Climate Change Risk Assessment and Governance(2021)

Insights from UK-China Cooperation

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Preface

In 2015, experts from the United Kingdom, China, India and the United States jointly published Climate Change: Risk Assessment, a report that proposes a new model for climate change risk assessment. In the same year, the China National Expert Committee on Climate Change (CNECCC) and the UK Climate Change Committee (UKCCC) signed the Cooperation Agreement on Climate Change Risk Assessment and Research, a bilateral arrangement that governs a cooperative study of the future pathways of global greenhouse gas (GHG) emissions, the direct risks brought by the global climate response to GHG emissions and the indirect risks arising from the interaction between climate change and complex human systems, based on which the UK-China Cooperation on Climate Change Risk Assessment – the study on climate risk indicators was completed in 2018.

Under the guidance of the two national committees and based on the risk indicators and risk assessments results from the first and second phases (2013-2019) of the cooperation, the program is in its third phase (2019-2021), which includes four interrelated working groups to focus on emission risk, direct climate risk, systemic climate risk and the integration of climate risk into national and international governance frameworks respectively. The current phase brings together scientists and policy research teams from 10s institutions in the UK and China, including the Royal Institute of International Affairs (Chatham House), Tsinghua University, Oxford University, National Climate Centre (NCC), University of Reading, Hubei School of economics and E3G. Under the research workstream of the direct and systematic risks of climate change, the cooperation in this phase focuses on the climate risks of the sub-regional and municipal China, including the Yangtze River Economic Belt, the Great Bay area of Guangdong, Hong Kong and Macao, as well as Shenzhen, Wuhan and other selected cities, while the international component focusing on the risk assessment and governance in the UK.

The report was released at the time of COP26 closing with the Glasgow Climate Pact adopted which is remarked as "the last chance to reverse climate change". The information provided in this report is to ensure the strategies and policies both in China and globally better informed by an evidence-based perspective on climate risks, leverage greater join effort towards aa more climate resilient natural and socio-economic system.

Content

Executive Summary

I. Introduction

Climate change is the most serious environmental problem commonly faced by the world today, while it is also the most challenging issue in risk governance. Changes in the climate system firstly cause a wide range of impacts on the natural ecosystem, and then on the socio-economic system, leading to the greater risks for the development of human society. According to The Global Risks Report 2021 from the World Economic Forum, environmental risks, represented by climate change, are the primary risks in terms of probability of occurrence and impact over the next decade.

From December 2019 to November 2021, a group of experts and scientists from China and the UK worked together to focus on assessing two types of climate risks: direct risks caused by climate change and systemic risks to complex human systems. The findings and conclusions described in this article could support policy makers a better understanding of the climate risks in the UK and China, and incorporate it into the decision making and actions to address climate change.

II. Key research results

According to the IPCC Sixth Assessment Working Group I Report, the global surface temperature will rise by 1.0°C-5.7°C by the end of this century compared with pre-industrial revolution. Over the next 20 years, the global temperature rise will reach or exceed 1.5°C. Many changes in the climate system caused by past and future greenhouse gas emissions, especially changes in the oceans, ice sheets, and global sea levels, are irreversible on the scale of centuries to millennia. The probability of concurrent extreme events will further increase in many regions of the world, with concurrent heat waves and droughts, and intensified compound flood events caused by the superposition of extreme sea levels and heavy precipitation. Based on the selected 35 climate factors in the study, almost all regions of the world will experience changes in at least 10 of these factors. By 2100, the once-in-100-year extreme sea level events experienced by more than half of the coastal regions will occur every year, and the superimposition of extreme precipitation will cause more frequent floods. In particular, the triggering of tipping points of the climate system, such as the collapse of the Antarctic ice sheet, the sudden change of ocean circulation and the die-off of forests, cannot be ruled out with major catastrophes to the living environment of the earth.

Increasing evidence shows that various extreme weather and climate events to be further increased in the UK in the future. By 2050s with high emissions, the magnitude of the 30-year daily rainfall increases by over 30% in the north and west of the UK. The risk of extreme high temperatures is greater in England than elsewhere. Especially in the Southeast, the impact involves health, infrastructure, and the natural environment. Water scarcity and the possibility of subsidence are also worsening. Coastal and inland floods, storms, thunder and lightning as well as strong wind will be more serious ones among the climate risks across England. In addition to the risks to the natural ecosystem in Northern Ireland, impacts on infrastructure networks, transportation, health, and cultural heritage caused by climate change are vital. The impact of flooding on people, communities and buildings is one of the most serious risks in Scotland and causes the highest economic loss to businesses. At the same time, increasing water shortage in summer, particularly for domestic water supply, is also a significant climate risk for Scotland. In addition to various extreme weather and climate events in Wales, the impact of sea level rise, coastal flooding and erosion on coastal enterprises should be attached great attention.

China is high-impact area of global climate change. Further temperature rise will result in significant changes in the timing, intensity, frequency, and regional characteristics of extreme disasters such as heat waves, rainstorms, floods, and droughts, with the average number of days of heat wave will increase by 7-15 days by middle of this century under the medium emission scenario, and the average extreme precipitation changing from the current once-in 50-years to once-in-20-years around 2030. The Sichuan Basin, middle reaches and the lower reaches of the Yangtze River Economic Belt may face serious risks of heat and extreme precipitation disasters in the future, which would result in significant human and economic losses. The Guangdong-Hong Kong-Macao Greater Bay Area may also become one of the regions in China with the greatest increase in heat-related fatality rate in the future, as well as exacerbating the epidemic spread of insect-borne infectious diseases such as dengue fever and malaria-borne infectious diseases in the Greater Bay Area. The risk of storm and waterlogging increases under the medium emission scenario, and the sea level in the South China Sea will rise by 34-79cm by about 2100, 20% to 30% higher than the global average. Under the combined effects of sea level rise and altered precipitation distribution, the risk of salt tides in the Pearl River Estuary has increased, threatening the safety of water supply in areas such as Macau and Zhuhai during the dry season. China's Qinghai-Tibet Plateau is the most sensitive area to climate change. Under the medium emission scenario, in 2050, the annual average temperature of the Qinghai-Tibet Plateau will increase by about 1.5°C, with a significant increase in extreme precipitation and an increase of 2-4 days in the number of heavy precipitation days in the Heng-duan Mountains. The cryosphere will continue to shrink in this century, and the frequency of extreme disasters and catastrophes will increase, which will intensify the compound risks of climate and ecological environmental disasters. Around 2050, the annual average temperature of the Yellow River Basin will increase gradually, from east to west across the region, with an overall increase in precipitation. The reduction of snow in the basin will reduce or disappear the spring snowmelt runoff, and the ability to regulate river runoff will be significantly weakened. The spring drought will become more serious, and the ecological environment will face severe risks. In Shenzhen, by 2050, the number of high temperature days will increase by 26 days, and the variation in heavy precipitation and extreme heavy precipitation will show interdecadal fluctuations.

Regarding systemic risks, in the Yangtze River Economic Zone, the medium-to-high-risk areas for heat waves are in the lower reaches, and the medium-to-high risks for heavy rains and floods are in the middle and lower reaches. The overall spatial distribution of health heat vulnerability in Wuhan is high in the central urban area and low in the urban areas; among the peripheral urban areas, the southwest is higher than the northeast. It is estimated that by the end of this century, the heat-related mortality rate under the high-emission scenario is expected to be about twice that under the medium-emission scenario. Among them, patients with respiratory diseases, women, and the elderly are the most vulnerable to temperature rise. The average losses due to power shortages caused by high temperatures in 2030, 2050, and 2100 are 905 million RMB and 1,442 million RMB, 2,103 million RMB and 3,417 million RMB, 6,649 million RMB and 11,070 million RMB for the medium and high emission scenarios respectively. If the drainage capacity of Wuhan in 2020 remains unchanged, the area of the inundated area under the heavy rainfall scenario in 2100 will be 76.64% larger than that in 2020. The economic sectors with the greatest indirect risks in Wuhan are transportation equipment and transport, finance, construction, highway transportation, wholesale and retail trade, leasing, and business services. Due to the differences in exposure of different social groups to climate risks, climate change may lead to a higher intensity of exposure of certain groups to climate change risks, thus resulting in climate vulnerable populations and rising issues of social inequality, social exclusion and inclusiveness in response to climate change based on climate risks, leading to the social risks of climate change.

III. Policy Suggestions

1. Set high priority to climate change risks and its integration into overall national security and risk assessment

Climate change risks need to be addressed with high priority by government. As an unconventional security risk, direct and systemic climate change impacts should be included in national risk assessments. Addressing climatic change impacts and proceeding low-carbon development should be taken as essential parts of a strategy for economic and social development.

Policy makers need to take all emission scenarios into the consideration to address the increasing direct and systemic risks, carry out targeted climate change risk assessments in different regions and sectors, incorporate extreme climate disasters and climate risks into the core content of adapting to climate change, strengthen preventive measures against extreme climate disasters. Conduct climate change impact assessments in key regions and featured industries, strengthen risk response to extreme climate events and disasters in agriculture, water resources, ecology, health, infrastructure, and social development, and improve the resilience of the socio-economic systems.

2. Improve the capability of comprehensive management of climate risks

Improving working mechanisms and strengthen long-term planning. Develop national, regional, and sectoral strategic plans for climate change adaptation and implement it with joint effort among meteorology, agriculture, water resources, ecology, health, transportation, and economics sectors while specific focus and responsibilities respectively. Strengthen climate risk monitoring, early warning and assessment, focusing on responses to the increasing risks to agriculture and water resources, escalating risks to ecological security, and increasing risks to health and safety associated with extreme weather events and disasters, to safeguard the security of food, water resources and health in China. Strengthen the development of a climate change adaptive society and improve the resilience of the socio-economic system. Strengthen the risk assessment of climate change on financial markets, global and national food systems, health systems, and important infrastructure systems, ensure comprehensive understanding on the characteristics of different system risks caused by climate and develop risk management platforms.

3. Strengthen international cooperation to improve policy-makers' capability to manage long-term and tipping points risks

Even if all the countries meet the commitments as pledged for carbon neutrality, the global average temperature may still rise by more than 2°C at the end of this century, and long-term risks will persist. At the same time, the tipping points, such as the accelerated melting of the Greenland ice sheet leading to a more rapid sea level rise and a slowing of the Atlantic thermohaline circulation, have far-reaching global impact. Policy makers need to consider the worst possible scenario to ensure that the policy decisions resilient to the impacts. Although risks are local, adaptation actions require global cooperation, and the world needs to scale up public climate adaptation finance through direct investment and overcome barriers to private sector engagement.

