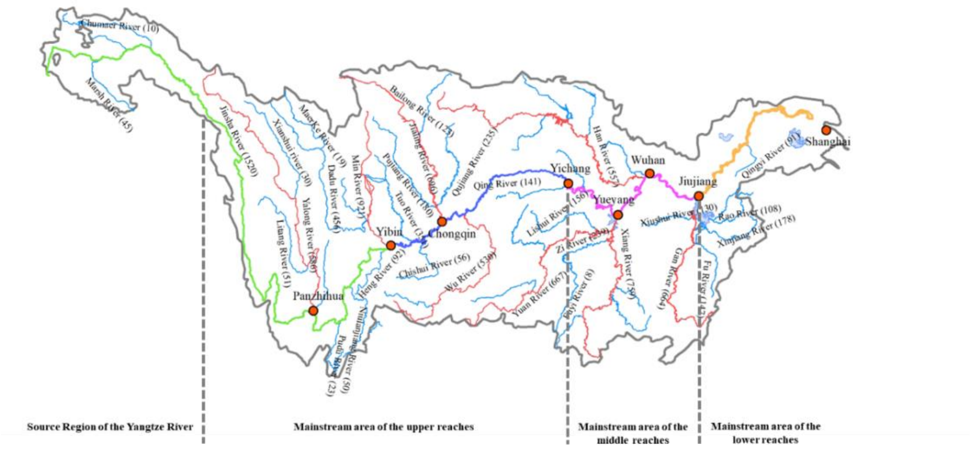


Figure 4-1 River system of the Yangtze River Basin

Demographic characteristics. The Yangtze River Basin is the main gathering area of China's population and economic activities. The land area is only 21.3% of the country, with 42.9% of China's population though. The year 2020 witnessed the total population of the region of about 606 million, with a population density of about 296 people/km^2, twice the national average

Economic characteristics. There is a significant gradient divide in development levels of economy and urbanization along the upper, middle and lower reaches of the Yangtze River Basin. The Yangtze River Delta, in the lower reach, is densely populated and economically developed, with a population density of about 800 people/km^2 and per capita GDP close to 20,000 US dollars. The urbanization rate is generally higher than 70%, close to the development level of the Rhine River Basin in the 1990s. The population density in its middle reach is about 330 people/km^2, the per capita GDP is about 10,000 US dollars, and the average urbanization rate is about 60%, close to levels of high-income countries in the World Bank. In its upper reach, the population density is low, about 180 people/km^2, the per capita GDP is less than 10,000 US dollars, the urbanization rate is between 50% - 55%, still in a relatively underdeveloped stage.

Urbanization characteristics. Cities and towns in the Yangtze River Basin are densely distributed, with the urbanization rate of 63.2% in 2020, ushering in middle and later stages of urbanization. There are 243 autonomous regions and cities, coupled with 584 county-level cities, most of which are distributed along the Yangtze River. Twenty-eight large cities of more than one million, along with numerous small and medium-sized cities and towns are perched on both sides of its trunk stream and main tributaries. Urban agglomerations in the Yangtze River Delta, Chengdu, Chongqing and the middle reach of the Yangtze River have been formed.

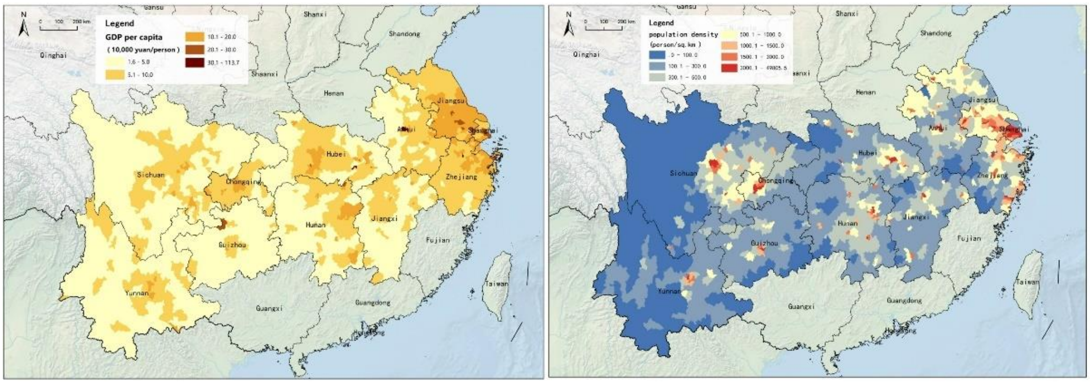


Figure 4-2 Distribution diagram of per capita GDP (left) and population density (right) of regions and counties in the Yangtze River Economic Belt in 2020

4.2 Climate change in the Yangtze River Basin

Pressures of climate change on the Yangtze River Basin are mainly heavy precipitations, droughts, rising temperatures and extreme weathers.

Heavy precipitation. Climate warming leads to more heavy precipitations. According to studies, there was an inconspicuous time change of the total rainfall in China, but the intensity of rainfall was increasing. Extreme precipitations (extremely little rain and extremely rainy) throughout the Yangtze River Basin and its tributaries were regular in terms of time change. On the whole, there was an increase in the change rate of heavy precipitations in the Yangtze River Basin since 1960[27].

Among 60 cities with serious waterlogging identified by the State Council in 2017, 36 are in the Yangtze River Basin. There were 166,000 geological disasters and hidden dangers in 11 provinces (cities) of along the Yangtze River Economic Belt in 2018, about 58% nationwide.

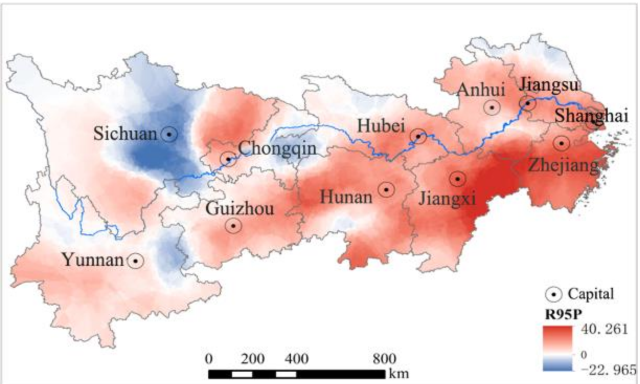


Figure 4-3 Change rates of extreme rainfalls in the Yangtze River Basin from 1960 to 2015

Rising temperature. Affected by global warming, the average temperature of Yangtze River Basin significantly increased from 1970 to 2014 (the temperature tendency rate was about 0.4℃/10A), and average temperatures in four seasons, in the coldest months and the hottest months soared[28].

From 1970 to 2015, the glacier area in the Yangtze River Basin has shrunk by 14.5%, the thickness of frozen soil in the source region of the Yangtze River, Yellow River and Lancang River has cut down by 5.6 cm per decade since 1984. In 2018[29], the number of summer hot days (temperature≥35℃) of more than 30 in the whole Basin involved about 220 million people in 40 cities. The rising rate of China's coastline is slightly higher than that of the global average, and it is predicted to rise by 0.145-0.2m by 2050.

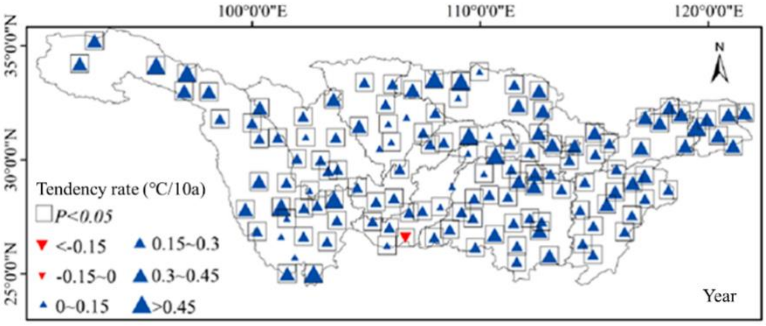


Figure 4-4 Spatial distribution of annual average temperature changes in the Yangtze River Basin from 1970 to 2014

Droughts. Climate change may lead to droughts in some areas of the Yangtze River Basin. Based on relevant studies, under the scenario of global warming of 1.5℃, the annual precipitation in the middle and lower reaches of the Yangtze River drops by 5% compared with that in 1986-2005; Under the scenario of global warming of 2.0℃, it drops by 3%[30]. The drought risk is mainly in the upper reaches. The year 2018 saw 862 forest fire points in the whole Basin. The number of fire points went down from 2010 to 2018[31].

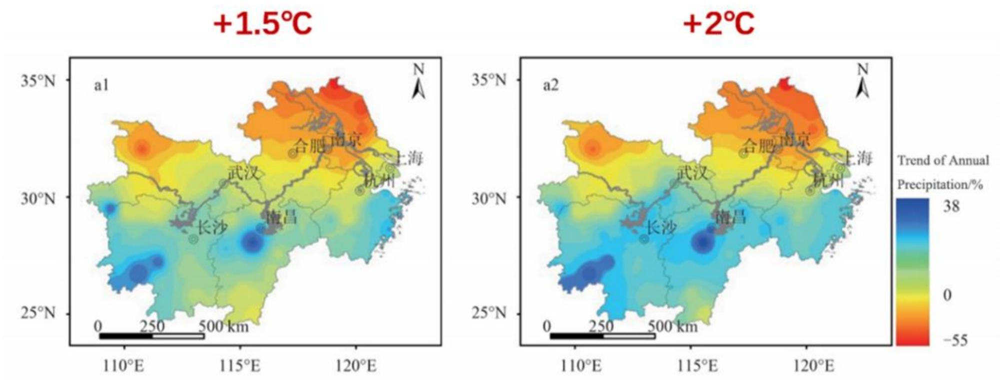


Figure 4-5 Prediction of annual precipitation changes in the middle and lower reaches of the Yangtze River under climate warming

Extreme weather. Relevant studies predict that under the goal of global warming of 1.5 ℃, extreme precipitations in the Yangtze River Basin once in 20 years and once in 50 years will rise by 10% and 9% from 1986 to 2005; Under the goal of global warming of 2.0 ℃, they will increase by 14% and 15%. Spatially, they increase generally in the middle and lower reaches, while drop in the upper reaches. Typhoons can be seen usually in the lower reaches of the Yangtze River. From 1949 to 2010, the average number of times affected by typhoons in cities in the Yangtze River Delta was 65.4[32] with an increasing trend in recent years. Jiangsu, Anhui, Hubei, Hunan and Yunnan saw serious low-temperature freezing disasters in China[33], and in recent years, the low-temperature freezing disasters and wind hail have shown a decreasing trend. In terms of overall losses caused by extreme weathers, casualties and house damage have decreased, but direct economic losses like infrastructure damage have continued growing.

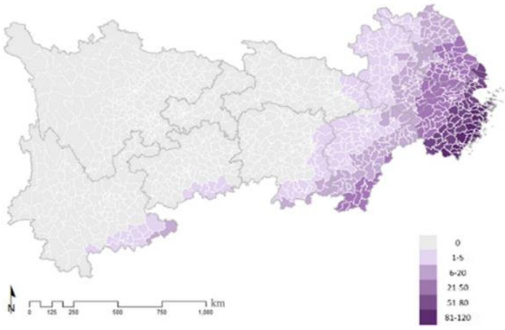


Figure 3-6 Impact frequency of typhoon disasters in the Yangtze River Basin from 1980 to 2016

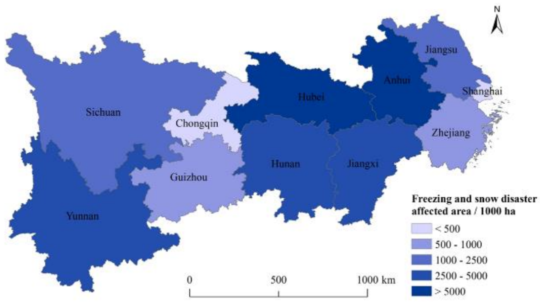


Figure 3-7 Spatial distribution of affected areas of low-temperature freezing disasters and snow disasters in the Yangtze River Basin from 2004 to 2020

Based on data of CMA Tropical cyclone data center

Sources: *China Statistical Yearbook, China Statistical Yearbook on Environment*

4.3 Risks caused by heavy precipitation

Increased flood risks in the trunk stream and main tributaries of the middle and lower reaches of the Yangtze River. Since 1840, catastrophic floods and severe floods in the Yangtze River Basin mainly occurred along the trunk stream of the middle and lower reaches. River basin flood occurred in the Yangtze River in 1998, five provinces in the middle and lower reaches were seriously affected. 334 counties (cities and districts) were affected, 2.2185 million houses collapsed and 1,526 people died[34]. In 2020, there occurred river basin floods in the Yangtze River, with five numbered floods in the trunk stream and the maximum inflow of the Three Gorges Reservoir since its establishment. A total of 378 rivers in the whole Basin saw floods exceeding the alarm water level, 156 rivers saw floods exceeding the guaranteed water level, and 51 rivers saw floods exceeding historical highs[35].From 2010 to 2020, the population of in the middle and lower reaches of the Yangtze River continued to move to large cities along the trunk stream of the Yangtze River and the main tributaries, causing higher flood risks in big cities.

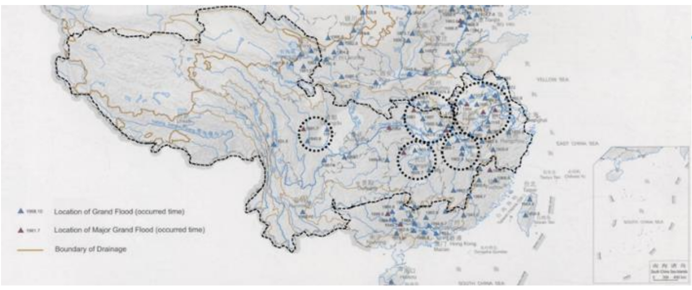


Figure 4-8 China's major flood points

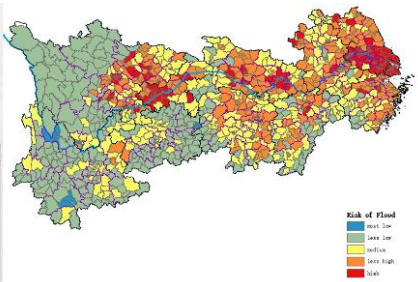


Figure 4-9 Distribution of flood risk levels in the Yangtze River Basin

Source: Shi Peijun, *Atlas of Natural Disaster System of China*, Science Press, 2003

Higher risks of waterlogging in large and medium-sized cities along the trunk stream and main tributaries. A total of 36 cities with serious waterlogging along the Yangtze River Basin determined by the State Council are mainly in Hubei (10), Hunan (9), Anhui (6) in the middle and lower reaches and Sichuan Basin (5) in the upper reach, most of which are cities along the trunk stream of the Yangtze River and main tributaries such as the Jialing River, the Han River, the Xiangjiang River and the Ganjiang River.

The total population of 36 cities is 93.37 million, an increase of 18.97 million from 2010 to 2020. Affected by heavy rainfalls, risks of waterlogging in major cities like Chengdu, Chongqing, Changsha, Hefei, Wuhan and Nanchang may further increase in the future.

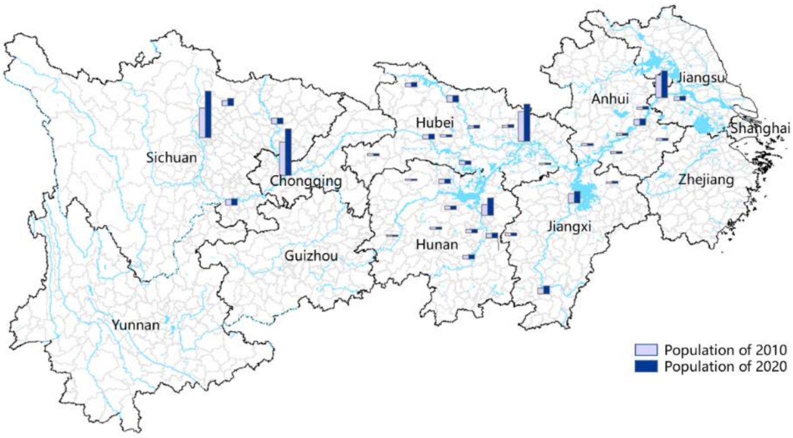


Figure 4-10 Changes of permanent resident population in 36 severely waterlogged cities in the Yangtze River Basin from 2010 to 2020

High risks of geological disasters in mountainous areas of Sichuan, Chongqing, Yunnan and Guizhou along the upper reach of the Yangtze River. Geological disasters in the Yangtze River Basin are mainly in mountain areas in west Sichuan, some areas in south Sichuan, northeast and southeast Chongqing, west and south Guizhou, the Xiaojiang River, the Lancang River and the Jinsha River in Yunnan. The overall population density in the above areas is not high, the population of some counties (autonomous regions, cities) in west Sichuan, northeast Chongqing, Southeast Chongqing, west Guizhou, south Guizhou, and west Yunnan has increased in recent years. Among them, the population of Dali City in west Yunnan and Dafang County in west Guizhou increased by more than 80,000, with further increasing risk of residential safety.

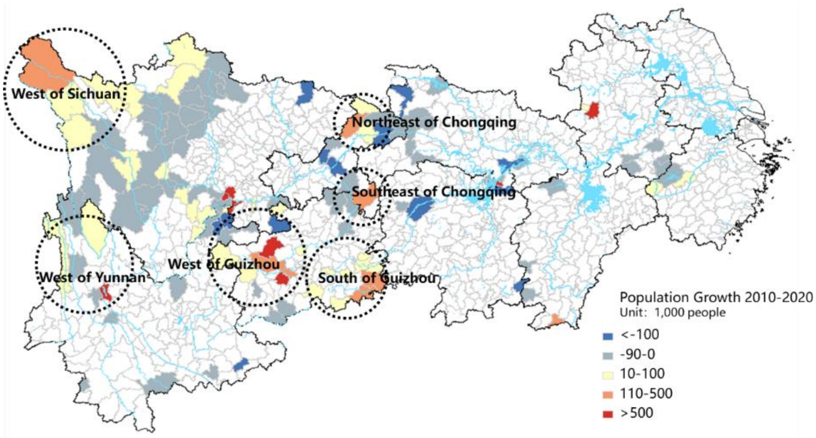


Figure 4-11 Change of permanent resident population in areas with frequent geological disasters in the Yangtze River Basin from 2010 to 2020

4.4 Impact of regional warming

Glacier retreat and frozen soil melting at the source of the Yangtze River threatening the ecosystem. Glacier retreat and snow line rise are mainly concentrated in Tanggula Mountain and

Bayankala Mountain, threatening the upstream ecological areas such as the source of the Yangtze River, the Yellow River and the Lancang River, which may lead to the less biodiversity and changed community structures and functions. Glacier retreat also affects the hydrological cycle of the Yangtze River Basin and trigger floods in the lower reach. About 40 glacial lake floods have occurred in the Qinghai Tibet Plateau since 1935, with the average glacier melt runoff in the Tuotuo River Basin at the source of the Yangtze River increased by 120.89% from 1960 to 2000[36].

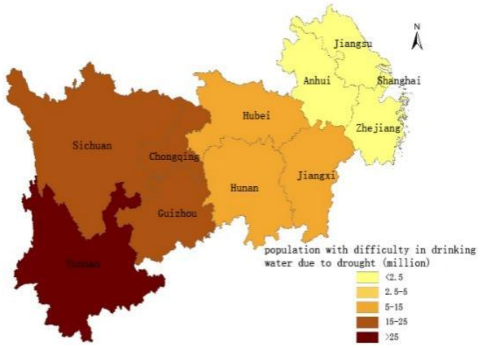
The depth of frozen soil in Qumalai, Zaduo, Chengduo, Maqin [37]. Frozen soil degradation greatly changes soil temperature and humidity, reduces the content of organic matter in the soil surface, leading to risks of vegetation degradation, reduced vegetation coverage and shortened plant heights, especially in alpine meadows and alpine swamp meadows.

More threat of heat waves in Chongqing along the upper reach, most places along the middle reach, metropolitan area in the south along the lower reach. In 2018, the number of summer hot days (temperature≥35℃) of more than 30 in the whole Basin involved the surrounding areas of Chongqing, most areas of Hubei, Hunan and Jiangxi in the middle reach, Anhui and south Zhejiang in the lower reach. If the global temperature rises from 1.5℃ to 2℃, the intensities of extreme heat waves in the Yangtze River Delta, the middle reach of the Yangtze River, Chengdu and Chongqing may be increased by 4.1 times[38]. The metropolitan areas in the Yangtze River Basin are densely populated and growing fast. From 2010 to 2020, the metropolitan areas in 11 provinces along the Yangtze River Economic Belt increased by 30 million, 91% of the total increment. In the future, Chongqing, Wuhan, Changsha, Nanchang and other metropolitan areas will face more severe high temperature and heat wave risk.

Coastal and lakeside areas along the lower reach threatened by sea-level rise. Coastal areas like Shanghai, Nantong and Zhoushan have low terrains and high risks of sea-level rise. Areas around the Hongze Lake, the Chaohu Lake and the Poyang Lake in the middle and lower reaches are low-lying, which may be easily submerged. Shanghai, Zhejiang province, Jiangsu province and Anhui province along the lower reach have dense and fast-growing population. The population in areas with high and higher risks of sea-level rise was 15.46 million in 2020, with a total increase of 550,000 from 2010 to 2020; The population in the medium risk area was 63.98 million in 2020, with a total increase of 8.64 million from 2010 to 2020. As the population further gathers, the threat posed by sea-level rise will further intensify.

4.5 Risks caused by droughts

Risks of water shortage in some areas in the middle and upper reaches. From 1981 to 2010, regions with annual drought days exceeding 50 mainly include Sichuan Basin, Panxi of Sichuan, the junction of Yunnan, Guizhou and Sichuan, southeast and south Yunnan, among others; Regions with annual drought days exceeding 40 include most parts of Yunnan, southeast Guizhou, north Hubei, north Hunan, south Jiangxi, among others[39]. Among these areas, water consumption in some places like Sichuan Basin, southeast Yunnan and south Jiangxi has seen continuous increase in recent years, and the ability to address droughts needs to be further improved.



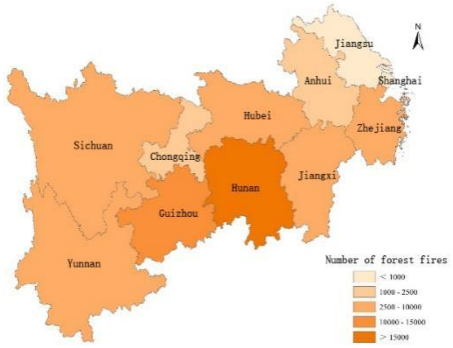


Figure 4-12
Spatial distribution of population with inaccessibility of drinking water due to droughts in the Yangtze River Basin from 2006 to 2020
(Source: *Bulletin of flood and drought disasters in China*)

Figure 4-13
Number of forest fires in the Yangtze River Basin from 2003 to 2020
(Source: *China Statistical Yearbook*)

High risks of forest fire in southern mountainous area of the upper and middle reaches. There exist a great many forest fire points in south Sichuan, south Yunnan, west Guizhou, south Hunan, south Jiangxi and north Hubei, where the overall population density is low, with increased population from 2010 to 2020 and possibly more residential safety risks. Since ecological protection in south Sichuan and south Yunnan is quite important, forest fires may threaten biodiversity there.

4.6 Risks caused by extreme weathers

More severe typhoon threats in coastal areas, tropical cyclones affecting parts of Yunnan. Typhoons mainly hit coastal areas of Shanghai, Jiangsu province and Zhejiang province in the lower reach of the Yangtze River, possibly submerging coastal areas. Shanghai has high levee level to resist storm surges with medium and low intensities, but typhoons in extreme weathers are still risky. Yunnan is partially hit by tropical cyclones landing on the South China Sea, reflected by disastrous weathers like strong wind and heavy rainfalls.

Affected agricultural production in the middle reach of the Yangtze River by low-temperature freezing disasters. Low-temperature freezing disasters and snow disasters mainly hit Hubei, Hunan and other areas along the middle reach, some areas in Yunnan, Guizhou along the lower reach, and some in Anhui along the lower reach. Since high-quality agricultural production areas of the Middle-lower Yangtze Plain are in areas with low-temperature freezing disaster risks, it is necessary to have better abilities of agriculture to deal with risks.

Wind hail-affected upper and middle reaches of the Yangtze River. Wind hails occur mostly in Chongqing, Yunnan and Guizhou, followed by Hunan and Jiangxi. Specifically, such areas include Dazhou City, Chongqing metropolitan area, Yibin City, Luzhou City, Bijie City, Liupanshui City, Qujing City along the upper reach in the border area between Sichuan and Chongqing, along with Changde City, Yueyang City, Yiyang City, Jiujiang City, Yichun City and Jingdezhen City along the middle reach. Among them, Chongqing, Changsha, Nanchang and other metropolitan areas are densely populated, with high risk of wind hail. Wind hail also hits high-quality agricultural areas in northeast Sichuan and north Hunan, triggering risks to agricultural production.

4.7 Spatial characteristics and risk analysis of major disasters

4.7.1 Spatial characteristics of major disasters

Floods and geological disasters caused by heavy rainfalls in the upper reach of the Yangtze River are the most prominent, with high frequencies, wide ranges and serious losses. Disasters like wind hails and low-temperature freezing disaster are also common in the area. Areas around the Sichuan Basin, including Longmen Mountain, Daba Mountain and Wushan Mountain, often see mountain torrents, landslides, debris flows and other geological disasters caused by heavy rainfalls; In the middle of Sichuan Basin, represented by Chengdu Plain, heat waves and urban waterlogging are the most common; In the Yunnan-Guizhou Plateau, mountain torrents, geological disasters, drought, low-temperature freezing disasters are common; And forest fires, mountain torrents and geological disasters often occur in Panxi of Sichuan and mountainous area of south Yunnan.

Middle reach of the Yangtze River is flood-affected, with frequent droughts and low-temperature freezing disasters. Jianghan Plain is often hit by floods, droughts and low-temperature freezing disasters; Areas along the Yangtze River in the middle reach are often hit by heat waves, urban waterlogging and river floods. Dongting Lake Plain is usually hit by floods, droughts and low-temperature freezing disasters; Floods and waterloggings often occur in Poyang Lake Plain; While Nanling area is often struck by forest fires, landslides and other geological disasters.

Coastal areas in the lower reach of the Yangtze River are greatly affected by sea-level rise and typhoons. The Yangtze River Estuary faces rising sea-level and typhoon storm surges; Areas along the Huaihe River mainly face floods and droughts; Areas along the lower reach are often hit by floods and typhoons; Mountainous areas in south Zhejiang are often hit by mountain torrents, geological disasters and typhoons.