4. Establish a framework for regular monitoring and assessment of climate risks

Developing and refining a standardized climate risk indicator system can keep the scientific knowledge and conclusion updated , such as the ongoing study on climate sensitivity and the relationships between general climate variables (such as temperature or sea level rise) and the probability of specific impacts and extreme events. The risk indicators can be updated to reflect changes in the population exposure and vulnerability. These trends will indicate whether adaptation challenges are increasing or decreasing, which may inform the priorities of social-economy development and investment decisions. It is important to ensure the data of climate-related risks and losses to be accessible, by developing earth system models and climate change impacts and risks assessment tools, developing indicators applicable to climate impact and risk assessment, improving the awareness of the impact on climate change on socio-economic systems and systemic risks.

Chapter 1: The risks of climate change to UK

1.1 Introduction: the assessment of direct risks in the UK

The UK is exposed to a wide range of weather and climate risks, and recent years have seen frequent floods, heatwaves, droughts, windstorms and wildfires: there have also been some extreme cold events, notably in 2018.

The UK also has a legislative framework for assessing risks and adaptation to climate change, underpinned by the Climate Change Act (2008). The primary purpose of the Act is to enable the reduction in greenhouse gas emissions through the setting of statutory carbon budgets and targets, but the Act also requires the government to plan for and adapt to climate change. The government produced the first National Adaptation Programme (NAP) in 2013, and the second in 2018: the third is currently under development. The NAP identifies a number of actions that the government needs to undertake to advance adaptation and resilience, and also includes actions from the private-sector organisations that are required under the Climate Change Act to report on their progress with adaptation. These organisations are primarily concerned with the delivery of public services and infrastructure.

The NAP is informed by the Climate Change Risk Assessment (CCRA), which the Climate Change Act also requires the government to undertake (Warren et al., 2018). The first CCRA was published in 2012, the second in 2017 and the evidence report to underpin the third was published in 2021: the formal government-published risk assessment is based on the evidence report. Although the CCRA is termed a 'Risk Assessment' it is in practice an assessment of the state of, and priorities for, adaptation. This is made up of an assessment of the magnitude and seriousness of a number of identified risks, and an assessment of progress towards adaptation to these risks. Figure 1.1 summarizes the approach used in the third CCRA.

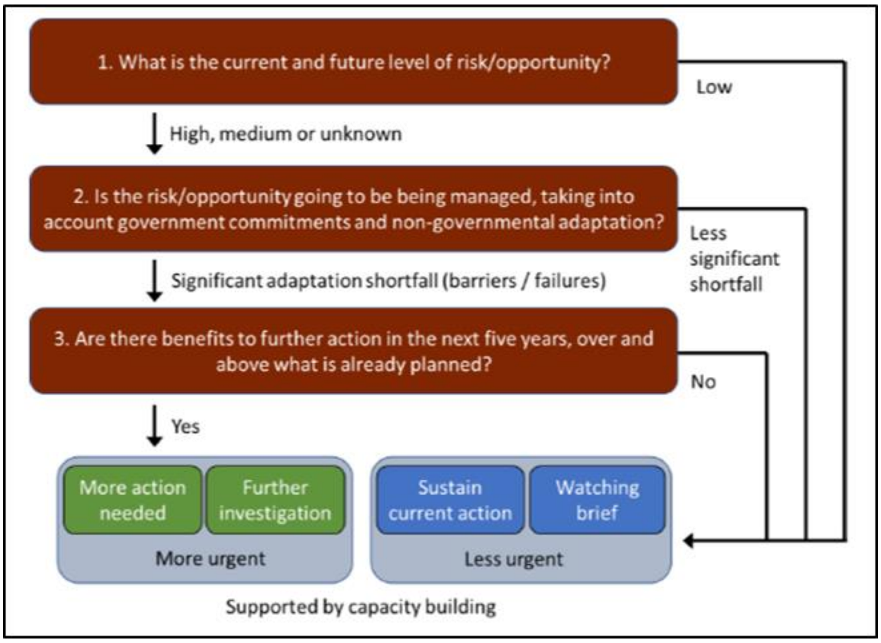


Figure 1.1 The framework used in the evidence report for the third UK Climate Change Risk Assessment (CCC, 2021)

The first stage in the process focuses on the identification of 'risks' and the characterisation of their magnitude. Stakeholders identified a total of 61 specific risks, classified into five areas covering the natural environment, infrastructure, health and communities, business and industry, and international dimensions. Risks are defined as 'the potential for consequences where something of value is at stake and where the outcome is uncertain' (Betts & Brown, 2021; Watkiss & Betts, 2021). These risks are mostly characterised as 'risks to', rather than 'risks from' (e.g. risks to public water supplies), and map onto specific policy areas. Individual climate drivers (such as high temperatures) therefore affect multiple risks, and individual risks may be affected by several climate drivers. This step in the assessment involved assessing the magnitude of each risk, at three different time periods (now, mid-century and late-century), and with warming consistent with increases of 2 and 4°c by the end of the century. 'Magnitude' is defined as low, medium, high or unknown, based on both quantitative and qualitative criteria (Table 1.1: Watkiss & Betts, 2021). In practice, the estimated magnitude of almost all risks was based on expert judgment, informed in some cases by quantitative assessments.

Steps 2 and 3 in the process build on the first step to assess the extent to which each risk is addressed by current or planned adaptation, and the benefits of additional action within the next five years. This defines the urgency score for the risk.

	High Magnitude	**Medium Magnitude**	**Low Magnitude**
Quantitative evidence	*Major annual damage and disruption or foregone opportunities:*[1]	*Moderate annual damage and disruption or foregone opportunities:*	*Minor annual damage and disruption or foregone opportunities:*
	-£hundreds of millions damage (economic) or foregone opportunities, and/or	-£tens of millions damage (economic) or foregone opportunities, and/or	-Less than £10 million damage (economic) or foregone opportunities, and/or
	-Hundreds of deaths[2], thousands of major health impacts, hundreds of thousands of people affected / minor health impacts, and/or	-Tens of deaths, hundreds of major health impacts, tens of thousands of people affected / minor health impacts. and/or	-A few deaths, tens of major health impacts, thousands of people affected / minor health impacts, and/or
	-Tens of thousands of hectares land lost or severely damaged[3], and/or thousands of km of river water/km^2 of water bodies affected, and/or	-Thousands of hectares of land lost or severely damaged, and/or hundreds of km of river water/km^2 of water bodies affected, and/or	-Hundreds of hectares of land lost or severely damaged, and/or tens of km of river water/km^2 of water bodies affected, and/or
	-Major impact (~10% or more at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or	-Intermediate impact (~5% at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or	-Minor impact (~1% at national level) to valued habitat or landscape types (e.g. BAP habitats, SSSIs), and/or
	-Major impacts on or loss of species groups, and/or	-Intermediate impacts on or loss of species groups, and/or	-Minor impacts on or loss of species groups, and/or
	-Major impact (10% or more at national level) to an individual natural capital asset and associated goods and services[4] and/or	- Intermediate impact (1 to 10% at national level) to an individual natural capital asset and associated goods and services, and/or	- Minor impact (~1% or less at national level) to an individual natural capital asset and associated goods and services, and/or
	-Major loss or irreversible damage to single nationally iconic heritage asset (e.g. Stonehenge, Giants' Causeway)	-Medium loss or irreversible damage of nationally iconic heritage asset (e.g. Stonehenge, Giant's Causeway)	-Low loss or irreversible damage to nationally iconic heritage asset (e.g. Stonehenge, Giants' Causeway)
Qualitative evidence	Expert judgement of chapter authors, confirmed with agreement across authors, CCC and peer reviewers suggest there is a possibility of impacts of the magnitude suggested above.		

Table 1.1 Magnitude classifications for the third UK CCRA (Watkiss & Betts, 2021)

There are numerous other reasons why organisations might want to assess climate risks. Whilst the CCRA is designed to inform national adaptation policy, high-level national-scale information on climate risks can be used to inform the priority given by government and others to climate and mitigation policy in general (Arnell et al., 2021). At the more local level, councils and communities would benefit from more locally-tailored information on potential climate risks. Specific adaptation strategies or plans would need information on risks that is directly related to design parameters. These different objectives of risk assessment mean that different approaches – in terms of spatial scale and scenarios used – may be necessary in different circumstances.

In the UK there have so far been no formally-coordinated quantitative assessments of current and future climate risks. However, there have been a large number of single-sector studies and, most significantly, the UK has over the years developed a series of 'official' climate projections. The first date back to 1998 (UKCIP98), and the most recent (UKCP18) were published in 2018 (Lowe et al., 2018). The UKCP18 projections consist of four strands, based around RCP climate forcing. The global, regional and local strands are primarily based on a number of simulations (between 12 and 15, depending on strand) made with the Hadley Centre HadGEM3.05 climate model with RCP8.5 emissions: they use increasingly fine resolution models. The range across these simulations represents climate model parameter uncertainty. The global strand also contains a further 12 simulations based on CMIP5 climate models, and this adds climate model structural uncertainty to the range. The probabilistic strand consists of 3000 equally-plausible projections for each of four RCP scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5). The probabilistic projections are produced using a statistical emulator built from the HadGEM3.05 and CMIP5 simulations.

These UKCP18 projections have been used in a series of studies evaluating several potential direct impacts of climate change. These studies – summarised below – concentrate on indicators of climate hazard and resource: few consider risk in terms of human and economic impact.

1.2 Climate change risks in the UK

Since the enactment of the UK Climate Change Act (2008), the UK Climate Change Commission has been required to submit assessment opinions to the government six months before parliamentary discussions on the UK Climate Change Risk Assessment (CCRA) every five years. Following the release of the first (CCRA1) and second assessment (CCRA2) in 2012 and 2017, the third report (CCAR3) will be released in 2022, detailing the climate change risks and opportunities faced by the UK by 2100, and making recommendations on the priorities for climate adaptation in the next five years. The UK Climate Change Commission issued the "Independent Assessment of UK Climate Risk-Recommendations for the UK's Third Climate Risk Assessment" in June 2021 (hereinafter referred to as the "Independent Assessment").

There have been a number of changes in the understanding of current and future climate change in this assessment. The scientific understanding of the possible level of future climate change has developed since the first risk assessment, and the range of global warming that the world may experience by 2100 beyond 1850-1900 level has been narrowed from between 1ºC and 6ºC in CCRA1, to between 2ºC and 4ºC used in CCRA3.

Different from the assessment five years ago, the epidemic, Brexit and the promise of net zero emissions have brought significant changes to the socio-economic context of this climate risk assessment. These have made projections of future risks more challenging than ever.

The spread of the epidemic has sounded the alarm of global complexity and cascading risks, and the risk management operation system between various departments, governments at all levels and countries has been tested. In this regard, the assessment put forward suggestions for future risk governance in the context of climate change.

Brexit in 2020 has a far-reaching implication for adaptation policies related to climate risks exposure and opportunities, across a wide range of areas including the natural environment, business, and international relations. The uncertainty of future geopolitical conditions has further increased, thus adding to the uncertainty of future policy directions.

In 2019, the UK passed a bill to achieve net zero by 2050. The decarburization process involves many of the departments in the risk assessment. This will have a major shift in assumptions about the risks and opportunities of future climate change. For example, the UK's energy production and distribution will be very different by 2050. This assessment therefore focuses more on the trade-offs and synergy between mitigation and adaptation measures.

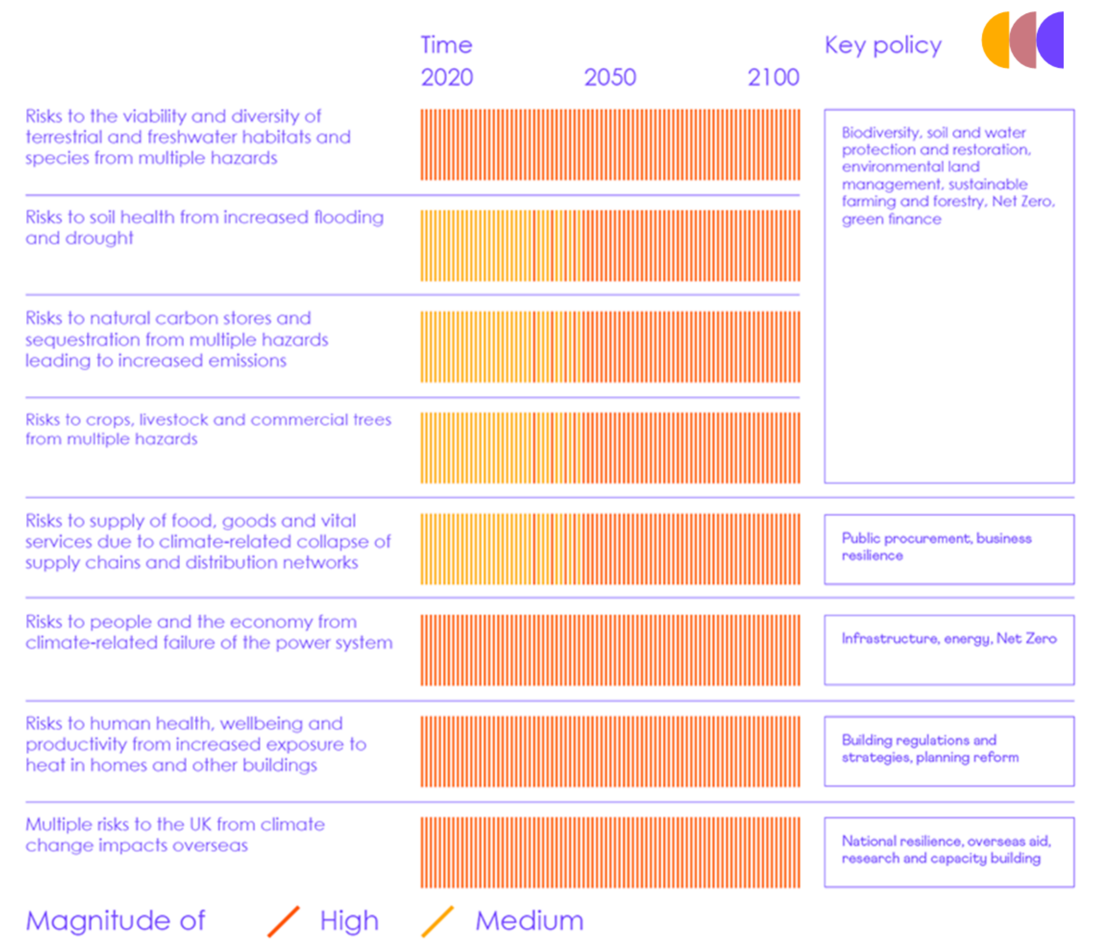
The "independent assessment" pointed out that compared to only 36% in the 2016 assessment, 56% received the highest urgency out of 61 risks and opportunities identified in the “Climate Change Risk Assessment” (CCRA3) technical report in which substantial new evidence were collected, including the natural environment, health, housing, infrastructure, and social economy, etc. Compared with the 2016 assessment, 14 comparable risks will have sizable increase in the future, and none will decrease. The severity of the risk is also higher than the earlier assessment and prediction. The scale of 15 types of risks in the third assessment report is higher than the forecast for 2020 in the first CCRA in 2012. Without further adaptive measures, and, the types of risk causing billions of pounds in economic losses each year by the 2080s will be three times greater than they are today, if global warming failed to managed below 2ºC in time.

The "independent assessment" believes that, despite the UK holding the capability and resources to effectively respond to the climate change risks, the current work on climate adaptability lags behind the situation, the gap between the level of risks faced and the existing adaptation levels has been further widened, and new evidence shows that risks will further increase; in the past five years, the increased demand for climate adaptability has significantly exceeded previous plans and anticipations.

In this regard, the "independent assessment" further identified eight risk areas that require the most urgent actions in the next two years, including:

(1) Risks to the viability and diversity of terrestrial and freshwater habitats and
(2) Species from multiple hazards.
(3) Risks to soil health from increased flooding and drought
(4) Risks to natural carbon stores and sequestration from multiple hazards,
(5) leading to increased emissions
(6) Risks to crops, livestock and commercial trees from multiple climate hazards
(7) Risks to supply of food, goods and vital services due to climate-related collapse of supply chains and distribution networks
(8) Risks to people and the economy from climate-related failure of the power
(9) system
(10) Risks to human health, wellbeing and productivity from increased exposure
(11) to heat in homes and other buildings
(12) Multiple risks to the UK from climate change impacts overseas

Figure 1.2 Risk areas requiring the most urgent action in the next two years



Source: CCC

Notes: Figure shows the changing magnitude over time of the risk areas that require the most urgent action in the next two years. Change in magnitude is shown up to 2100 for the highest scenario assessed in the Technical Report for the relevant risks for that theme. Details are set out in an accompanying Annex to the related report of Climate Change Committee, UK.

Reviewing the risk assessment and its governance process in the UK, this independent assessment found that the previous recommendations have not attracted enough attention, adopted and implemented. In the past ten years, adaptive governance has been weakened, and there is a growing evidence shows that climate risks are increasing. Therefore, while the third independent evaluation highlights the need for immediate action in this situation, while proposes ten principles and recommends it to be incorporated into the national adaptation plan, which will strengthen risk assessment and adaptation measures, as shown in Figure 1.3.

1. Set a vision for a well-adapted UK

The new National Adaptation Plan should provide a clear vision for a well-adapted UK, incorporating adaptation as a standard into policy decisions and business operations, with clear implications for the people, local governments and various sectors. The new plan must specify feasible and measurable targets at the end of the next reporting period (2023-2029).

2. Integrate adaptation into policies, including for Net Zero

Climate risk must be assessed in policies, investments and decisions related to a range of government and social objectives. At the same time, it is particularly important tointegrate adaptation and mitigation measures, especially in areas such as infrastructure, building, and the natural environment, where the best way to deal with climate change and avoid unintended consequences is to ensure that adaptation and mitigation are considered in tandem.

3. Adapt to 2ºC; assess the risks up to 4ºC

Even if the temperature rise can be kept to 2ºC, the UK's climate will still undergo major changes. If the climate's response to emissions is at the high end of the current uncertainty range, it is likely that the temperature rise may be as high as 4ºC between 2080 and 2100. This has a fundamental impact on adaptive planning. This level of warming will greatly limit the effectiveness of adaptation measures, posing widespread threats to life and well-being, leading to economic losses and systemic changes to the natural environment. The UK must adapt to the minimum global average temperature rise of 1.5-2°C during the period 2050-2100, and take into account the risk of a 4°C warming scenario.

4. Avoid lock-in

Failure to take adaptation before irreversible changes occur can lead to a "lock-in" effect, increasing the damage caused by climate change, or requiring greater investment and greater effort. For example, retrofitting windows and shutters that can adapt to future conditions (such as extreme high temperatures) is around four times more expensive than including them at design stage.

5. Prepare for unpredictable extremes

The current risk assessment has identified and determined the basis for low-likelihood and high-impact changes outside the "likely range" used in the assessment, including global warming above 4°C by 2100 and the potential for instability of the earth system that could happen at a range of warming levels, such as significant shifts in the jet stream, leading to more extreme weather. However, there is currently no early warning system in the UK, nor an assessment on what adaptation actions can be taken to reduce the resulting impact. These should be incorporated into the national risk plan.

6. Assess interdependencies

Interacting risks pose one of the greatest challenges when assessing climate risks. A single hazard often has a knock-on effect on a range of sectors, amplifying the impact and harm. At the same time, risks can interact across different sectors. Multi-sector collaboration continue to face difficulties in the governance of interconnected or cascading risks.

In view of the far-reaching impact that power failure may have on the society as a whole, and the increasing importance of the power sector in the overall infrastructure system in the transition to a net-zero economy, the risks to people and economy from climate related failure of the power system as one of the top priorities for the government.

7. Understand threshold effects

Threshold refers to the point at which "non-linear" changes occur in a system due to changes in climate variables (such as temperature). For example, when the water temperature exceeds 17˚C, algae blooms begin to appear. Understanding where these thresholds exist and how often they may appear in the future is very important to understand the magnitude of specific risks and when new actions or different adaptation methods may be required to achieve more targeted actions. The current literature on climate adaptation generally lacks consideration of thresholds. National adaptation plans should emphasize how to take the threshold effect into consideration.

8. Address inequalities

Climate change may further increase social inequality due to its impact on vulnerable groups. In the UK, low-income households face a relatively high risk of flooding. People living in Scotland, Wales and Northern Ireland also face higher annual flood losses per capita than those living in England. Actions to address climate change may also exacerbate existing inequalities if not carefully planned. The risk assessment found that inequality related to characteristics such as residence, income level and assets, age and ethnic background may be associated with current vulnerability and capability to adapt to climate change. The new national adaptation plan should map these effects and include actions to deliver positive distributional effects, in line with updated guidance in the Treasury Green Book.it should also reduce the major and irreversible impacts on environmental damage and climate change. The discount rate for standard economic appraisal related to significant and irreversible impacts of environmental damage and climate change should be lowered, to avoid unfairly disadvantaging future generations.