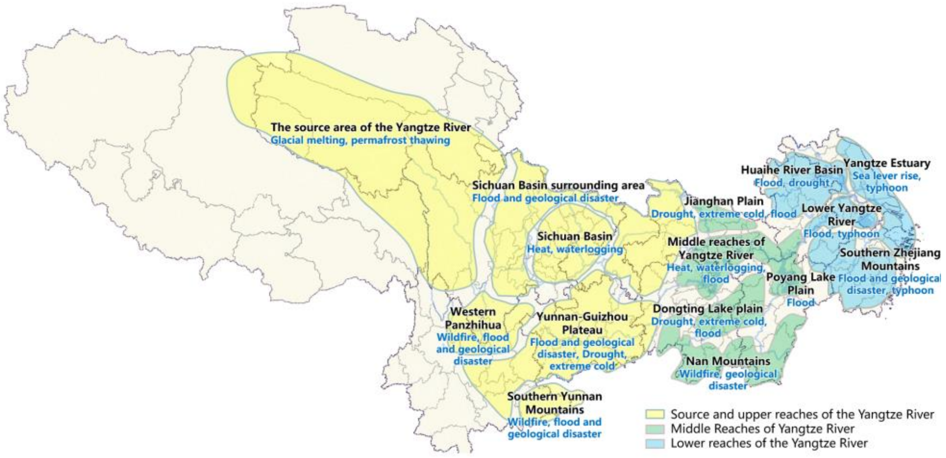


Figure 4-14 Sub-divisions of major disasters caused by climate change in the Yangtze River Basin

4.7.2 Risk analyses of key areas

Municipalities directly under the central government, provincial capital cities and their metropolitan areas have fast-growing population, with high disaster risks caused by climate change. Chengdu, Chongqing and Changsha are often hit by heat waves and urban waterlogging; Guiyang and

Wuhan are often hit by floods, droughts, low-temperature freezing disasters; Nanchang, Hefei and Nanjing often see floods; Shanghai and Hangzhou often see typhoons, while cities in south Zhejiang are struck by mountain torrents and geological disasters. The population of the above regions and counties in the metropolitan area has generally gone up by more than 100,000 in recent ten years.

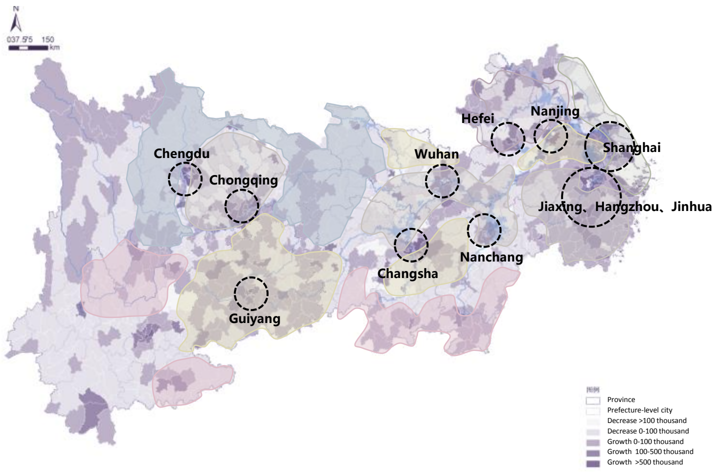


Figure 4-15 Superposition analysis of disaster zoning and population growth

Agricultural production areas in the north of the upper, middle and lower reaches are at high risks of floods, droughts, low-temperature freezing disasters. Agriculture is widely distributed in Sichuan Basin, Hanjiang plain, areas along the middle reach, Dongting Lake Plain, Poyang Lake Plain and Huaihe River Basin, which are affected by floods, droughts, low-temperature freezing disasters, with higher agricultural industry risks under climate change. Among them, Sichuan Basin along the upper reach is mainly hit by short-term floods; Jianghan Plain and Lianghu Plain along the middle reach are key rice producers in China, which may be hit by low-temperature freezing disasters during flower stage of early rice booting in late May, and low-lying floods and waterlogging in summer, along with droughts in spring and autumn are likely to reduce agricultural production. Areas along the lower reach can be hit by floods and typhoons.

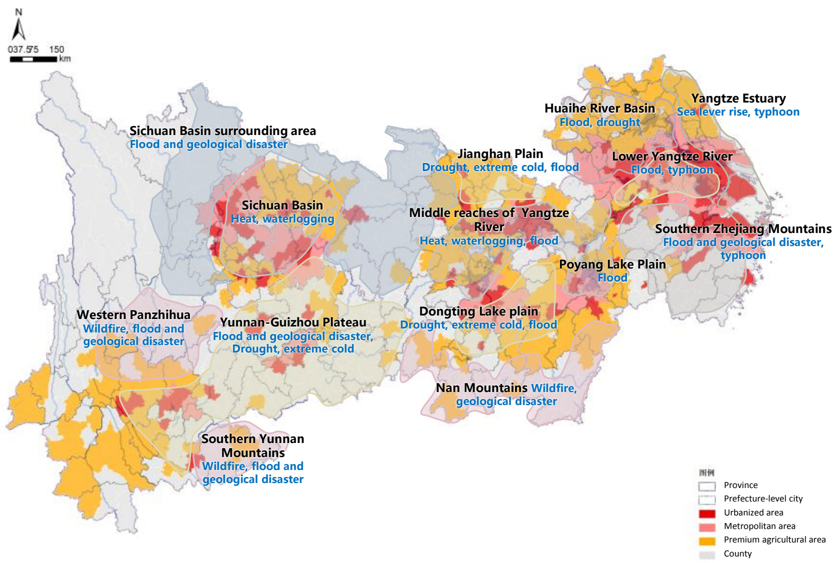


Figure 4-16 Disaster zoning and superposition of high-quality agricultural areas and urbanized areas

5. Resilience Strategies of the Yangtze River Basin in Response to Climate Change

The safety and resilience of urban and rural settlements along the Yangtze River basin is the key to cope with climate change and disaster risks at present, and it is necessary to improve long-term disaster prevention and adaptation capabilities, as well as to be more adequately prepared for short-term impacts of extreme weather. Specifically, engineering measures and nature-based solutions (NbS) should be integrated to form a comprehensive safety and resilience strategy through four aspects: ecological protection, spatial optimization, facility construction, and emergency management.

5.1 Strategies on improving resilience of the Yangtze River Basin

5.1.1 Strategies on ecological protection

Ecological protection strategy reduces risks from the source by reducing the frequency and intensity of disaster events and plays an important role in increasing carbon sinks and helping China achieve its "double carbon strategy".

Manage and control ecological function areas and nature reserves. Multiple important ecological function areas are distributed in the Yangtze River Basin, and the implementation of strict "Ecological Protection Red Line" system and "Compensation for Environmental Damage" system can maintain and improve the ecological level of important ecological function areas and nature reserves. The use of carbon sinks in nature reserves is encouraged to achieve carbon neutrality and carbon sinks in nature reserves is further explored to meet the relevant requirements and conditions of carbon emissions permit trading for carbon sink additionality and cooperation so as to improve the efficiency of ecological compensation.[40][41][42][43][44]

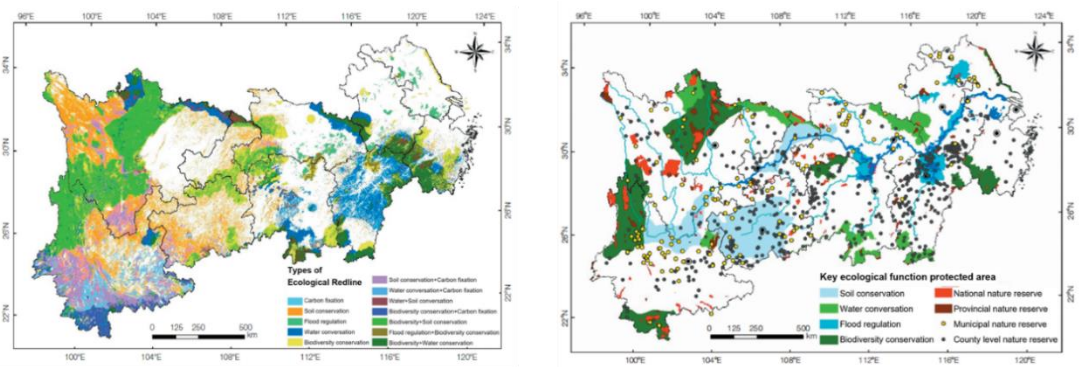


Figure 5-1 Spatial distribution of ecological protection red line of the Yangtze River Basin (left) as well as important ecological function areas and nature reserves (right)

Strengthen the comprehensive governance of water and soil conservation. The Yangtze River Basin is one of the most serious areas of water and soil loss in China, and climate change will create more pressure on water and soil loss. We should delineate and announce by law the areas with serious water and soil loss and fragile ecology as soon as possible, scientifically promote the comprehensive governance of the areas with serious water and soil loss, improve the monitoring service capacity and the problem detection, and strengthen the supervision of industrial soil and water conservation. Comprehensive governance can adopt a series of technical methods, including: intercepting and draining slope runoff and interflow, and storing a certain amount of water in the rainy season; returning farmland to forest and grass on steep slopes, and greening barren mountains and hills; promoting the projects of changing slopes into terraced fields, soil conservation tillage, and other soil conservation measures on slow slopes; reasonably deploying small intercepting and draining storage projects and field roads on slopes during planting forestry and fruit; configuring mutual cooperative engineering measures to control the development of channel erosion. In general, the foundation of scientific research on soil and water conservation in the Yangtze River Basin is still weak, and current research should focus on the critical areas such as soil and water mechanism and water-sand dynamics of the river basin under climate change. [45][46][47]

5.1.2 Strategies on spatial optimization

The land use and spatial layout of urban and rural settlements should not be based solely on development efficiency but should also fully consider the multiple objectives such as safety, livability, and ecology. The spatial optimization strategy can avoid disaster impact space and reduce disaster risks through scientific urban land site selection and achieve symbiosis with disasters and adaptation to disaster development by increasing disaster tolerant cushion space. In the selection of the spatial optimization strategies, emphasis should be laid on the selection and implementation of nature-based solutions.

Establish a strict disaster safety assessment system for site selection of a new city and a new district. The mainstream and major tributary areas of the Yangtze River are affected by river flood and thus they are closely related to urban site selection. Where involving off-site reconstruction after major earthquakes or geological disasters, the site selection of new cities and relocation sites should be subject to strict disaster safety assessment and full scientific appraisal, and safe sites should be used as far as possible to reduce disaster risks by using natural conditions and reduce site exposure from the source. The development of waterfront and coastal area must be based on scientific safe defense system planning and vertical site planning; The site selection and construction methods by filling rivers and lakes, cutting mountains and filling valleys should be strictly limited.

Control the population layout of dwelling and employment and land development intensity. Prevent excessively high population density from leading to expanded disaster losses. There are still a large number of residential areas in some provincial capitals in China where the population density is above 20,000 people/square kilometer and should continue to be reduced.

Implement the group layout model of urban space. Optimize and improve the layout of urban land use which has neglected safety and ecology in the rapid development, change the "big pie" layout to group layout, and introduce the large-scale green belt, green wedge and wind corridor, which can not only mitigate the heat wave and heavy precipitation disaster impact, but also provide more space for the city to avoid disasters. **“Returning land to river” to leave space for river.** The spatial organization of river waterfront areas is critical for long time scale. In respect of the natural and historical water systems the historical and flood discharge river channels occupied by industrial land and housing development shall be returned to the rivers for floodwater drainage and storage. At the same time, natural riparian land should be preserved as much as possible to provide strategic flexibility for future suitability initiatives and increase the safe resilience of the river basin. This concept, proposed by Netherlands, summarizes a solution with “retaining, storage, and drainage” strategy in wide practice to create a resilient buffer ability of the river channel against precipitation by modifying the river channel. The main technical measures for “returning land to river” include embankment moving backwards, restoration of river floodplains, and reduction of the riverbed.

Delineate disaster risk areas and leave disaster tolerance space. The cushion space for disaster tolerance is delineated according to the scope and intensity of disaster impact, especially in risk areas of torrential floods, earthquakes, landslides, mudslides and other mountain disasters; If necessary, the relocation project in high-risk areas is implemented, and the construction of disaster prevention engineering facilities is strengthened at population accumulation points; At the same time, the disaster monitoring and early warning as well as emergency response system of disaster risk areas and surrounding areas is perfected, and the evacuation of people in the risk areas is timely guided.

5.1.3 Strategies on facilities construction

Disaster defense system and infrastructure construction are the basic guarantee of urban safety resilience, and the long-standing inertia of local governments that emphasize development rather than safety and focus on over-ground rather than the underground must be changed fundamentally. In the construction of facilities, the engineering thinking of individual projects should be avoided. Instead, the emphasis should be placed on implementing the systemic disaster defense. Special attention should be paid to the construction of disaster defense system, sponge city resilience adaptation system, emergency supply guarantee system, and lifeline facility system for urban and rural settlements in the river basin.

Strengthen the construction of systematic and engineering disaster defense systems. On the basin scale, the reinforcement of embankments is organically combined with the construction of flood storage areas and the joint optimal scheduling of reservoirs in the main stream and tributaries of the Yangtze River to form a more complete "embankment + reservoirs + floodplain" comprehensive flood control system of the Yangtze River, so as to realize the prevention, blocking, evacuation, drainage and interception of floods; Great importance should be attached to the overall plan and coordination of flood control capacities of cities and basins so as to avoid the risk of urban disasters caused by different flood control standards in the basin. At the level of urban and rural settlements, the actively adaptive disaster prevention and mitigation measures combining with "blue, green, and gray" facilities should be taken as much as possible to form a comprehensive disaster prevention and mitigation strategy.