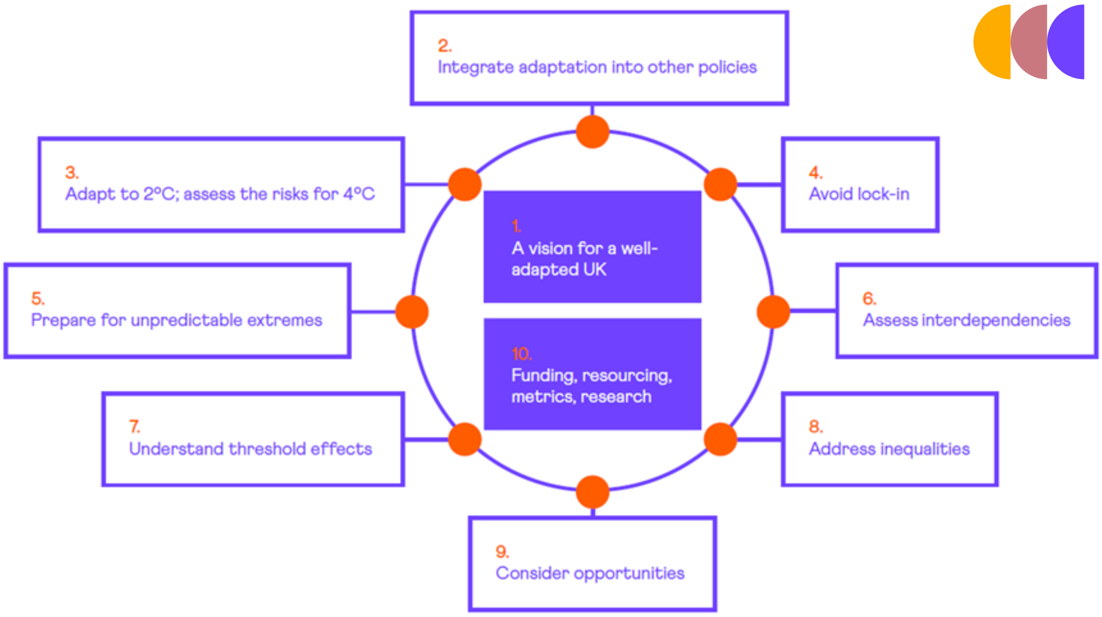
9. Consider opportunities from climate change

Climate change could bring some potential benefits to the UK, such as longer growing seasons, the arrival of new species in the UK or the health benefits of warmer winter. However, there is still a lack of substantial evidence to assess the extent of these opportunities.

10. Support the implementation of adaptation through funding, resources, indicators and research to link adaptation actions to reductions in risk

Sufficient funding and resources are prerequisites for effective adaptation. Government should play a major role in integrating adaptation and resilience into the financial system and existing economic planning, such as providing funding for net-zero emissions and green recovery, reducing policy uncertainty, and encouraging private sector investment. One of the biggest obstacles to supporting more investment in adaptation is the lack of understanding of the effectiveness of different adaptation actions in different context. Raise awareness of the positive effects of adaptation actions is at urgent need, following the approaches set out in the UK Government’s Magenta Book (Guidance for Evaluation) and using indicators to monitor change over time.

Figure 1.3 Ten principles of good adaptation



1.3 Overview of direct risks in the UK

Although there have been no explicit comparisons using consistent metrics, the most important direct risks in the UK are considered to be flooding (from rainfall, rivers and coastal flooding), heat extremes, drought and windstorm. Wildfire is increasingly recognised as a potentially significant risk, and changes in climate resource have the potential to affect agricultural and wind-power production.

The UKCP18 climate projections (Lowe et al., 2018) produce increases in temperature across the UK that are similar to the global average increase (with slightly greater increases in summer). Rainfall is projected to increase most substantially in the north and west and in winter. In summer rainfall is projected to decrease in southern and eastern England. There is relatively little change in spring or autumn rainfall, but in all seasons there is large uncertainty in how rainfall will change in the future.

1.3.1 Flooding

It is a well-established conclusion that climate change will lead to increases in the frequency of intense rainfall, because the warmer atmosphere can hold more water. This has been found to be the case in the UK. The number of days with rainfall above high rainfall thresholds increases with level of warming (Hanlon et al., 2021), and the magnitude of the T-year sub-daily and daily rainfall increases across the UK (Dale, 2021). By the 2050s with high emissions, the magnitude of the 30-year daily rainfall increases by over 30% in the north and west of the UK.

Changes in short-duration rainfall do not necessarily translate directly into changes in river flood risk, due to the effect of catchment geology and storage. Rivers in the UK are short in global terms, but the large diversity in catchment geology means that they respond very differently to changes in rainfall. The catchments with very permeable geology respond to prolonged accumulations of rainfall, whilst catchments on more responsive geologies react quickly to rainfall. The variation in change in flood risk across the UK therefore reflects variation in change in rainfall, and variation in catchment geology. Under most climate projections, rainfall increases most significantly in the north and west of the UK, and it is here that the increases in flood frequencies are greatest (Figure 2: Arnell et al., 2021; Kay et al., 2021). Further south and east the increases are smaller because the increases in rainfall are less, but the pattern is made complicated by the variation in geology.

Sea level rise around the UK are slightly lower than the global average change (Lowe et al., 2018), with greater increases in the south and east where land level is sinking due to isostatic processes. By 2100, sea level will be between 0.53 and 1.15m higher than at present with high emissions, and this means both an increase in the magnitude of the T-year event and a reduction in the return period of the current T-year event. In some cases, the current 1000-year event could occur once a decade by 2100 under the most extreme scenario (Lowe et al., 2018), although in most places and for most scenarios the increases are considerably smaller.

1.3.2 Heat extremes

High temperature extremes obviously increase with global warming. The number of hot days (above specific thresholds) increases (Hanlon et al., 2021), and the number of times heatwaves or public health heat alerts are declared increases (Arnell et al., 2021; Arnell & Freeman, 2021a) – particularly in the south and east (Figure 2). Low temperature extremes occur less frequently, but still occur sufficiently frequently for them to continue to pose a hazard (Arnell & Freeman, 2021a). The reduction is greatest in the warmer parts of southern and eastern England.

Heating degree days reduce with warming – resulting in lower heating energy demands – but cooling degree days' increase from a very low base (Figure 2).

High temperature extremes affect many sectors, including health, transport and agriculture. Figure 2 shows for example the large increase in days with temperatures above thresholds known to cause infrastructure problems on the roads and railways, particularly in southern England. At present, temperatures sufficiently high to cause crop damage are extremely rare, but in southern England may become much more significant with high emissions (Figure 2; Arnell & Freeman, 2021b). Hot and humid days which lead to increases in stress in dairy cattle and reductions in milk yield are projected to increase substantially (Garry et al., 2021; Arnell & Freeman, 2021b).

1.3.3 Drought

In the UK, drought has three primary effects: it affects agricultural productivity, it affects the reliability of water supplies, and it affects the natural environment. It also influences, with high temperatures, wildfire risk (1.3.5).

The different impacts of drought are characterised by different indicators. Agricultural and ecosystem drought are best characterised by indicators based on precipitation and evaporation. Reductions in summer rainfall mean that precipitation based indicators such as SPI (Arnell & Freeman, 2021b) and rainfall deficit indicators

(Hanlon et al., 2021) show increases in drought occurrence. When potential evaporation is included – for example in the Standardised Precipitation and Evaporation Index (Figure 2) – then the increase in drought risk is even greater.

Water resources drought is best characterised by indicators based on groundwater levels or river flows. These combine the accumulated effect of rainfall and evaporation over time with the effects of catchment geology and storage. Such indicators also show increases in drought frequency (Figure 2), particularly in the south and east of England where the reductions in river runoff are greatest.

1.3.4 Storms

Windstorms that affect the UK are typically generated by pressure gradients across the Atlantic Ocean, and the annual number and intensity varies with the position of the Jetstream. Although it is projected that windstorm frequency will increase across northern Europe, projections of changes in windstorms that affect the UK are highly uncertain.

1.3.5 Wildfire

Until recently, wildfire has not been recognised as a significant hazard in the UK, but a series of potentially serious fires in recent years has raised awareness. Whilst these wildfires have so far caused little damage to infrastructure or property, the potential for large impact exists and the fires have caused environmental damage.

Wildfire risk is a function of both environmental conditions and the chance of ignition. In the UK, most wildfires are a result of human action, usually accidental or inadvertent. The largest number of fires are therefore where the risk of ignition is greatest, not where the environmental conditions are most suitable. Climate change will affect environmental conditions, but not necessarily the locations that fires start. The effect of climate change on wildfire is therefore assessed using indicators of wildfire danger: these indicators are widely used to limit access to land or issue warnings.

Higher temperatures lead to an increase in the frequency with which wildfire danger indices exceed warning thresholds (Arnell et al., 2021b), particularly in the south and east. The effects of higher temperatures are increased by projected reductions in humidity, but changes in drought appear to have a smaller effect on future wildfire danger – although this does depend on the indicator used.

1.3.6 Change in climate resource

Climate not only creates hazard, but also it provides a resource. The types of agricultural production that are economically feasible are constrained by climate: for example, low temperatures mean that most of the uplands of the UK are suitable only for grazing. Increases in growing season length and the amount of growing degree days (Figure 2; Arnell & Freeman, 2021a) offer the opportunity for new annual crops to be planted and increase the productivity of grassland systems. However, higher temperatures may also mean that crops develop more rapidly leading to a reduction in yield – unless this is of offset by increased sunshine during the important seed-filling period. Increased drought frequency would lead to reduced productivity, although earlier temperatures may mean that crops are planted earlier in the season and thus avoid water limitations. The effect of climate change on crop production therefore depends on the balance between changes in the different climatic factors that affect yields, and this balance may be very uncertain. It also depends on how farmers and the agricultural system adapt to change.

Agricultural productivity is also affected by changes in operations. Wetted winters, for example, could mean that farmers cannot access fields to prepare for planting, and livestock cannot be moved to pasture.

Wind power makes an increasing contribution to the UK's energy supply system, and changes to wind regimes would affect the reliability of supplies. However, changes in wind regimes across the UK are uncertain, so the effects are unknown. Cradden et al. (2012), using earlier climate scenarios, projected little change in wind power potential.

Table 1.2 Climate change in the UK

variable	**data observation**			
	England	**Northern Ireland**	**Scotland**	**Wales**
The annual average temperature	From the mid-1970s to mid-2010, increase by 0.9°C	Between the mid-1970s and mid-2010, an increase of 0.7°C	--	From the mid-1970s to mid-2010, increase by 0.9°C
Average annual rainfall	Increase of 4.5% from mid-1970s to mid-2010	From mid-1970s to mid-2010, an increase of 6.4%	--	From the mid-1970s to mid-2010, 2.0% increase
sunshine	Increase of 9.2% from mid-1970s to mid-2010	--	--	From the mid-1970s to mid-2010, 6.1% increase
extreme weather	Increase in extreme high temperature weather in the UK There is no evidence for changes in extreme rainfall	Increase in extreme high temperatures in the UK There is no evidence on changes in extreme rainfall	--	Increase in extreme high temperature events in the UK There is no evidence on changes in extreme rainfall
Sea-level rise	Since 1901, there has been an increase of approximately 1.4 millimeters per year across the United Kingdom (16 centimeters so far)	Since 1901, there has been an increase of approximately 1.4 millimeters per year across the United Kingdom (16 centimeters so far)	--	Since 1901, there has been an increase of approximately 1.4 millimeters per year across the United Kingdom (16 centimeters so far)

1.4 Overview of direct risks in the UK

The third independent assessment of the UK Climate Change Risk Assessment (CCRA3) presented the risks and opportunities brought by climate change in England, Northern Ireland, Scotland and Wales, covering business, infrastructure, housing, natural environment, health and international climate change and other aspects in total are 61 items and categories , and categorised into "Watching brief", "Sustain current actions", "further investigation" and " More action needed" from low to high urgency.