Promote the construction of sponge cities. Reduce emissions at source first, build green facilities, enhance the "resilience" of the city in response to climate change and storm disasters, and promote the formation of an ecological, safe, healthy, and sustainable urban water cycle system. According to the rainfall characteristics, flooding problems, and water resources problems of specific cities along the Yangtze River Basin, on the basis of full analysis and demonstration, reasonable targets are selected to carry out reasonable design by combining with local groundwater level, soil geology, meteorological characteristics and other factors. The combination of multiple measures such as "seepage, retention, storage, purification, use, and drainage" is selected flexibly to enhance the local rainwater absorption and storage capacity.[48][49][50]

Attach importance to the emergency supply guarantee system. The construction of regionalized and localized production, distribution, and consumption systems can greatly reduce the cost and carbon emissions of daily food and product consumption, and it is an important measure for carbon reduction and zero carbon in developed countries. The regionalized and localized supply system is also an important guarantee of urban safety resilience which enjoys obvious advantages in the case of long-period natural disasters, epidemic control, and so on. The renewable distributed energy is used for urban emergency supply security systems, which is not only green and low-carbon, but also improves the supply resilience in disasters.

Strengthen the construction of lifeline facilities. The toughness of telecom, medical treatment, rescue, and other lifeline systems can reduce the vulnerability of urban and rural settlements, guarantee that cities maintain basic operations during disasters, and support rapid recovery after disasters. In the terms of engineering measures, the flexible connection of the pipeline network system can be strengthened to cope with uneven settlement, earthquake, and other disasters. In aspect of network reliability enhancement, multi-source and multi-route connections should be built and a distributed layout should be adopted so as to improve supply reliability; Hierarchical prevention is used to cope with different levels of disaster scenarios, as well as adapt emergency security needs in case of disasters; Emergency supply security facilities should be configured in combination with emergency service facilities to enhance rescue security capabilities under catastrophes. In the planning of municipal pipeline network, the toughness measures for reliability enhancement should be finally determined through the reliability analysis of water supply nodes under multiple scenarios of medium, large, and giant earthquakes.

5.1.4 Strategies on emergency management

Improve cross-regional and cross-sectoral cooperation mechanisms in response to climate risks. We should implement the requirements of the *Yangtze River Protection Law* and promote the establishment of a cooperative governance mechanism in cities and towns at the upper and lower reaches as well as the left and right banks of the Yangtze River and its major tributaries; Joint scheduling and mutual assistance mechanisms should be established with a sub-basin as a unit.

Establish a monitoring information network for climate change and disaster assessment in the Yangtze River Basin. A monitoring and early warning system should be built with the basin as a unit, and a risk assessment and scenario simulation platform should be established to provide risk assessment and disaster avoidance guidance for government departments and residents in the basin. The integration of Radarsat remote sensing, artificial intelligence, cloud computing, 5G and other advanced information technologies with disaster monitoring business should be promoted to achieve collection, storage, sharing, and exchange of disaster risk information of floods, earthquakes, typhoons and other multi-hazards. The “Disaster Risk Map” information platform should be established to send warning information to relevant governments, social organizations, and residents at first time after formation of a disaster, reduce information difference, and help residents perform self-help and mutual assistance within golden 72 hours.

Promote the emergency response capabilities of local governments, grassroots organizations, and the public. The grassroots emergency response plans should be made according to local conditions and the emergency decision-making process should be shortened in the face of sudden disasters; The public emergency training should be strengthened by referencing the experience of Hong Kong's “wind-ball response mechanism”; The resilient communities should be established to enhance the autonomy of community emergency response.

5.2 Resilience strategies of regions along the upper, middle, and lower reaches

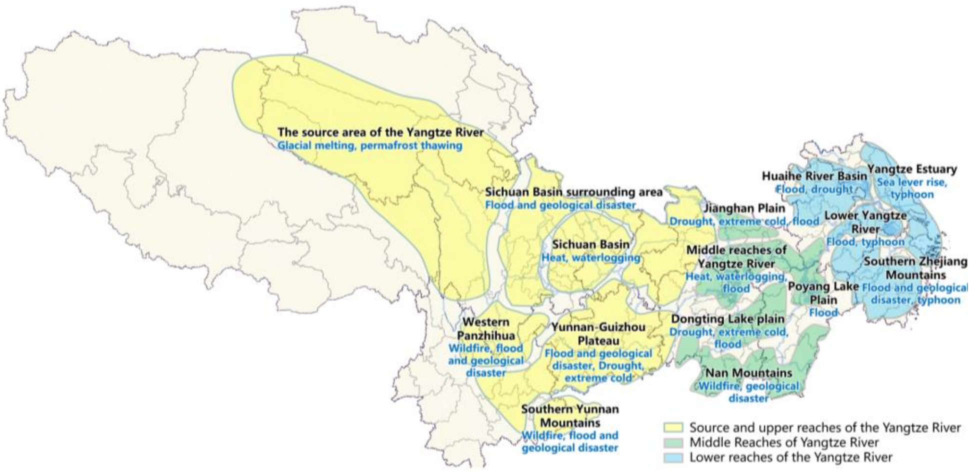


Figure 5-2 Secondary geographical zones and disaster feature map of regions along the upper, middle, and lower reaches of the Yangtze River Basin

5.2.1 Strategies on resilience of regions along the upper reaches

Headwater region of the Yangtze River: To cope with habitat changes brought about by melting of glaciers and permafrost, we should continue to strengthen biodiversity conservation and improve glacier monitoring mechanisms. We should continue carrying out ecological restoration in ecologically important areas such as SRYYL. Combining with the change of animal living and migration area, we should optimize and adjust the scope of the reserves and control wildlife migration passages. In the aspect of management method, we should establish a sound monitoring system and early warning mechanism for glacier ecosystem.

Middle part of the Sichuan Basin: To cope with high temperature and heat wave, the first step is to optimize the layout of urban ecological space, reserve space for urban ventilation corridors and upwind cooling sources, and use natural means to reduce the heat island effect, and the second step is to strengthen high temperature early warning and adjust high temperature working hours when available. To cope with urban waterlogging, restore natural lake water systems, control the urban blue and green line, and increase the space for flooding within the city, and the second step is to construct green infrastructures such as sponge cities, strengthen the construction of grey infrastructures such as drainage networks and flood pump stations, and renovate drainage and flood prevention facilities for flood-prone areas.

Circumference area of the Sichuan Basin: To cope with landslides, mudslides, and other geological disasters, the main measures are disaster early warning and staged opposition transfer, and engineering measures are adopted locally. Firstly, strengthen ecological protection, promote ecological returning farmland, and reduce the risk of geological disasters; Secondly, strengthen spatial optimization, and gradually promote relocation due to geological disaster; Thirdly, strengthen the construction of lifeline , optimize the location of municipal facilities, and reduce the vulnerability of facilities; Fourthly, improve management methods, issue timely rainstorm and disaster early warnings, and enhance the guarantee of emergency material reserve. Strengthen the comprehensive governance of the hydro-fluctuation belt of the Three Gorges Reservoir Area.

Yunnan-Guizhou Plateau: To cope with drought, emphasis should be put on enhancement of monitoring and reasonable construction of water conservancy facilities. Firstly, strengthen ecological protection, optimize vegetation structure, and reduce strong transpiration; Secondly, moderately adjust agricultural planting structure and layout; Thirdly, strengthen engineering measures, build farmland water conservancy facilities and emergency water sources, and implement artificial rainfall; Fourthly, improve management methods, establish dynamic analysis and early warning system, and construct water-saving society.

Southern mountainous regions of Yunnan and Sichuan: To cope with forest fire risks, we should integrate ecological, engineering and management measures to improve the capacity of forest fire prevention. Firstly, strengthen ecological measures by introducing fire-resistant tree species and building fire prevention belts; Secondly, take engineering measures to increase firefighting water points and forest firefighting channels, such as the establishment of aerial firefighting water points in Danba County, Sichuan; Thirdly, improve management methods, including the establishment of no-fire zones, intelligent monitoring, early warning systems, etc.

Mitigate the impact of the upstream hydropower development on ecological environment. We should strengthen the protection of rare and endemic fish nature reserves in the upper reaches of the

Yangtze River. The environmental impact assessment of hydropower development should be strengthened, and the needs of fish habitat and breeding should be met through measures such as enhancement and release, setting up fish passage, and ecological dispatching of reservoirs. We should also study the dismantling of small- and medium-sized hydropower stations in ecologically sensitive areas of rivers such as the Qingyi River and the Anning River to restore the natural state and habitat of rivers and implement ecological restoration in the river basins.

5.2.2 Strategy on resilience of regions along the middle reaches

Western mountainous regions of Hunan and Hubei: To cope with geological disasters, we should attach importance to source ecological governance and engineering measures and strengthen monitoring and forecasting. We should conserve soil and water through ecological afforestation, slope governance, and other source management methods, reserve disaster tolerance buffer space, and avoid disaster high-risk areas. We also need to construct interception ditches, slope protection and other geological disaster prevention and control projects, and collapse engineering treatment, improve monitoring and early warning and information release mechanism to guide people to move to avoid danger and protect life and property. In aspect of low temperature and freezing, we should improve the monitoring and early warning capability and promote the construction of facilities. We should also focus on scientific and technological innovation, and construct energy supply projects, improve the monitoring and early warning and information release mechanism to guide the people to avoid danger; improve the regional coordination and mutual assistance mechanism.

Jianghan-Dongting-Lake Plain and Poyang Plain: To cope with rainstorm and flood, we should adopt a systematic approach combining river and lake system protection linkage, embankment construction, pump station upgrading, river channel governance, ecological restoration, and sponge cities. Strict control of ecological space is carried out to maintain and increase the area and shoreline length of urban lakes and ensure the storage function; A water resource utilization system with river and lake cut-through and ecological storage is established to play a role in waterlogging prevention and control; strengthen the construction of source sponge facilities, build over-standard drainage channels and rainwater and sewage diversion transformation; carry out over-standard emergency research and make an over-standard storm waterlogging prevention and control plan, while enhancing public awareness of disaster prevention and avoidance and self-rescue ability through publicity and education. **To cope with high temperature and drought,** improve ventilation conditions. We should alleviate the heat island effect by improving local microclimate and improve ventilation conditions and create ventilation corridors.

Nanling region: We should focus on fire isolation, improve the rescue system, and cultivate public awareness of fire prevention. We should set fire prevention barrier, plant fire prevention trees, build and improve monitoring stations in forests and surrounding areas, and equip efficient monitoring equipment. In addition, we should also strengthen public education and propaganda to cultivate the awareness of fire prevention, improve monitoring and early warning and information release mechanism to guide people to avoid danger and improve forest fire rescue system. The construction of professional staff teams shall be strengthened and regional coordination and linkage mechanism shall be built.

5.2.3 Strategy on resilience of regions along the lower reaches

Stem stream of the Yangtze River and the great lakes region: We should establish a water and land ecological safety network, protect important natural spaces such as wetlands, mudflats and islands, build landward buffer zones along the river front, and restore the water and land ecological corridor hung over the River. To cope with the impact of flood in the plum-rain season, we should carry out the “returning dikes to water" to increase the flood storage space in the basin, and increase the flood discharge channels in the great lakes region through the linkage of rivers and lakes. The flood control standards of the Yangtze River main stream and the Great Lakes should be raised, and the construction of flood control levees and sluice pumps in the lower reaches of the Yangtze River should be strengthened in a green low-impact manner.

Estuary and coastal regions: To cope with the impact of rising sea level and surging typhoon storm, the structure of shoreline land use should be adjusted; a control system for zoning and segmentation of the coastal zone should be established. The restoration of wetland mudflats and the construction of key reserves and biological habitats should be strengthened by combining with the complexity and fragility of the ecosystem in the estuarine region; increase the resilient water storage area by using the space of coastal saline polder. In terms of facilities construction, we should strengthen the construction of coast defense engineering to cope with surging extreme storm and strengthen the construction of urban drainage projects. In aspect of emergency management, we should improve the safety early warning mechanism at the estuary and coastline.

Mountainous regions of southern Anhui and northern Zhejiang: We should establish a smooth water system network of the upper, middle, and lower reaches, and build a mutually complementary rainwater storage system consisting of rivers, lakes, reservoirs, and wetlands. We should restore the floodplain area of the natural water system and take the initiative to incorporate rainwater floods into the site. In terms of facilities construction, we should build the storage reservoirs in the upper reaches for staggered regulation of transit flood peaks, strengthen embankment construction in the middle reaches to ensure safety of flood drainage, and carry out river dredging and chokepoint clearance in the lower reaches to enhance the overflow capacity of the river. In aspect of ecological protection, we should strengthen the construction of mountainous woodlands and wetlands to enhance the function of soil and water conservation. In terms of emergency management, we should establish a joint prevention and control system mechanism of the upper, middle, and lower reaches.

Regions of the Huaihe River Basin: To cope with the impact of floods, we should strengthen the construction of flood storage and detention areas and waterfront buffer zones, build slow-slope river flood zones for improvement of the storage capacity of river channels, and improve regional engineering measures such as reservoir scheduling, water transfer of flood storage and detention areas, and cross-basin. To cope with the impact of drought, we should strengthen the use of water-saving facilities to improve the efficiency of agricultural irrigation and encourage the cultivation of water-saving agriculture. We should also improve the management of river catchment areas, and replenish water for large lakes and reservoirs.

6. Shorelines Utilization Problems and Optimization Strategies in the Lower Reaches of The Yangtze River

As an engine of economic development and a densely populated region in China, the lower reaches of the Yangtze River are facing the stage problem accumulated in the previous development, namely a sloppy development model with high resource consumption at the cost of the environment, one of the main manifestations of which is shoreline utilization. Therefore, it is crucial and beneficial for the downstream region to help the sustainable development of the basin around a higher quality of shoreline protection and utilization.

6.1 Analysis of the Current Situation of Shorelines Utilization

Based on the image data of Google Maps in 2010 and 2020, this study systematically sorted out the utilization situation of the shorelines of the mainstream of the Yangtze River from Nanjing to the estuary and the shorelines of the island, and drew it into drawings. According to the purpose, shorelines could be divided into two categories: artificial and natural, and six subcategories: living, port, industrial storage, other use, ecological protection, and natural reserved (see Table 6-1).