Table 1.3 Trends of future climate change in the UK

How could the climate change in future	2050s RCP2.6 (50th percentile)				2050s RCP6.0 (50th percentile)				2080s RCP2.6 (50th percentile)				2080s RCP6.0 (50th percentile)			
	England	N. Ireland	Scotland	Wales	England	N. Ireland	Scotland	Wales	England	N. Ireland	Scotland	Wales	England	N. Ireland	Scotland	Wales
Annual Temperature	+1.3°C	+1.1 °C	+1.1°C	+1.2°C	+1.2°C	+1.2 °C	+1.0°C	+1.1°C	+1.4°C	+1.2 °C	+1.1°C	+1.3°C	+2.4°C	+2.1 °C	+2.0°C	+2.3°C
Summer Rainfall	-0.15	-11%	-7%	-15%	-14%	-11%	-6%	-15%	-15%	-10%	-12%	-18%	-22%	-15%	-16%	-26%
Winter Rainfall	+6%	+3%	+7%	+6%	+6%	+3%	+7%	+5%	+8%	+7%	+7%	+7%	+13%	+10%	+13%	+13%
Sea level rise (London)	+23cm	+14cm	+12cm	22cm	+29cm	+16cm	+18cm	28cm	+45cm	+27cm	+23cm	43cm	+78cm	+58cm	+54cm	76cm

Data source: Evidence documents attached to the third climate risk assessment (CCRA3) of the United Kingdom

A total of 23 risks have increased in urgency score in England compared with the second assessment five years ago, with only one risk has decreased in urgency score, and some new risks are for the first time in this assessment.

There is increasing evidence that the risk of extreme heat is greater in England than in other places, compared with other countries. Especially in the southeast, the impact related to health, infrastructure and the natural environment. Water scarcity and the possibility of subsidence are also worsening. Floods (coastal and inland), storms, thunder and lightning and high winds are also more serious climate risks facing England as a whole.

In Northern Ireland, there are now 31 risks that require more action, 19 are for further investigation, 5 risks or opportunities that can sustain the current adaptation measures, and 6 are classified as "wait and see". Among them, 6 are considered both risks and opportunities, 4 of which are related to the natural environment, each of which is "further action required" or "further investigation". There are also 8 opportunities that are considered to be opportunities brought by climate change to Northern Ireland, 4 of which are related to the natural environment.

While many of risks and opportunities are similar in urgency and seriousness to those faced in other parts of the UK, the lack of high-quality evidence is a prominent issue in Northern Ireland and the relatively limited climate related policies in place in some sectors add to the uncertainty of future climate change impacts (although there are many policies under development and baseline studies are also underway). The impact of changing climatic conditions and extreme weather events on Northern Ireland are likely intensify in the future due to the degradation of the natural environment and its interaction with external factors such as pollution, overfishing and land use.

Compared with the last assessment, a total of 25 risks in Scotland have increased in urgency score, and only one risk has decreased in urgency score. In addition, there are some new identified risks.

The impact of flooding on people, communities and buildings remains one of the most serious risks in Scotland and causes the highest economic damage to business. At the same time, the water shortage in summer, especially for domestic use, is becoming increasingly problematic in summer. The impact of climate change across the Scottish region also includes the natural and marine environment, as well as its ecological services such as agriculture and forestry, landscape and pollination. The extensive impact of heat waves on health and social economy cannot be ignored either.

In the Welsh region, a total of 26 risks in this assessment has increased in urgency score, and only one risk has decreased in urgency score. There are also some new risks are for the first time in this assessment.

Taking into account all existing adaptation measures, the risks identified in this assessment with higher urgency across the UK which need more actions are mainly:

Table 1.4 Risks of high urgency and need more actions across the UK

England	Northern Ireland	Scotland	Wales
The impact of climate change on the natural environment, including terrestrial, freshwater, coastal and marine species, forests and agriculture. Species, forests and agriculture.	The risks of changing climatic conditions and extreme events to terrestrial species and habitats, including temperature changes, water scarcity, wildfires, floods, wind and hydrological changes (including water scarcity, flooding and salt water intrusion)	The impact of climate change on the natural environment, including terrestrial, freshwater, coastal and marine species, forests and agriculture.	The impact of climate change on the natural environment, including terrestrial, freshwater, coastal and marine species, forests and agriculture.
The increase in the range, number and consequences of pests, pathogens and invasive species has negatively affected terrestrial, freshwater and marine species, forests and agriculture. Affects priority species in terrestrial, freshwater and marine habitats, forestry and agriculture.	The risks of pests, pathogens and invasive species to terrestrial species and habitats.	The increase in the scope, number and consequences of pests, pathogens and invasive species has negatively affected terrestrial, freshwater and marine priority habitat species, forestry and agriculture.	The increase in the scope, number and consequences of pests, pathogens and invasive species has negatively affected priority species in terrestrial, freshwater and marine habitats, forestry and agriculture.
The risks of climate change impacts, especially more frequent floods and coastal erosion, cause damage to infrastructure services. Infrastructure services, including energy, transportation, water, and information and communication technology.	The risks of changing climate conditions to the soil include seasonal aridity and wetness.	The risks of climate change impacts, especially more frequent floods and coastal erosion, cause damage to infrastructure services, including energy, transportation, water, and information and communication technologies.	The risks of climate change impacts, especially more frequent floods and coastal erosion, cause damage to infrastructure services, including energy, transportation, water, and information and communication technologies.
The water supply is reduced due to the increasingly frequent water shortage period.	Changes in climate conditions (including temperature changes and water scarcity) pose risks to natural carbon storage and sequestration.	The impact of extreme temperatures, high winds and lightning on the transportation network	The impact of extreme temperatures, high winds, and lightning on the transportation network.
The impact of extreme temperatures, high winds and lightning on the transportation network.	Extreme events and changing climate conditions (including temperature changes, water scarcity, wildfires, floods, coastal erosion, wind and salt water intrusion) pose risks and opportunities for	The impact of higher and higher temperatures on people's health and well-being, as well as changes in household energy demand caused by seasonal temperature changes.	The impact of increasing high temperature on people's health and well-being.

	agricultural and forestry productivity.		
The impact of high temperature on health and well-being, as well as seasonal temperature changes on residential energy demand. The severity and frequency of flooding in homes, communities, and businesses has increased.	The risks of pests, pathogens and invasive species to agriculture. The risks of pests, pathogens and invasive species to forestry.	The severity and frequency of flooding in homes, communities, and businesses has increased. The viability of coastal communities and the impact of sea level rise, coastal flooding and erosion on coastal businesses.	The severity and frequency of flooding in homes, communities, and businesses has increased. The impact of rising sea levels, coastal floods and erosion on coastal businesses.
The viability of coastal communities and the impact of sea level rise, coastal flooding and erosion on coastal businesses.	Changes in climate conditions and extreme events pose risks to freshwater species and habitats, including rising water temperature, flooding, water scarcity, and phonological changes.	Damage to cultural heritage assets due to temperature, precipitation, groundwater and landscape changes.	More frequent extreme weather disrupts health and social care services.
More frequent extreme weather disrupts health and social care services.	Changes in climate conditions pose risks to marine species, habitats, and fisheries, including ocean acidification and rising water temperatures.	International impacts that may have an impact on the UK, such as risks to food supply, safety and security, as well as risks to international law and governance of climate change and its impact on the UK, international trade routes, public health, and cross-industry and cross-regional risks Doubled	Damage to our cultural heritage assets due to temperature, precipitation, groundwater and landscape changes.
Damage to cultural heritage assets due to changes in temperature, precipitation, groundwater and landscape.	The risks of pests, pathogens and invasive species to marine species and habitats.	--	International impacts that may have an impact on the UK, such as risks to food supply, safety and security, as well as risks to international law and governance of climate change and its impact on the UK, international trade routes, public health, and cross-industry and cross-regional risks Doubled
International impacts that may have an impact on the UK, such as risks to food supply, safety and security, as well as risks to international law and governance of climate change and its impact on the UK, international trade routes, public health, and cross-industry	The risks and opportunities of coastal flooding, erosion and climatic factors to coastal species and habitats.	--	--

and cross-regional risks Doubled.			
--	Infrastructure networks (water, energy, transportation, information and communication technology) are exposed to risks due to joint failures.	--	--
--	The risks of river, surface water and groundwater flooding to infrastructure services.	--	--
--	Risks of high and low temperatures, strong winds, and lightning to transportation.	--	--
--	Risks of high temperature to health and welfare.	--	--
--	Risks of flooding to people, communities and buildings	--	--
--	The risks faced by cultural heritage.	--	--
--	The risk of flooding to commercial premises.	--	--

Box 1 The case of flood control in the UK

The UK is one of the countries most affected by urban waterlogging and other surface water flooding. For this reason, the UK government, has been exploring and optimizing flood prevention and management methods based on the legislation, and established an urban flooding and waterlogging prevention system with timely warning and optimised drainage system as its main characteristics.

The UK established a national-level working group for water affairs in 2001, which issued the *Framework for Sustainable Urban Drainage System* in England and Wales in 2003 and *Interim Code of Practice for Sustainable Urban Drainage Systems* in 2004, which set out a hierarchical and prioritized integrated management chain of preventive measures, source control, site control, and regional control, and integrate the concept of sustainable urban drainage system (SuDS) with the urban planning system to ensure the application of “win-win” concept of ecological protection and urban development into various levels of planning. On April 11, 2009, the Flood Forecasting Center was established in the UK, which combines the forecasting techniques of Met Office and the Environment Agency's hydrological knowledge to issue early warnings on the risk of surface water flooding from heavy rainfall, distributes warnings of heavy rainfall to the county level, and help local authorities and agencies to respond to flooding. In April 2010, the UK Parliament passed the *Flood and Water Management Act*, which mandates the use of 'sustainable urban drainage systems' for all new construction projects, with the Department for Environment, Food and Rural Affairs being responsible for setting national standards on the design, construction, operation and maintenance of the system.

"Sustainable Urban Drainage System" includes a range of management methods and technologies for sustainable management of surface water and groundwater. There are mainly four ways to "absorbing" rainwater and reduce the pressure on the urban drainage system: firstly, rainwater collection, where the rainwater from roofs, parking lots, etc. is stored on-site or in nearby water tanks for reuse; secondly source control through paving the permeable surfaces soakaway pits, permeable walkways and green roofs; and thirdly, site-specific management,, that is, rainwater flowing from the roof and other places is introduced into ponds or depressions; the fourthly, bio retention. Use a series of landscape features, such as reed beds, filter drainage pipes, etc., to filter and process surface water, usually in areas with low pollution risk.

Take London as an example. London faces the risk of tidal flooding on the Thames and other rivers such as Ravensbourne or Quaggy. On the other hand, the annual rainfall in London reaches 1100mm, and there is a high percentage of impermeable pavements, which prevents rainwater from going deep into the ground. Moreover, clay soils in some areas of London have reduced the rate of infiltration, which can easily lead to flooding of surface water and increase the possibility of urban waterlogging. London is extremely vulnerable to surface water flooding. Increasing climate change has led to further increase in the frequency and intensity of heavy rains. London is facing more risks of harm and loss to people, property and infrastructure.

In order to effectively use the existing and planned drainage infrastructure and avoid increasing the risk of flooding, in 2016, the Greater London Authority issued the "London Sustainable Drainage Action Plan" to provide sustainable drainage for existing buildings, land and infrastructure System transformation to improve the service efficiency provided by existing drainage pipes and sewers.

At the same time, 33 local authorities in London, as the local flood prevention authority (LLFA), are implementing the London Sustainable Drainage Fact Sheet from April 2019. They work with the Environment Agency, Thames Water Company and other stakeholders to manage flood risks. LLFA are required to regularly identify and update flood risks in their area, identify interventions that can help mitigate these risks, and apply for funding for measures that have successful operations.

The London Assembly appointed the Thames Regional Flood and Coastal Committee. The Chair of the London Assembly's Transport and Environment Committee and the Chair of the Thames Regional Flood and Coastal Committee work jointly on on flood management in the Greater London area, and provide flood prevention and control advice to London boroughs through the Thames River Flood Advisory Team.

1.5 Key messages and conclusions

The UK has a robust framework for assessing climate risks, but this framework is specifically designed to assess priorities for adaptation. Although an evaluation of the potential magnitude of risks is a part of this assessment, there have so far been no consistent multi-sectoral quantitative assessments of the magnitude of direct climate risks to the UK. However, the UK does have a coherent set of climate projections (most recently UKCP18), which provide the basis for such an assessment.

This brief review has examined potential direct impacts of climate change on the UK, focusing on a set of studies that have used the latest UKCP18 climate projections. There are several conclusions.

First, the use of a consistent set of climate projections across studies provides opportunities for studies in different sectors to be compared and synthesised. However, the characteristics of these climate projections can potentially constrain assessments. The UKCP18 projections prioritize very high RCP8.5 emissions and therefore tend to produce large increases in climate risk. Such an emissions scenario may be unrealistically high. The probabilistic strand uses a wider range of projections, but these do not necessarily map closely onto the projections of greatest interest to the policy community. The CCRA3, for example, focused on worlds consistent with increases in temperature of 2 and 4ºC by 2100, but these do not correspond directly to RCP scenarios.

Second, the studies have highlighted considerable uncertainty in the projected magnitude of the direct impacts of climate change in the UK. This is particularly important for indicators based on precipitation change. This highlights the importance of using as wide a range of climate projections as possible to define potential direct impacts and changes in risk.

Third, the studies have shown considerable variation in impact across the UK. For the temperature-based indicators, this is primarily because current climate varies across the UK from the relatively warm south to relatively cool north: the projected change in temperature varies little across the UK. For the rainfall-based indicators, this is primarily because the change in rainfall is projected to vary across the UK, with the greatest increases in the north and west and greatest decreases in the south and east. This highlights the importance of undertaking assessments at the most appropriate spatial scale: averages over large areas may hide considerable and significant local variability.

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Chapter 2: The Direct Risks of Climate Change to China

2.1 Introduction

In the past 100 years, global climate change characterized by warming has been a scientific fact, and poses major risks to the natural ecosystems and human society development. According to the latest results published by Working Group I of the IPCC Sixth Assessment Report ,Climate Change 2021: The Natural Science Basis" (IPCC, 2021) , climate change is already affecting all regions of the globe in different ways, and will intensify with warming in the future. Each 0.5°C increase in global temperature will result in an increase in the frequency and intensity of extreme heat, extreme precipitation and, in some regions, extreme drought events. When global temperature increases by 2°C, extreme heat is more likely to exceed critical threshold for crop growth and human health. When global temperature rises by 2°C compared to 1.5°C, it will cause many regional-specific changes, including the risk of intensified tropical cyclones and extratropical storms, increased runoff floods, reduced and drier average precipitation in some areas, and increased fire danger. The probability of a compound extreme events such as heat waves and drought occurring simultaneously is higher. Global warming has a wide range of impacts on natural ecosystems, human management, and social economics, and as the exposure of population and economies to the effects of climate change continues to increase, the challenge of climate change risks s faced by humans will become even more severe in the future. This chapter provides an overview of climate change risks in China with focus on selected key regions such as the Yangtze River Economic Belt, the Guangdong-Hong Kong-Macao Greater Bay Area, the Qinghai-Tibet Plateau and the Yellow River Basin. At the same time, taking Shenzhen as an example, it has presented an in-depth study of the climate risks and responses in key cities by using Shenzhen as example.

The data used in the risk study of key regions and cities are regional statistical downscaling data driven by five CMIP5 global climate models with high-resolution regional climate models. The reference period for future projections is 1986-2005, which is divided into three periods 2026–2045, 2046–2065 and 2080–2099 (representing the near, mid and late 21st century, respectively). The indicators of extreme events are summarized as below:

Table 2.1 Definition of extreme event index

Index abbreviation	Index name	definition	unit
SU35	Number of hot days	Annual count of days when daily maximum temperature (TX) > 35°C	days
TR25	Number of hot nights	Annual count of days when daily minimum temperature (TN) > 25°C	days
HWDI	Heat wave duration index	Annual total number of days with at least three consecutive days when TX > 35°C	days

TXx	Maximum value of daily maximum temperature	Annual maximum value of TX	°C
TNx	Maximum value of daily minimum temperature	Annual maximum value of TN	°C
DTR	Diurnal temperature range	Annual mean difference between TX and TN	°C
R25	Number of heavy precipitation days	Annual count of days when daily precipitation (PR) ≥ 25 mm	days
R50	Number of very heavy precipitation days	Annual count of days when PR ≥ 50 mm	days
R95p	Total amount of extreme precipitation	Annual total precipitation amount when PR > 95th percentile of precipitation on wet days in the reference period	mm
Rx1day	Maximum 1-day precipitation amount	Annual maximum of the precipitation amount for 1-day interval	mm
Rx5day	Maximum consecutive 5-day precipitation amount	Annual maximum of the precipitation amount for 5-day interval	mm

2.2 China's climate change risks

China is highly sensitive to climate change, and the extent to which climate change affects key areas and key regions of China varies. The results of a large number of studies have shown that the effects of climate change do more harm than good. From the perspective of changes in the climate system, the future trend in temperature and precipitation extreme will be more pronounced, with significant changes in the timing, intensity, frequency, and regional characteristics of extreme disasters such as high temperature heat waves, rainstorms, floods, and droughts will change significantly in China under a state of high climate variability. (Qin et al., 2015). Water security risks have increased significantly, the cryosphere has shrunk severely, sea level rise has increased the risk of coastal submergence, and the fires, diseases and pests that accompany climate warming will also severely constraint ecosystem services in China. With global climate change, the layout of agricultural crops in China has changed, and the area of suitable cropping has expanded (Ye et al., 2015). The increase and intensification of extreme weather events (precipitation, snow disasters, strong winds, etc.) in the future will pose risks to transport, especially in areas with high road network vulnerability. Climate change will affect the supply and demand of energy as well as the operation of the entire system, with increased energy consumption and a general increase in urban energy demand drive by extreme events (Chen Sha et al., 2017). The climate change risk pattern of various fields and key projects in China is shown in Figure 2.1 (Feng and Chao, 2020). In terms of ecosystems, in the next few decades, water resources risks in Northwest and North China will be at high risk, while ecosystems and cryosphere in Northwest China will receive greater attention. In terms of the socio-economic system, South China is at overall higher risk due to the increased extreme events, while the North China is at relative high risk due to water scarcity. The future trend of increased heavy rainfall and heat waves will make the transportation and energy risks higher in East China, while transportation and tourism industry in Southwest China will be more severely affected by the high temperature. Overall, the frequent occurrence of extreme weather events will significantly affect industries such as energy, transport and tourism sectors. Among major projects, ecological projects and permafrost projects are at higher risk from climate impacts, followed by road/rail projects and water conservancy projects.

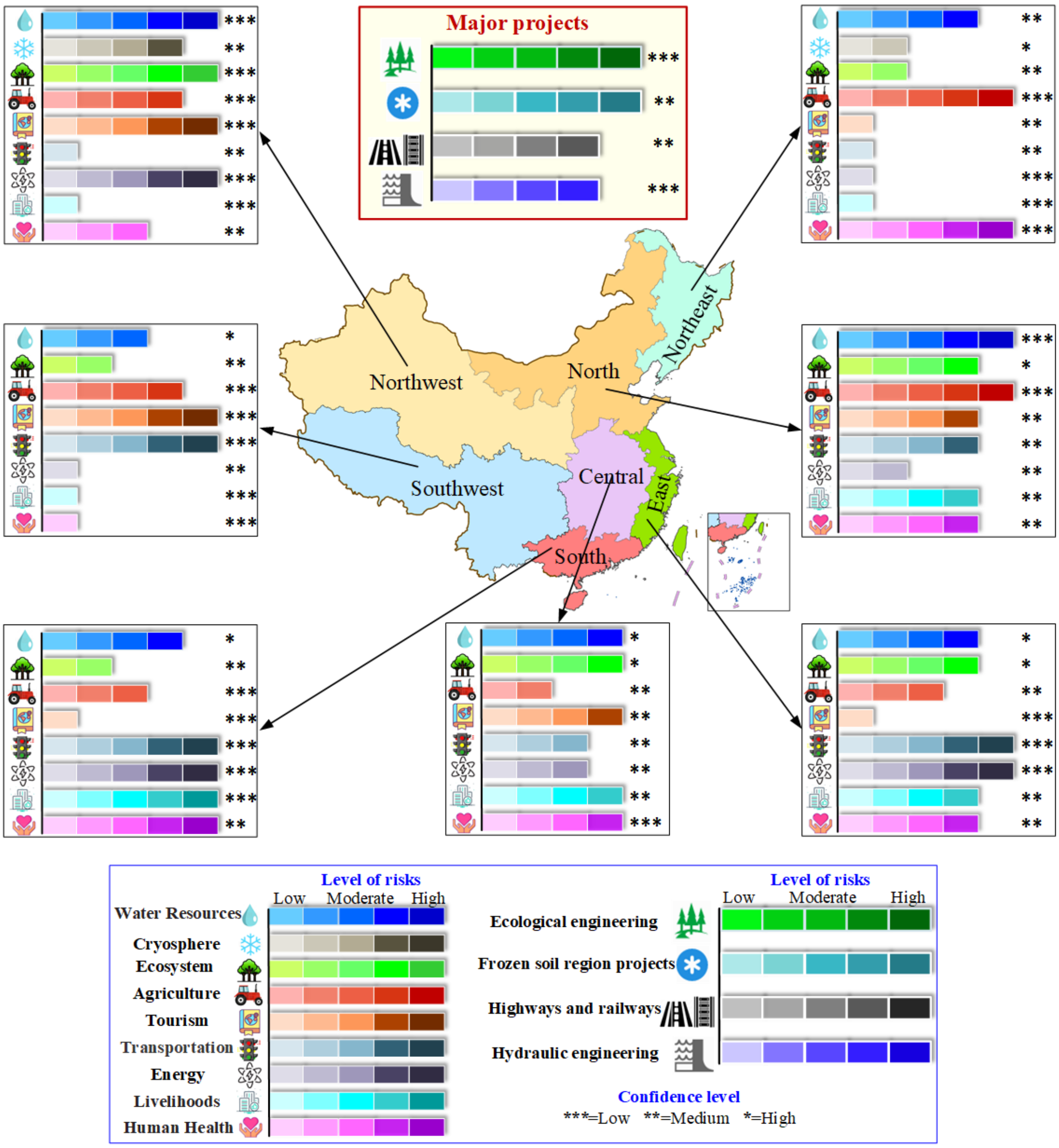


Figure 2.1 The climate change risk pattern of various fields and key projects in China (quoted from Feng and Chao, 2020)