Table 6-1 Shorelines drawing method classification

Shorelines Classification		Drawing Method and Specific Explanation
Category	**Subcategory**	
Natural Shorelines	**Ecological Protection**	Including the relevant shorelines involved in the provincial and municipal ecological protection red line list
	Natural Reserved	The main ecology and agriculture function within 1 km of the land area
Artificial Shorelines	**Port**	Drawing according to the current ports in cities along the river and other data
	Industrial Storage	industrial parks and industrial enterprises within 1 km of the land area
	Living	The function of urban life within 1 km of the land area, including life and recreation shorelines, landscape shorelines, urban water intake shorelines, etc.
	Other Use	Including river crossings, municipal infrastructure, special-purpose shorelines, etc.

According to statistics, the total length of the Yangtze River shorelines below Nanjing in 2020 is about 2,020 km. Among them, the natural shorelines accounts for 61%; the artificial shorelines accounts for 39%. From the aspect of artificial shorelines, industrial storage shorelines accounts for 41%, port shorelines accounts for 32%, living shorelines accounts for 23%, and other use shorelines account for 4%. From 2010 to 2020, the length of the shorelines has increased by 42 km, of which the natural shorelines has decreased by 170 km, and the artificial shorelines has increased by 212 km.

Shorelines utilization is extensive, inefficient, and lack of overall arrangement. Nearly 60% of the main river shorelines has been developed as artificial shorelines. Among them, the length of the port shorelines account for 32% of the artificial shorelines. The utilization efficiency of the port shorelines varies greatly. Shanghai, the highest utilization efficiency area, is 3.5 times that of Nantong, the lowest utilization efficiency area. A large number of high-quality shorelines are occupied by enterprise wharves, which often leads to idle and waste of shorelines resources. The various utilization methods of some ports are disordered and cross-mixed, making it difficult to form economies of scale. In the lower reaches of the Yangtze River, there are 107 km of shipyard shorelines, of which the shorelines of low-level, small-scale, and scattered shipyards reaches about 30 km, accounting for 28% of all the shipyard shorelines.

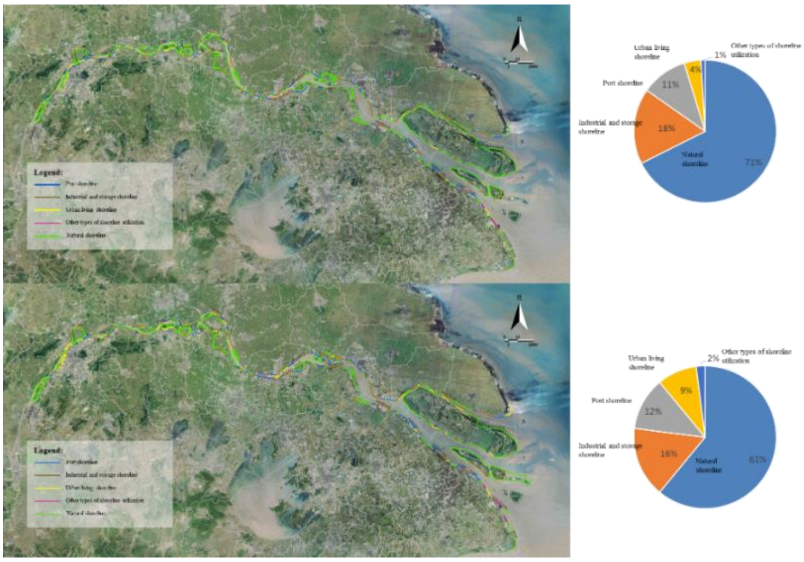


Figure 6-1 Classification and statistics of the lower reaches of the Yangtze River in 2010 (first half of the year) and 2020 (second half of the year)

The heavy chemical industry is concentrated in the areas along the river, which puts great pressure on energy saving and carbon reduction. There are 322 km of industrial storage shorelines in the lower reaches of the Yangtze River. Among them, the chemical enterprises shorelines is 72 km, including 13 provincial chemical parks (concentration areas) and several small scattered chemical parks in Jiangsu Province; the iron and steel enterprises shorelines is 28 km, dominated by large steel mills such as Baosteel, Nangang and Shagang, etc.; the thermal power plant shorelines is about 25 km, and 14 large power plants are distributed on both sides of the main river. Such a high-density distribution of heavy chemical and energy enterprises will bring about extremely high-intensity carbon emission pressures.

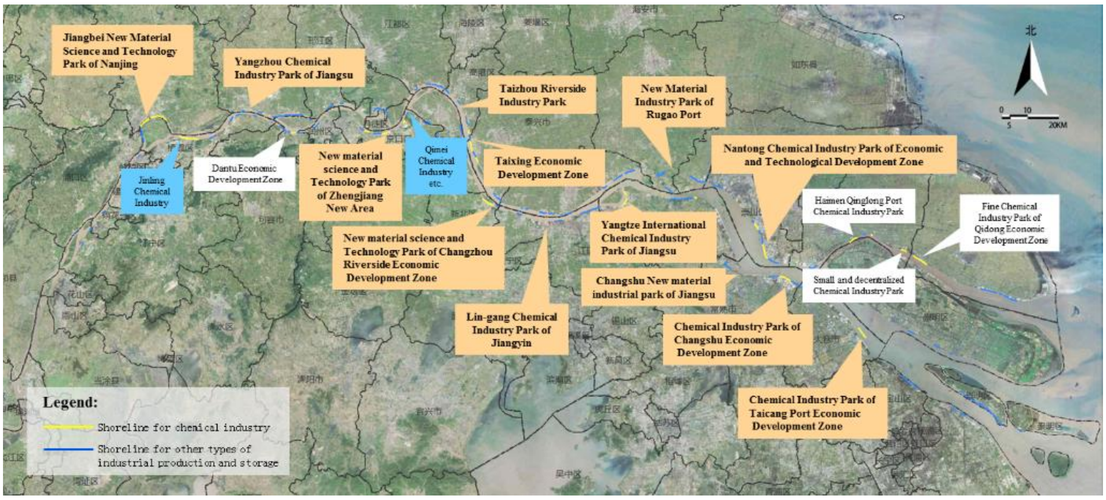


Figure 6-2 Distribution of chemical parks in the lower Yangtze River

"The chemical industry surrounds the river" leads to the hidden danger of production safety. The chemical industry parks in the lower reaches of the Yangtze River are located densely, with the nearest distance of only 7 km. The artificial bank has obvious water pollution zone, and the contaminant content of nitrogen and phosphorus in ports, urban bank zones, urban inland river estuaries and sea estuaries is generally higher than that of natural river sections and riverside wetlands. The risk of heavy metal pollution in the waters of the middle and lower reaches of the industrial shorelines is prominent, and the surface sediments and persistent organic pollutants in the waters adjacent to the shorelines tend to increase from upstream to downstream[51]. At the same time, 23% of environmental risk enterprises in the lower reaches of the Yangtze River are located within 5 km of drinking water sources[52], the water intakes and sewage outlets are staggered, and the situation of drinking water safety is grim.

High-intensity and continuous development along the river has compressed the water and land ecological space. From the changes in the past ten years, the natural shorelines has decreased by about 170 km, and the ratio of natural shorelines to artificial shorelines has changed from 7:3 in 2010 to 6:4 in 2020. Taking the Zhangjiagang-Changzhou section as an example, the artificial shorelines is more than 55 km long, which has concentrated the function of industrial, wharf, and urban living. High-intensity development has resulted in the upstream and downstream of important ecologically sensitive areas such as ecological protection red line, and drinking water sources being surrounded by chemical parks and ports. Large-scale artificial development has also encroached on tidal flats, wetlands, islands in the middle of the river, etc.

A Large number of extensive artificial constructions and activities affect biodiversity. Firstly, the "blockade of rivers and lakes" in the middle and lower reaches has led to the blocking of the ecosystem. Since the mid-to-late 1950s, a large number of lakes in the middle and lower reaches have been reclaimed into farmland, and the lakes have been isolated from the Yangtze River by control gates. At present, only the "two lakes" maintain natural connection with the Yangtze River, and the effective lake area for supporting fish in the Yangtze River has decreased by 76%[53]. Secondly, the high-strength artificial shorelines along the river greatly compresses the living environment of fish. Artificial shorelines, especially industrial and port shorelines, will seriously affect the living space of fish seedlings. At the same time, the terrain along the middle and lower reaches of the Yangtze River is relatively low. In order to prevent the scouring of the shorelines, it is often necessary to harden the embankment and cut the river channel to be straight, which also reduces the habitat or breeding ground of fish in the river channel to a certain extent.[20]。

The riverside public space serving the citizens needs to be increased. Although the living shorelines in the lower reaches of the Yangtze River has increased by 109 km during the decade of 2010-2020, and its growth rate ranks first among all artificial shorelines. However, the proportion of living shorelines is still low. In 2020, the proportion of living shorelines in artificial shorelines is only 23%, and they are concentrated in the main urban area of Nanjing, Zhenjiang urban area, the north side of Jiangyin urban area, Shanghai Baoshan Wusongkou, Qidong Yuantuojiao and so on. In some cities, the road from the urban area to the riverside is blocked, and the sight lines and viewing corridors leading to the river are blocked by dock cranes, storage yards and inefficient industrial plants. In Zhenjiang, Jingjiang, Yizheng and other places along the riverside suburbs, the land use is mixed, and it is still common for a large number of shorelines to be occupied by low-end functions such as small shipyards, bulk cargo terminals, and building materials enterprises.

The contradiction between the management department of water, shorelines, and land areas is prominent. Before the promulgation and implementation of the *Yangtze River Protection Law of the People's Republic of China*, the relevant management departments seldom coordinated management from the perspective of water and land coordination, resulting in problems such as the layout of non-port industries along the river, more shorelines being occupied and less used or not being used. At the same time, the development and management of the shorelines involves many departments such as development and reform, water conservancy, land, transportation, and environmental protection. In the management and control of local shorelines, the division of responsibilities of different departments is too detailed, and there is a lack of cross-departmental overall management at the river basin level[54]. A typical example is pollution control. Although the past "water and shore do not manage each other" phenomenon has been improved, the current contradiction of pollution discharge in water and land areas still exists.

The coordinated governance of cross-regional shorelines lacks overall planning. During the period of rapid economic development, the cities along the river focus on the "GDP championship", and take shorelines development as a weight for attracting investment and expanding the economic scale. There is a lack of overall planning, development and utilization of the shorelines between adjacent administrative entities. The high-intensity and continuous development along the river has led to the lack of ecological buffer space and facility layout space. Even during the period of great development, relatively complete berth types have been formed, and there are problems of repeated port construction, such as Taicang Port, Changshu Port and Zhangjiagang Port, which all belong to Suzhou City.

6.2 International Experience in Shorelines Utilization and Management

Adopt a more active and flexible shorelines utilization strategy to adapt to the new situation of flood control safety. Under the influence of frequent extreme climates and aggravation of major natural disasters around the world, ensuring the long-term security of shorelines and land areas has become a primary concern. Pay attention to the overall toughness of water and land areas, combine engineering methods with natural solutions, and "breathe and loosen" the downstream shorelines developed with high strength. Learning from the Netherlands' "Towards Adaptive Delta Management", which advocates "more space for rivers" and leaves blanks on land along rivers to provide strategic flexibility for future suitability initiatives.

Support the goal of green carbon reduction in the river basins through optimal utilization of shorelines and replacement. For a long time, the main body of carbon emission along the river has been high energy-consuming industries such as chemical industry, steel and power plants along the Yangtze River, as well as port shipping. Learning from the experience of the Rhine River and other places, the values should change from "controlling water with functions" to "guiding functions with water", promote the iterative upgrading of industrial structure, energy structure and transportation structure trough the extensive adjustment of the use of shorelines, and change from the previous high-carbon and high-pollution development model to a low-carbon and clean development mode.

Protect, improve and expand ecologically important areas and restore typical habitats of the Yangtze River. The lower reaches of the Yangtze River are a treasure trove of biodiversity. Today, downstream regions are under enormous pressure. The protection of biodiversity depends on our natural values. Learn the previous editions of the *Rhine Action Plan*, gradually restore suitable habitats for animals and plants, restore the natural appearance of the river, and protect a healthy biosphere with all ecosystems, a wide variety of flora and fauna, fertile soil, pure water and clean air[55].

Return the waterfront to life, and continuously improve the happiness and satisfaction of citizens. With the increase in income level, people pursue a higher quality of life. With the increase of leisure time, people allows to have more opportunities to contact nature, enhance their yearning and aesthetics for nature, and resonate with its future development[56]. Learning from the practices of Amsterdam and other cities, and change the shorelines from production functions to living functions to create waterfront spaces with local characteristics to meet the needs of citizens for leisure, recreation, sports and other aspects. With the renewal of shorelines and ports as catalysts, the overall function of the city will be upgraded.

6.3 Green, Low-carbon and Livelihood-oriented Shorelines Optimization Strategies

6.3.1 Promote the industrial function vacating and green transformation of the shorelines along the industrial belt.

Accelerate the relocation and transformation of heavy chemical industry, and the clearing of low-level, small-scale, and scattered industrial shorelines and shipyard shorelines. It is recommended to take safety, environmental protection, and energy consumption as preconditions, and guide the heavy chemical enterprises along the river in downstream areas with overloaded resources and environment transfer outside the river basin from the perspective of the layout of productivity in the river basin. For areas within 1 km of land depth and outside the centralized chemical park, it is necessary to speed up to guide enterprises to relocate and integrate into provincial chemical parks and chemical concentration areas. Promote the gradual withdrawal of low-level, small-scale, and scattered shipbuilding shorelines, and reduce the occupation of waterfront and fine shorelines resources. Combined with the national green energy transformation, reduce the scale of thermal power plants along the shorelines, and promote the transformation of high-polluting thermal power plants to new energy. In view of the relatively concentrated steel smelting shorelines, it is recommended to optimize, compress and carry out clean production.