2.3 Climate change risks in key regions

2.3.1 Yangtze River Economic Belt

Based on the high-resolution joint dynamical and statistical downscaling projection data driven by 5 GCM models under the RCP4.5 scenario, the extreme event variability characteristics for three time periods in the 21st century (near-term 2026-2045, mid-term 2046-2065 and late-term 2080-2099) are predicted based on the assessment of the model's ability to simulate extreme climate in the Yangtze River Economic Belt. The main conclusions are as follows:

(1) The projection for the 21st century is shown in Figures 2.2 and 2.3. The number of high temperature days (HD), maximum daily maximum temperature (TXx) and minimum daily minimum temperature (TNn) in the Yangtze River Economic Belt will increase significantly in the future, by 13.9 d/2.6 ℃/2.4 ℃ in the late 21st century, and the number of frost days (FD) will decreased significantly, by 16.1 days in the late 21st century. Future maximum 5-day precipitation (RX5day), number of heavy rain days (R20mm), precipitation intensity (SDII) and total rainy day precipitation (PRCPTOT) in the Yangtze River Economic Belt show an increasing by 13.7 mm/0.7 d /0.5 mm/d/39.3 mm, respectively, in the late 21st century.

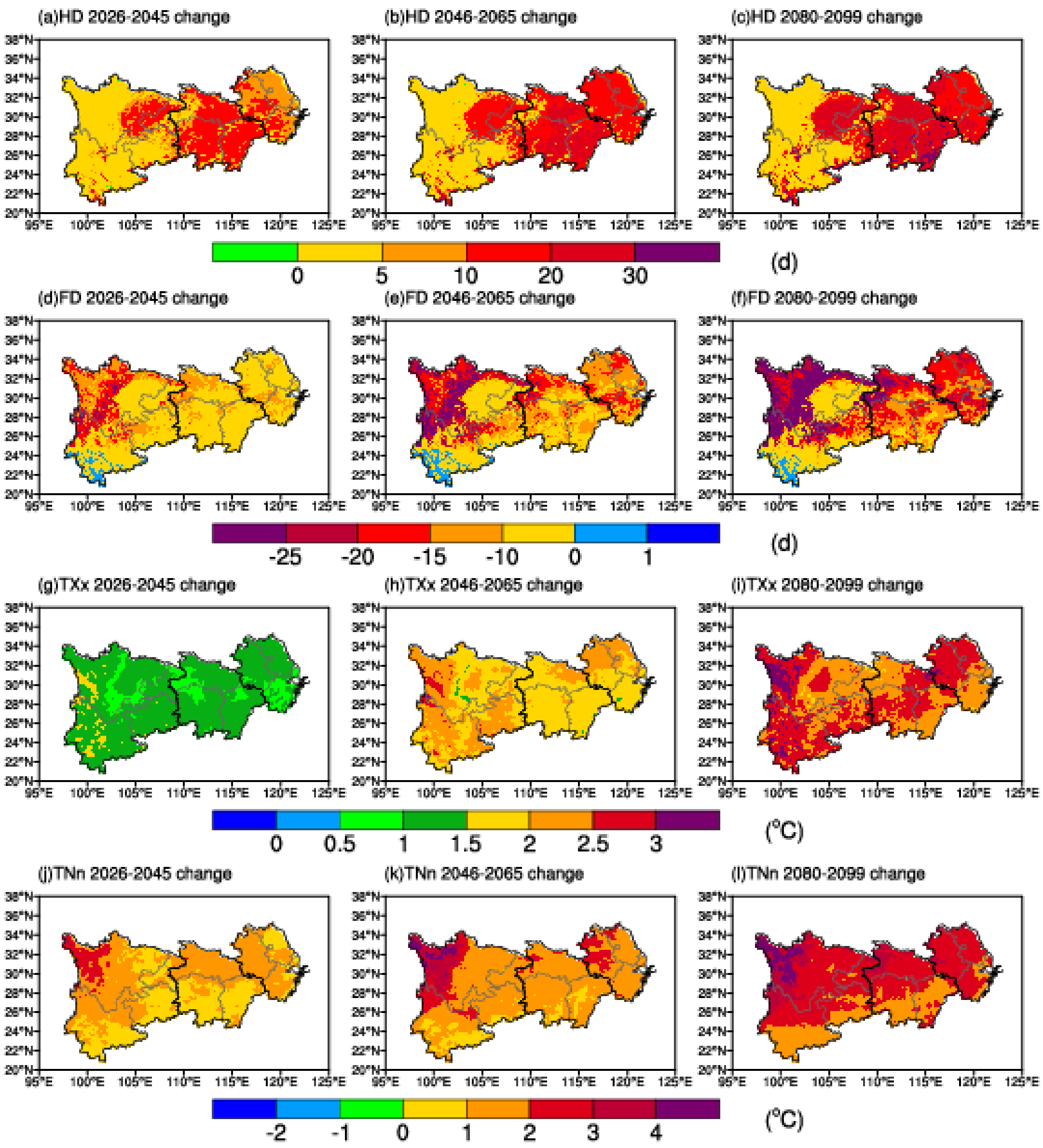


Figure 2.2 Changes in temperature-related extreme events in the Yangtze River Economic Belt in the century (relative to 1986–2005) (a-c: HT, d; d-f: FD, d; g-i: TXx, ℃; j-l: TNn, ℃)

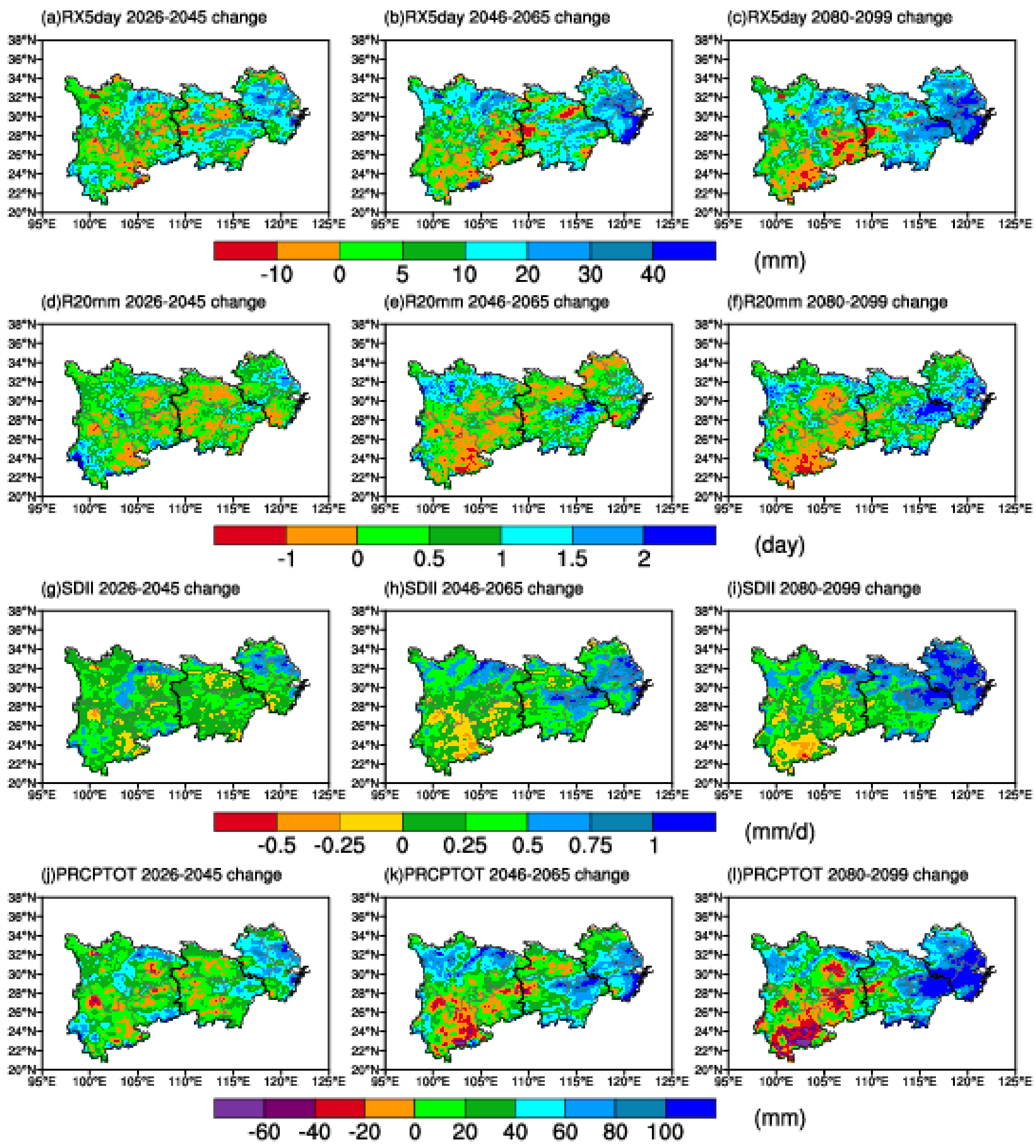


Figure 2.3 Changes in extreme events related to precipitation in the Yangtze River Economic Belt in the century (relative to 1986–2005) (a-c: RX5day, mm; d-f: R20mm, d; g-i: SDII, mm/d; j -l: PRCPTOT, mm)

(2) As shown in Figures 2.4 and 2.5, GDP exposure to high temperature events and heavy precipitation events in the 21st century for both the Yangtze River Economic Belt and the three sub-basins showed an increasing trend, with the largest increase in the downstream basins; the population density (POP) exposure showed a trend of first increasing and then followed by a decreasing trend in both regions, with the peak of high temperature population exposure occurring in the middle of the 21st century and the exposure of heavy rainfall population density in the near term of the 21st century, with the greatest variation in the downstream basin. The population density exposure of high temperature events mainly depends on the population distribution factor, with the distribution factor of GDP exposure being equally important as the non-linear factor. Exposure for heavy precipitation events is largely dependent on the GDP (POP)

distribution factor.