Encourage the integration and merger of ports and promote the transformation and exit of inefficient terminals. In response to the extensive adjustment of energy structure and industrial structure in the future, predict the changing trend of transportation structure and flow direction in advance. In the future, it is necessary to speed up the promotion of “road to railway, road to waterway” for bulk materials, and to speed up the construction of an efficient and green and multimodal transport system consisting of large ports along the river, and the inland ports. Give play to the basic allocation role of the market, and promote the integration and merger between ports in the lower reaches of the Yangtze River. Coordinating port transportation functions, on the one hand, realizes the specialization of cargo development and promotes dislocation development; on the other hand, for the industrial supporting wharf with insufficient throughput and low utilization rate, it is necessary to guide the public transformation and open to the society.

Promote the "co-management of water and land" and carry out comprehensive management of pollution and consumption reduction. Learn from the “Three Lines and One List” system of the Ministry of Ecology and Environment to establish a zonal management and control of shorelines utilization and an access threshold mechanism for shorelines utilization, including the red line for natural shorelines protection, the upper limit for shorelines resource utilization, the control bottom line of environmental quality and economic benefits, and the negative list of shorelines utilization access. Improve the national and local, upstream and downstream, and left and right bank collaborative management of water and land areas.

6.3.2 Strengthen protection and restoration of typical aquatic and terrestrial habitat networks.

Restore animal and plant habitats. Improve the construction of river basin biodiversity survey and observation network in the basin to deal with climate and environmental changes. Fully study the habits and characteristics of protected organisms. Create a better living environment for organisms by means of shorelines near-natural form design and natural habitat reconstruction. Continue to improve and enrich the fish and bird biological reserves along the Yangtze River, speed up the improvement of the list of natural protected areas, and carry out boundary survey and demarcation to anchor the protection space.

Construct the riverside-land buffer zone and restore the water-land ecological corridor along the river. In order to effectively intercept and purify surface source pollution, it is recommended to build a landward buffer zone with a width of 0.5-1.0 km in the mainstream of the lower reaches of the Yangtze River[57]. Establish ecological isolation corridors between riverside towns and groups through vegetation restoration, water system connectivity, retreat of low-efficiency land, and environmental improvement., and restore ecological corridors between tributaries, lakes, mountains, other important land ecological spaces and the main stream of the Yangtze River.

Combine natural and engineered measures to create a safer resilient defense. On the one hand, strengthen the construction of disaster prevention and safety projects in a low-impact and greener way. Through the construction of green and ecological embankment and shorelines, the promotion of “gray, green, blue, and management” measures to improve urban drainage and water logging prevention capabilities, and advocate sponge cities. On the other hand, seek natural solutions. For example, in response to the frequent floods in the Great Lakes Basin, it is necessary to advocate “returning the polder to the water”, restore free water surface, increase the flood storage space in the basin, and increase the flood discharge channels in the Great Lakes Basin through the linkage of rivers and lakes.

6.3.3 Create a more dynamic waterfront space.

Actively create a people-oriented waterfront living space. Overall consideration should be given to the life cycle of the port and industry, to promote the transformation of production-oriented functions to comprehensive service-oriented functions. Make the waterfront public space connected, and to gradually become a multi-functional living shorelines. The shorelines plays a leading role in planning in the process of renewal, promotes the combination of government macro-guidance and market-oriented operation, and guides diversified investment and social participation, and achieve a win-win situation for all parties.

Pay attention to the cultural value of water, create a pleasant waterfront landscape, and continue the urban cultural. Fully respect the original spatial texture and pattern, protect industrial heritage, historical buildings, structures and elemental symbols, and closely integrate with subsequent functions. Shape a pleasant open space system and waterfront pedestrian environment by promoting the organic integration of work, residence, and leisure, and organizing diversified public activities. Taking the historical and cultural space of waterfront as the catalyst, cultural activities, festivals, etc. are implanted to drive the overall renewal of the port and the old industrial base.

Build leisure areas with suburban and wild scenery to improve the quality of urban and rural environments. Restore the natural and original ecological environment and become a space for urban people to enjoy the scenery and relax. Carry out ecological restoration, demolish land used for inefficient shipyards and building materials, and build a landscape with regional characteristics. Meanwhile combined with flood control embankments, county and township roads, etc., to build country greenways and post stations, connecting scenic spots and towns along the riverside.

Table 6-2 Cases of shorelines transformation in the lower Yangtze River in recent years

Case Classification	Transformation of Industrial Terminal shorelines		Ecological Restoration of Natural Shorelines
	Transformation to Natural Shorelines	Transformation to Living Shorelines	
Yangtze River Shorelines	Ecological restoration of Nantong's five mountain areas and riverfront; “Ten miles of spring river in Yangtze River”	Connection of "two rivers" in Shanghai; Yangpu Riverside, Xuhui Riverside, etc. in Shanghai; Renewal of	Lvshuiwan Wetland of Jiangbei New District in Nanjing; Longpao Wetland in Nanjing

	line in Qiaolin; Renovation of shipbuilding belt in the 12 polders of Yizheng	Xiaguan, Pukou Riverside in Nanjing; Construction of riverside park in Jiangyin	
Important Island	Ecological restoration of Changqing Sand Island in Rugao; Chongming East Beach and Jiuduansha Wetland; Remediation and restoration of dolphin reserve in Zhenjiang; Xinjizhou National Wetland Park in Nanjing; Ecological restoration of Shuangshan Island in Zhangjiang Port		

6.4 Continuing Concern for Sustainable Development in the Delta Region

6.4.1 The delta region is a high-value and highly sensitive area that is widely concerned in the world.

Under the background of climate change, the delta region is generally faced with the challenges of extreme climate problems such as sea level rise, flood erosion, and storm surge. For a long time, the excessive human activities in the delta region have caused the changes in hydrological conditions and natural land forms in the estuary area, resulting in a fragile ecological environment and serious threats to biodiversity. For example, the Netherlands, as a delta region where most of the country is formed by sedimentary basin systems, it is actively advocating the transition from “resistance to water” to “coexistence with water”[58], and gradually forming the consensus like “untouched estuaries and deltas will not be touched if there is a choice”[59].

All the countries are actively exploring the methods of rational development and utilization of the delta region. The delta region is a highly dense area in terms of both population and economy, and it is also an important carrier of urban space expansion and economic growth. On the one hand, the unique water system, wetlands, and polder landscape are conducive to carrying out extensive engineering technology, agriculture, and aquatic city experiments to shape the unique delta landscape. For example, in the 1970s, the Netherlands gave birth to a new generation of “garden cities” represented by Almere and Lelystad in the polder area. On the other hand, in the context of globalization, the shipping function of international ports has always been one of the focuses of the estuary area. For example, the Port of Rotterdam in the Netherlands has consolidated its central position in international shipping by continuously expanding to the estuary area.

Column 6-1: History of the "seaward expansion" phase of the Port of Rotterdam in the Dutch Delta

The Port of Rotterdam is located on the North Sea coast and at the confluence of the Rhine River and Nieuwe Maas. By the 19th century, the Port of Rotterdam was increasingly important in terms of transit trade, and the construction of Wallhamn (the orange part of the picture) made it become one of the largest dredging ports in the world. The Port of Rotterdam was rebuilt in the period of 1946–1960 (the blue and purple part of the picture). An expansion took place in the period of 1960–1970 (the light blue part), and a huge area in the further west was developed as the "Gateway to Europe" (the lake blue part of the picture), making the Port of Rotterdam become the world's largest port at that time. In 1970, the Port of Rotterdam launched the Maasvlakte, and created a man-made port at the sea-river interface of the delta. The second phase started in 2008 and put into service in 2013. Maasvlakte had a total area of 1000 hectares, which would enable the Port of Rotterdam to expand the current scope by 20% and increase the container throughput by three times.

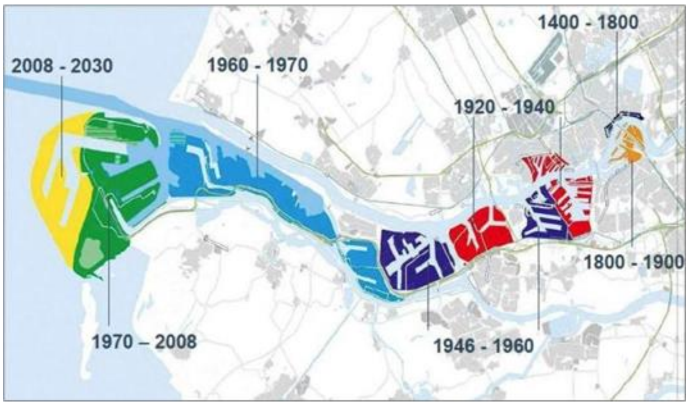


Figure 6-3 History of Seaward Expansion of Rotterdam

Data source: https://www.portofrotterdam.com/en

6.4.2 High complexity of the sustainable development of the Yangtze Estuary Area

Firstly, the evolutionary trend of the hydro-geomorphology of the delta is a fundamental factor of the primary consideration for long-term development. From the viewpoint of historical evolution, the development model of the Yangtze Estuary for 2,000 years can be summarized that "the beach in the south bank spreads out, the sand island in the north bank merges with the bank, the estuary is narrowed, the river channel takes shape, and the river trough is deepened"[60]. From the perspective of a century scale, the hydrological and geomorphological evolution of the estuary area is strongly influenced by climate change and artificial engineering construction, leading to a decrease in runoff and sediment runoff in the Yangtze River Estuary and a slowdown in the overall siltation trend[61].Therefore, continuous monitoring of hydro-geomorphology needs to be enhanced to allow for more refined simulation and prediction of future development trends.

Secondly, from the perspective of response to natural disasters under the influence of climate change, the Yangtze Estuary Area is vulnerable to the influence of rising sea level, typhoons, and surging storm, and thus it is a region with high vulnerability and exposure. The rate of rising sea level in the Yangtze Estuary Area is slightly higher than the global average, and the frequency and intensity of surging typhoon storm faced in recent years also show an increasing trend[62]. Under this superimposed influence, the conservation and development of the Yangtze Estuary Area needs to dynamically adjust the land use structure of the coastal zone and make resilient flood control strategies in response to natural disasters.

Thirdly, the Yangtze River Estuary Area, as a channel for material exchange between land and sea, has rich biodiversity and ecological specialties. The Yangtze River Estuary is not only a spawning ground, a feeding ground, a nursing ground, and a migration channel for fish, but also a habitat for more than 200 species of migratory birds, and an important water source for the city. In order to consolidate and enhance biodiversity, it is also necessary to strengthen the construction of targeted multi-category ecological reserves and strictly control the impact of human activities such as fishing, water conservancy construction, and shipping.

Fourthly, the Yangtze River Estuary Area needs to meet the busy shipping pressure and international large port construction needs under the premise of overall planning of ecological protection. The trend of large-scale international shipping vessels has led to the continuous extension of port construction to deep-water shorelines. In the process of port development, firstly, the ecological damage and pollution problems that may be brought about should be assessed and corresponding ecological compensation and restoration measures should be carried out. Secondly, port construction needs to be comprehensively intelligent and green and low-carbon to improve the competitiveness of ports and the ability to adapt to climate change.

6.4.3 Construction of an ecological green beach at the Yangtze River Estuary Area to reserve strategic space for the future

On the one hand, attention should be paid to the enhancement of the security and resilience capacity of the Yangtze River Estuary Area. Combining the simulation of climate change impacts, engineering measures should be combined with natural means to build a green barrier for ecological flood control. Key wetland mudflat protection zones and biological habitat protection zones are established around the unique biodiversity protection requirements of the delta. On the other hand, the ecological green beach of the Yangtze Estuary should be built to reserve a flexible space for long-term sustainable development. Under the premise of integrating various factors, the sediment resources from the dredging of the Yangtze River waterway should be used rationally, and the ecological land in the estuary area should be increased through measures such as promoting siltation and enclosure to reserve national strategic space for long-term development, in order to cope with the uncertainties of the external environment such as international shipping, energy revolution, and scientific and technological agriculture in the future.

7. Social Equity and Gender Issues in the Yangtze River Basin

7.1 Situation analysis and problem identification

Gender and social equity are key issues in global river basin governance today. On the one hand, vulnerable groups such as women, children, old people, and the poor are significantly less able to cope with disasters caused by climate change and undertake significantly greater risks and suffer greater physical and mental health damage from disasters such as food shortage, high temperature, and floods caused by climate change[63]. 80% of people displaced by climate-related disasters and changes around the world are women and girls [64].On the other hand, vulnerable groups have low awareness and opportunities to participate in river basin governance and policy decisions. Among all adverse factors affecting gender and social equity, the impact of poverty is particularly critical, making rural areas in developing countries the most prominent in terms of gender equity and social equity issues[65].

Significant urban-rural and regional gaps and the disaster resist capacity are key factors affecting gender and social equity issues in the basin. The former national poor counties within the Yangtze River Basin (2014) are mainly distributed in the upper and middle reaches of the basin. The resilience of poor rural areas is generally low, leading to a higher vulnerability to disasters brought by climate change than that in towns. There are a great number of reasons, including the low standards of house and infrastructure, the high number of hidden hazards of environmental disasters such as mountainous areas, the high sensitivity of agriculture, forestry, animal husbandry and fishery industries, and the weak disaster resilience and relief at the grassroots level. According to statistics from the Ministry of Emergency Management, more than 70% of meteorological disasters in China occur in rural areas, especially in the western region; the phenomena of disaster chains, multiple disasters, and disaster encounters in rural areas show an increasing trend.

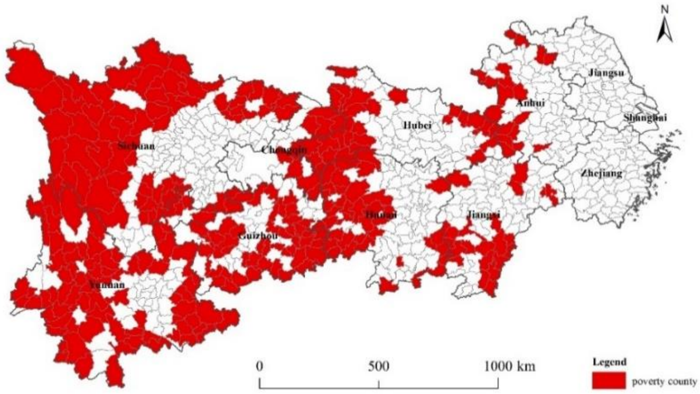


Figure 7-1 Distribution of national-level poor counties in the Yangtze River Basin
(Data source: List of 832 Poor Counties of The National Rural Revitalization Administration)[1]

Population outflow leads to higher concentration and deeper poverty of women, old people, children, and the like in rural areas. According to data from the census, there is a general outflow of young people in rural areas in the Yangtze River Basin, and the proportion of old people in rural areas is significantly higher than that in urban areas. Taking Sichuan Province for example, the people at 60 years old or above accounted for 27.32% in 2020, which was 9.89 percentage points more than that in urban areas. There are more than 700,000 left-behind children in Jiangxi, Sichuan, Guizhou, Anhui, and other provinces along the Yangtze River. The total number of left-behind women in rural China has tended to decrease in recent years as the female labor force has become more mobile; however, the data from provinces show that women still take a high percentage of the population in rural areas, mainly including left-behind mothers and girls. In relatively poor areas and rural areas, a large number of women, old people and children left behind are the most vulnerable population in response to climate change risks because they are responsible for both agricultural and sideline production and taking care of the family, are far from social support systems, and lack social participation, security and health services, and flexible livelihood opportunities. The limited disaster records of the Yangtze River Basin area demonstrate that children, old people, and women in rural areas suffer from greater mental and physical health impacts after disasters[66].

[1] China has been able to lift all 832 poor counties out of poverty by the end of 2020 through poverty alleviation efforts in recent years; however, the economic level in these areas is still relatively low.

Guaranteeing the resilient security and livelihoods of these populations is the key point for sustainable management of the Yangtze River Basin.

7.2 Strategies on social equity and gender in river basin governance

(1) Formulate and monitor the implementation of gender-sensitive and socially inclusive basin climate strategic plan so that gender and social inclusion objectives become a priority consideration for all fields in the planning, implementation, and assessment phases of policies and projects. In this process, it is critical to review and amend the relevant legal frameworks and policies for river basin resources, environment, and industry. At the same time, multidimensional performance indicators sensitive to gender and social equity for sustainable development of river basins should be developed through participatory methods to assess social equity impacts of various policies. Indicators measuring environment and equity can be aggregated for a comprehensive assessment. Finally, the availability of gender and population division data needs to be particularly ensured among social and community information and disaster impact statistics in each field.

(2) Focusing on poor and backward areas and rediscover the value of social contributions of people left behind in villages: We should pay attention to the local planning, implementation and management of policies related to relatively poor areas and villages, and continuously innovate rural management modes. In combination with the new urbanization and rural revitalization strategies, a variety of support policies are used to raise the economic incomes of women and old people left behind, enhance the capacity of climate-adapted modern agriculture, and protect the rural ecological environment and biodiversity. It is necessary to develop a long-term system of health services for people left behind under climate stress, strengthen talent training, professional studies and incentives, and establish rural culture, health, education, activity, psychology and legal service places. Enterprises and private capitals are encouraged to jointly build special disaster response spaces for women and other marginalized populations. To meet the needs of women, old people and children, we should update community-based information-based medical and disaster management systems and coordinate cross-sector and cross-system service guarantee capabilities. We should also raise the guaranteed standards of new-type pension insurance and increase funding for accidental injury risk prevention work for children and women left behind in rural areas.

Column 7-1: Koshi Basin Initiative fully integrated gender and social equity issues into assessment through data system

From 2012 to 2022, Koshi Basin Initiative, sponsored and carried out by the International Centre for Integrated Mountain Development (ICIMOD), was dedicated to sustainable development and cross-border governance of the river basin which flows through China, Nepal, and India. With gender equality as a prerequisite for sustainable development, the project believed that women and vulnerable people were key transformative power in building strong and resilient communities in the Koshi Basin, and therefore gender and equity issues were considered at first in the perspective long-term plan, issue assessment, policy selection, and program implementation phases of the river basin. To support evidence-based decision-making and enhance communication, the project established a long-term public information system for the Koshi Basin, which contained a gender data subsystem. The system integrated the existing knowledge on gender inequalities in access to and control resources and emerging gender nuances related to water, food and energy insecurity. Through detailed analysis of gender data, the research team made several work suggestions on gender equality in the river basin. [67]

(3) Promote gender equity in the river basin governance decision-making process: Gender perspective should be included in the mainstream of the structures of river basin governance institutions and relevant departments; women are empowered at all administrative levels to equally participate in and lead river basin governance decision-making and climate change-related policies. The abilities of technical staff are trained to integrate gender issues into work plans and project implementation, and gender and public participation methods are created and carried out to raise awareness. The ability building is conducted in grassroots women organizations, children and older people organizations, non-governmental organization to assist their participation in the river basin governance process and encourage women in organizations to develop and implement their own climate actions. The ability building is done in central and local governments to enable them to include gender perspectives in their own analytical work and planning work. Gender alliances and mechanisms are established between climate change related organizations and institutions. Gender and social equity participation is used as an opportunity to expand society-wide discussion and cooperation in response to climate change. We should also focus on the gender equality perspective of male groups and increase the active participation of men in equitable and inclusive actions.

Column 7-2: The Nile Basin Initiative focused on poverty and gender equality and developed a range of policy measures

The World Bank took actions through CIWA and carried out the Nile Basin Initiative (NBI) to build the capacity for cross-boundary issues in Integrated Water Resources Management (IWRM). At the beginning of the project, NBI formulated a formal gender mainstreaming policy and strategy at first. In the ancillary action plan, 0.14% of the social development budget was set aside for gender-related activities, and the allocation and implementation of funds was tracked to assess the actual effect of projects on improving women's lives; At the same time, the formulation of gender-sensitive budgeting was attempted in some projects. A project to build the ability of national controlling authority staff was developed and women were encouraged to actively participate in internship programs at regional river basin management agencies, which was highly successful. The work experience of NBI points out that: gender equality training should be ongoing and continuously refreshed, as well as specific and suitable for operational activities, clearly demonstrating the relevance of gender and the priorities of each institution; At the same time, schemes and projects must allocate sufficient resources to carrying out gender analysis and promoting gender-responsive planning.[68]

(4) Strengthen river basin management mechanisms and funding guarantees for gender and social equity: We should review and update management methods and incentives for basin-related aquatic and land resource systems, ecosystems, and economic systems. River basin planning and management process should be reviewed from the perspective of gender and social inclusion and the results should be used as an important source of information for evidence-based policy and social advocacy of each relevant department so as to focus on the experience, priorities, and needs of vulnerable groups in the design of research and actions. Pilot study work should be conducted suitably to raise awareness of proactive participatory and inclusive risk management and sustainable planning at the local level. Gender and social equity audit should be done for social security-based financial compensation and incentive plans. The degree of key institutions' priorities for gender issues in their daily work and the reflection in their budgets should be assessed, and gender perspectives should be included in budgeting, auditing and financing. Equal participation and profitable opportunities for men and women should be created in the financing process of climate related actions.

8. Policy Recommendations on River Basin Governance

(1) Act now on climate change and build a "watershed community of life". China should organize and disseminate a thorough understanding of the changes in its large river basins – because of human interventions and climate change – now and in future decades. This includes advocate of a "watershed community of life", setting of new monitoring focused on the impacts of anthropogenic stresses and climate change, carrying out a risk assessment focused on a long-term basis (2050-2100), and preparing for more than one scenario.

(2) Improve security in view of extreme events and restore ecosystems. Climate change will affect the number and intensity of extreme events, but the extent to which is uncertain. Pro-active strengthening is needed of protection against a wide range of natural hazards, including floods, droughts, wildfires, and landslides. Part of this strengthening can be obtained by applying nature-based solutions such as "room for rivers" action to restore river and lake systems, and thus rebalancing natural and man-made elements of the river basin landscape. A shift to regenerative agriculture can bolster lands resilience, while renewables should be sited on lands less suitable for other uses.

(3) Build resilient urban and rural settlements to improve Security and Resilience. By making the right choices in the spatial layout of river basins, exposure and vulnerability to extreme events can be reduced, disaster risk is reduced at the beginning, and resilience of urban and rural settlements – including vulnerable groups – is increased. Using spatial layout wisely means taking the layout of the natural environment including rivers and streams – the blue-green space – as a starting point for spatial planning and combining classical engineering with nature-based solutions. Accelerate the construction of "sponge cities", a successful experience from China; advocate the group layout of cities to reduce the population density and land development intensity of built-up areas; pay attention to the coordination of urban and watershed flood control capacity to avoid disaster risks caused by different flood control standards.

(4) Develop comprehensive planning for key industrial port cities in a low-carbon era, selecting major tributaries and deltas for pilot exploration. The economic planning horizon to 2050 will be heavily influenced by the global transition to a low-carbon future. This will particularly affect key industrial port cities. Ports will have to transform in response to the transition of handling large volumes of fossil fuels to facilitating regional growth based on renewable energy. Carbon-neutral and resilient infrastructure will require careful planning and smart investments. Many large port cities are flood-prone, necessitating foresight to address the risks and uncertainties of climate change. Thus, the spatial layout of ports will change, and so will shipping, industry, and the urban environment. Given the longevity of the hardware involved, the uncertainty of regional climate projections and the complexity of changing port city economies, it is urgent to start planning and consulting now. It is proposed to select major tributaries with high value and sensitivity, and the Yangtze River Delta region to carry out pilot exploration of comprehensive planning.

(5) Strengthen integrated water and land management of the basin. Focus on shorelines. In particular, as a means to reduce risks and increase basin-wide resilience, promote transformation of selected downstream industrial port shorelines into an ecological and living shorelines. Focus on integrated water and land management, treating river shorelines as long-term resource management, and to ensure future strategic flexibility, shorelines should be maintained in their natural state as much as possible. Through the optimal use of shorelines and their replacement, we can support the goal of green carbon reduction in the river basin; we should pay attention to the cultural value of water and promote shoreline renewal and public space construction. At the national level, the "three lines and one list" of shoreline management should be formulated as soon as possible and the implementation should be monitored.

(6) Strengthen response capacities to improve the emergency response capabilities of local governments and the public. An important element of resilience is being able to respond quickly and adequately to emergencies. Adaptation to the consequences of climate change calls for investments in monitoring and early warning systems, and in the response capacities of local governments and the public. In addition to these investments in disaster risk management, innovative insurance instruments will increase people's resilience to extreme events. The Government should pay more attention to gender equality and social equity issues in disaster-prone areas and among disaster-prone people; and may well need to plan for flooding and drought scenarios simultaneously.

9. Programmatic Recommendations

In the scoping study for this SPS – Managing River Areas in Times of Climate Change – eight high-level guiding principles were introduced as a framework to both select river cases for in-depth analysis by this SPS and structure Chinese or CCICED input for the 2023 UN Water Decade Conference. These principles address the system approach – from the headwaters to the coastal seas, a long-term perspective, the engagement of all relevant stakeholders, the inclusion of all stressors, and the need to strengthen and continue innovation. As stressed in the scoping study, these principles will play out differently in each individual river area. We will learn more about these principles, and possibly redefine them as we learn from the analyses of cases, globally.

The five high-level guiding principles are defined as five 'themes of annual research' for the successive years of the 5-year programme. Important aspects to be addressed throughout the 5-year program are decarbonization and green development (including ecosystem and wetland restoration, and keeping river banks free from urban and industrial development), sustainable development in the delta region, biodiversity conservation, systematic governance of river pollution, shipping modernization, sediment flows (including the link with biodiversity and ecology, and the link with hydropower), planning for both flood and drought scenarios driven by increased glacier melt, balancing adaptation and mitigation, and balancing engineering and nature-based solutions. In addition, a possible focus of research on these themes is presented as well (Table 9-1).

Table 9-1 Proposal for research foci in 5 subsequent years based on the 5 high-level guiding principles presented in the scoping study Managing River Areas in Times of Climate Change

Research year	Principle/Theme of annual research	Possible research focus[#]
2022-2023	Make good on your responsibility stretching from the headwaters to the coastal seas	The mechanism for regional collaboration
2023-2024	Adopt a 100-year perspective and plan your steps	A proactive approach to adapt to projected climate change and increase resilience
2024-2025	Engage everybody who can contribute and develop a shared vision	The organization of collaboration in multi-subjects' interests
2025-2026	Adapt to climate change and other principal river stressors in every aspect of the management of river areas	Dealing with the uncertainty of climate change and other stressors, and of disasters
2026-2027	Continue to strengthen and innovate	Management approaches, knowledge programs, policy tools and forward-looking financing

		mechanisms, etc.; international exchanges

The order over the years should be fine-tuned in view of opportunities to align with international events

The analysis and design focus questions for working visits should consider feedbacks between policies, such as the impact of decarbonization (moving away from fossil fuels) on land and water resources (such as water for irrigation of biofuel crops), and not address issues in isolation. Also, in designing future management of river basins, one should always consider more than one scenario.

The proposed 5-year program should take advantage of special occasions in each given year, such as the UN Water Decade Conference in early 2023, as they emerge. The work programme each year would see：

- A stock-taking paper
- A work conference, with field visits if possible (otherwise, good video reports)
- A report to the AGM and the wider community reporting on lessons drawn and, importantly, identifying areas for development

Along this line, it is proposed to co-organize, or align with, the following events:

- 2022/2023: (i) an international seminar considering River basins and Delta areas of the Yangtze, Rhine and Mississippi, with special focus on the transformational challenges of port city economies – October 2022; (ii) a side event or similar on water and biodiversity in the context of maintaining river systems, at or around the Biodiversity COP at Kunming; (iii) building on the results of the envisaged event at the Biodiversity COP: a side event or similar at or around the UN Water Conference, March 2023.
- 2023/2024: work conferences on quantification of river basin health, of important e-flows such as sediment, and of progress towards acknowledged goals.

References

[1] Eisner et al., 2017. An ensemble analysis of climate change impacts on streamflow seasonality across 11 large river basins. Climatic Change 141: 401-417.
[2] Eisner et al., 2017. An ensemble analysis of climate change impacts on streamflow seasonality across 11 large river basins. Climatic Change 141: 401-417.
[3] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.
[4] Global Facility for Disaster Reduction and Recovery.(2016).GFDRR Annual Report 2016: Bringing Resilience to Scale. gfdrr-2016-annual-report.pdf.
[5] Kramer, H.A., 2017. A future on fire. Science 358 (6360): 178.
[6] Marvel, K., Cook, B.I., Bonfils, C.J.W., Durack, P.J., Smerdon, J.E. and A.P. Williams, 2019. Twentieth-century hydroclimate changes consistent with human influence. Nature 569: 59-65.
[7] Smirnov, O., Zhang, M., Xiao, T., Orbell, J., Lobben, A. and J. Gordon, 2016. The relative importance of climate change and population growth for exposure to future extreme droughts. Climatic Change 138: 41–53.
[8] Tickner, D. et al., 2020. Bending the curve of global freshwater biodiversity loss: An emergency recovery plan. BioScience 70: 330-342.
[9] UNECE, 2020. Climate change impacts and adaptation for transport networks and nodes. Report ECE/TRANS/283, 199 pp.
[10] IPCC, 2014. Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge (United Kingdom) and New York (USA), 1131 pp.
[11] Van Vliet, M.T.H. et al., 2013. Global river discharge and water temperature under climate change. Global Environmental Change 23: 450-464.
[12] Sabater. S, Elosegi. A. and R. Ludwig, 2019. Multiple stressors in river ecosystems: Status, impacts and prospects for the future, Elsevier, 404 pp.
[13] Sabater. S, Elosegi. A. and R. Ludwig, 2021. Framing biophysical and societal implications of multiple stressor effects on river networks. Science of the Total Environment 753, 141973, doi:10.1016/j.scitotenv.2020.141973.
[14] California Department of Water Resources, 2018, Using Flood Water for Managed Aquifer Recharge to Support Sustainable Water Resources, https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/DWR_FloodMAR-White-Paper_a_y20.pdf
[15] IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.
[16] UNISDR (United Nations International Strategy for Disaster Reduction). 2015. Sendai framework for disaster risk reduction 2015–2030. Geneva: UNISDR.
[17] WWAP (United Nations World Water Assessment Programme), 2018, The united National World Water Development Report 2018: Nature-based solutions for water. Paris: UNESCO.
[18] Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., (2016) Nature-based Solutions to address global societal challenges. IUCN, Gland, Switzerland, p. xiii + 97.
[19]Ochoa-Tocachi BF, Bardales JD, Antiporta J, Perez K, Acosta L, Mao F, Zulkafli Z, Gil-Rios J, Angulo

O, Grainger S, Gammie G, DeBievre B, Buytaert W., 2019, Potential contributions from pre-Inca infiltration infrastructure to Andean water security. Nat Sustain, 2:584–93.
[20] Palmer M.A., Liu J., Matthews J.H., Mumba M., D'Odorlco P., 2015. Manage water in a green way. Science 349 (6248): 584-585.
[21] IUCN 2016 : International Union for Conservation of Nature annual report 2016
[22] Hilde Eggermont, Estelle Balian, José Manuel N. Azevedo, Victor Beumer, Tomas Brodin, et al..Nature-based Solutions: New Influence for Environmental Management and Research in EuropeNature-based Solutions, an Emerging Term. GAIA - Ecological Perspectives for Science and Society, oekom verlag, 2015, 24 (4), p. 243-248. ff10.14512/gaia.24.4.9ff. ffhal-01245631
[23] https://www.icpdr.org/flowpaper/app/#page=1.
[24] Xiao Chunlei, Guo Yixuan, Xue Hao . Enlightenment of Mississippi River Basin Monitoring, Restoration and Management Experience to China's River Basin Ecological Protection and Restoration [J] Geological Survey of China, 2021, 8(6) : 87 - 95 .
[25] https://www.lmrcc.org/wp-content/uploads/2020/12/RARG-plan.pdf.
[26] https://www.lmrcc.org/our-work/success-stories.
[27] Zhang Jun, Gao Yaqi, Xu Weili, Xiong Kaiguo, Du Liangmin, *Temporal and Spatial Distribution Characteristics of Extreme Rainfall Events in the Yangtze River Basin*[J]. *Yangtze River*, 2019,50(08):81-86+135.DOI:10.16232/j.cnki.1001-4179.2019.08.014.
[28] Shi Guangxun. *Analysis of Temporal and Spatial Characteristics of Climate Change in the Yangtze River Basin from 1970 to 2014* [D].Jiangxi Normal University, 2016.
[29] Zhu Yurong, Xu Kaiyu, Fu Yongchao. *Variation Characteristics and Impact of Frozen Soil in the Source Region of the Yangtze River, Yellow River and Lancang River from 1961 to 2017* [J].*Research and development*, 2018:73-76
[30] Liu Fengxia, Wang Yanjun, Zhao Jing, Chen Xue, Jiang Tong. *Variation Characteristics of Extreme Precipitation in the Middle and Lower Reaches of the Yangtze River under the Scenario of global warming of 1.5 ℃ and 2.0 ℃* [J]. *Resources and Environment in The Yangtze Basin*, 2017,26(05):778-788.
[31] *Yearbook of Meteorological Disasters in China (2019)*, China Meteorological Administration.
[32] Chen Wenfang, Fang Jian, Xu Wei, Shi Peijun, Nie Jianliang.*Quantitative analysis of typhoon risk in Yangtze River Delta* [J].*Journal of Natural Disasters*, 2012,21(01):1-8.
[33] Sang Jing. *Temporal and Spatial Pattern And Drought Risk Assessment of Protocol Fields of Major Agrometeorological Disasters in China in recent 30 years* [D].Nanjing University of Information Science and Technology, 2018.
[34] Shi Peijun, *Atlas of Natural Disaster System of China*, Science Press, 2003
[35] Shang Quanmin, Chu Minghua, Luo Jinjun, Yan yongluan, Li Rongbo. *Prevention of Major Floods in the Yangtze River Basin in 2020* [J].*Yangtze River*, 2020,51(12):15-20.
[36] Yao Tandong, Wu Guangjian, Xu Baiqing, et al. *Change and Influence of "Asian Water Tower"* [J].*Bulletin of Chinese Academy of Sciences*, 2019, 34(11): 1203-1209.
[37] Zhu Yurong, Xu Kaiyu, Fu Yongchao. *Variation Characteristics and Impact of Frozen Soil in the Source Region of the Yangtze River, Yellow River and Lancang River from 1961 to 2017* [J].*Research and development*, 2018:73-76
[38] Guwei Zhang et al 2021 Environ. Res. Lett. 16 064073.
[39] *Atlas of Hazardous Weather and Climate in China* (1961-2015).
[40]Liu Zhenzhong. *Promoting the Ecological Protection and Construction of the Yangtze River Economic Belt* [J].*Macroeconomic Management*, 2016(09):30-33+38.
[41]Gan Yuanfang, Zhang Xuan. *Analysis and Evaluation on Ecological Status of National Key Ecological Functional Areas in the Yangtze River Economic B*elt [J]. *Surveying and Mapping*, 2019,42(01):36-41.
[42]Qu Chao, Liu guihuan, Wu Wenjun, Wang Jinnan. *Evaluation on Environmental Efficiency of Ecological Compensation in National Key Ecological Functional Areas of the Yangtze River Economic Belt* [J].*Research of Environmental Sciences*, 2020,33(02):471-477.
[43] National Forestry and Grassland Administration. *Reply of "Suggestions on Improving the Role of Nature Reserves in Achieving the Goal of 'Carbon Neutrality'"* (2021 No. 2399) [R].2021
[44] National Development and Reform Commission. *Overall Planning of Resource Development and Ecological Protection, Promoting Harmonious Human-Nature Development —— Implementing Peak Carbon Emissions and Carbon Neutralization in All Aspects of the Development, Utilization And Protection of Natural Resources* [R].2021

[45] Zhang An Tian, Zhang Xiao Lin. *Enlightenment of the Yangtze River Protection Law on Soil and Water Conservation in the Yangtze River Basin* [J].*Technology and Economy of Changjiang,* 2021,5(02):21-25.DOI:10.19679/j.cnki.cjjsjj.2021.0203.
[46]Liu Jigen, Ding Wenfeng, Huang Jinquan. *Progress and Prospect of Scientific Research on Soil and Water Conservation in the Yangtze River Basin* [J].*Journal of Yangtze River Scientific Research Institute*, 2021,38(10):54-59.
[47]Zhang Pingcang, Cheng Dongbing. *Discussion on the Governance Strategy of Soil and Water Loss in the Yangtze River Basin* [J].*Yangtze River*, 2020,51(01):120-123.
[48] Guo Tienv, Yu Qihui. *Study on Flood Control System and Overall Layout Planning of the Yangtze River* [J].*Yangtze River*, 2013,44(10):23-27+36.
[49] State Flood Control and Drought Relief Headquarters. *Flood Prevention Scheme of the Yangtze River* (2015) [EB/OL]. 2015
[50] Zhang Linwei, Niu Zhangbin, Zhang Quan, Ma Hongtao, Ren Xinxin, Ren Xiyan, Wang Jiazhuo, Wang Wenliang, Chen Wei, Hu Yingjun, Zhao Ye, Lv Yongpeng. *On the Top-Level Design of Sponge City Construction* [J] *Water & Wastewater Engineering*, 2017,53(09):1-5.
[51] Yao Ruihua, et al. *Basic Situation and Prevention and Control Strategy of Water Issues in the Yangtze River Basin* [J]. Environmental Protection, 2017, 45(19):46-48.
[52] Lin Jianbo, et al. *Study on the Practice of Ecological Environment Supervision and Management in the Lower Reach of the Yangtze River* [J]. *Technology and Economy of Changjiang,* 2021, 5(05):48-51.
[53] Xie Ping. *The Biodiversity Crisis of the Yangtze River from Perspectives of Historical Origin and Modern Ecology* [M]. Beijing: Science Press, 2018.
[54] Yu Xiaogan. *Research on the Construction and Development of the Yangtze River Industrial Belt* [M]. Beijing: Science Press, 1997 .
[55] 1992 *Rio declaration*.
[56] *The Second Policy Document on Spatial Planning in the Netherlands, 1966*.
[57] Song Chunlei, et al. *Construction Scheme of Landward Buffer Zone of the Trunk Stream and Lakes in the Middle And Lower Reaches of the Yangtze River,* 2019.
[58] Han Meyer. *The State of the Delta——Engineering, Urban Development and National Building in the Netherlands* [M]. Shanghai: Shanghai Academy of Social Sciences Press, 2021.
[59] Guo Wei, Hou Xiaolei. *Elastic Strategy Analysis of Flood Control in the Dutch Delta* [J]. *Landscape Architecture,* 2016(01):34-38.
[60] Chen Jiyu, et al. *Development Model of the Yangtze River Estuary in the Past 2,000 years* [J]. *Haiyang Xuebao (Chinese version),* 1979(01):103-111.
[61] Mao Zhichang, et al. *Study on Induced Siltation, Enclosure of Tidal-Flat Areas in Shanghai* [J]. *Journal of Sediment Research,* 2003(02):77-81.
[62] Yi Si. *Study on Risk Assessment and Adaptation Strategy of The Combined Effect of Sea-Level Rise and Possible Maximum Storm Surge* [D]. East China Normal University, 2018.
[63] International Water Management Institute: A framework to understand gender and structural vulnerability to climate change in the Ganges River Basin: lessons from Bangladesh, India and Nepal [R], 2014
ADB: Initial Poverty and Social Analysis. Philippines: Integrated Flood Risk Management Sector Project [R], 2018
European Institute for Gender Equality: Gender in environment and climate change [R], 2016
UN WomenWatch: Women, Gender Equality and Climate Change [R], 2009
[64] UN News. “Women Bear the Brunt of the Climate Crisis”, 9 November 2021. https://news.un.org/en/story/2021/11/1105322.
[65] UN News: Women Bear the Brunt of the Climate Crisis, November 2021.
[66] Xiao Qunying, Liu Huijun.*The Impact of Sudden Disasters on Life Qualities of The Elderly* [J]. *Population and Society*, 2019, 35(4): 18-27.
[67] ICIMOD. “Koshi Basin Initiative”, Accessed 8 May 2022. https://www.icimod.org/koshi/gender-portal/.
[68] CIWA: Gender equality and social inclusion in Nile basin transboundary water resources management and development [R], 2022.