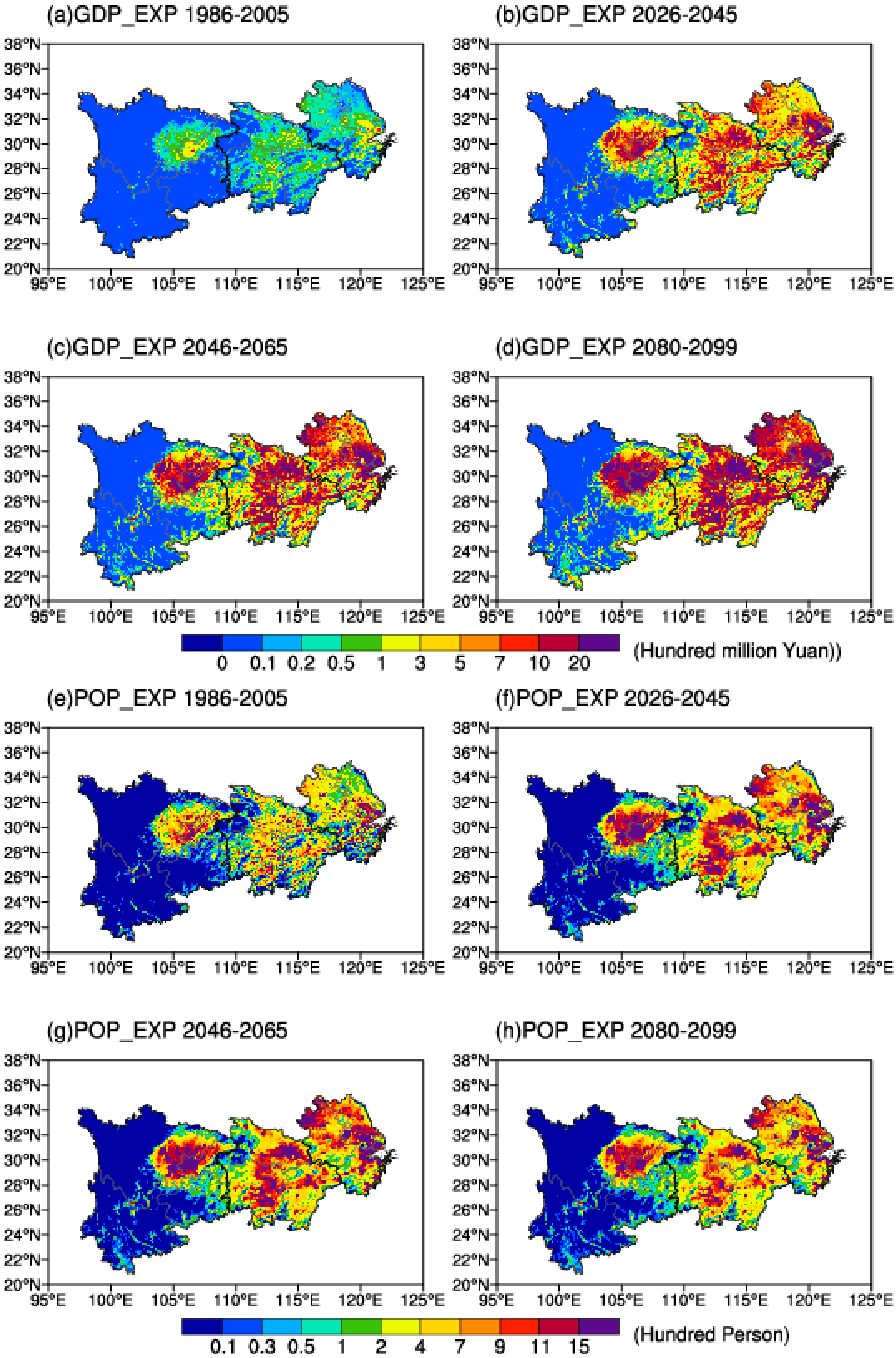


Figure 2.4 Spatial distribution of GDP and population density exposure to high temperature events in the Yangtze River Economic Belt during the reference period

(1986-2005) and different periods of the 21st century (a-d: GDP, unit: 100 million yuan; e-h: population density, unit: Hundreds of people)

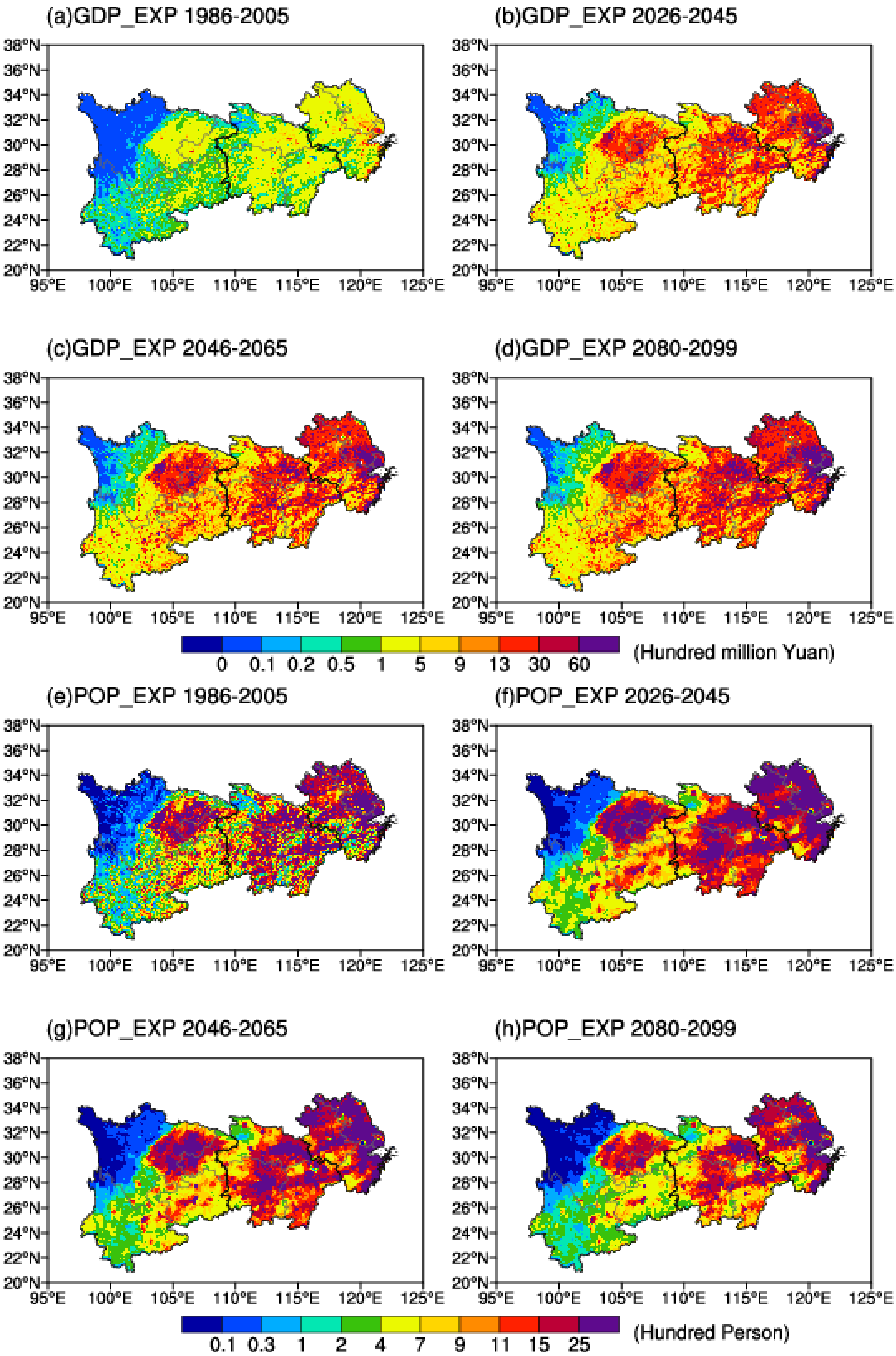


Figure 2.5 Changes in GDP and population exposure of heavy rainfall events in the Yangtze River Economic Belt in the 21st century (a-d: GDP, unit: 100 million; e-h: population density, unit: 100 people)

In this paper, the use of multi-model ensemble averaging can effectively reduce the uncertainty of regional models, but there are certain limitations in using only 5 modes for uncertainty analysis; secondly, future research needs to further integrate multiple indices, especially multi-factor indices, and combine disaster vulnerability to refine the forecast of future disaster risks to reduce the uncertainty of the prediction.

2.3.2 Guangdong-Hong Kong-Macao Greater Bay Area

Urban heat islands of the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) have intensifying year by year, and have increased substantially since the 21st century, with multiple heat island centers forming a semi-ring- "U"-shaped cluster of heat islands spread over oa wide area.

(1) High temperature heat wave and future risks of heat island

Both the observation and projected simulations show a warming and wetting tendency and large interdecadal variability in the GBA from the past 60 years to the end of the 21st century. The linear trends for past (1961–2019) and future (2021–2099) annual temperature are 0.22 [0.17–0.30] °C/10a and 0.19 [0.17–0.21] °C/10a respectively, and the trends in annual precipitation are 29 mm/10a (insignificant) and 20 [6–32] mm/10a, respectively. Regardless of the greenhouse gas concentration scenario, the extreme heat wave events in the Guangdong-Hong Kong-Macao Greater Bay Area and South China region in which it is located will increase significantly in the future (high confidence) (Wang et al., 2015; Zhu et al., 2019).

As shown in Figure 2.6 and 2.7, SU35, TR25, HWDI, TXx and TNx are projected that to increase significantly the end of the 21st century show s at the rates of 3.6 [3.2 − 3.8] d/10a, 6.8 [6.3 − 7.4] d/10a, 2.9 [2.6 − 3.1] d/10a, 0.24 [0.21–0.27]°C/10a and 0.20 [0.18–0.22]°C/10a, respectively, and by 2050 the magnitudes of the increases are 15 days, 50 days, 12 days, 1.6°C and 1.5°C relative to those in the reference period, respectively. The DTR shows a decreasing trend over most periods of the 21th century, however, the trend is small and not significant. The most pronounced increase in extreme heat events is found in the central part of the GBA, including Guangzhou and Dongguan. Values in these areas in the mid-21st century (2046–2065) will increase by three times over the reference period SU35 and six times for HWDI. Then the proportion of the area with heat risks of Grades IV and V will be as high as 65.9% at that time, with the value of 41.5% for the risk of Grade V mainly distributing in the central part of the GBA. Compared with the baseline period, the area with the highest risk of heat disaster shows increases by a factor of 11 in the mid-21st century.

The risk of high temperature heat waves in the Guangdong-Hong Kong-Macao Greater Bay Area will also increase if the synergistic effects of future urbanization and land use changes are taken into account.

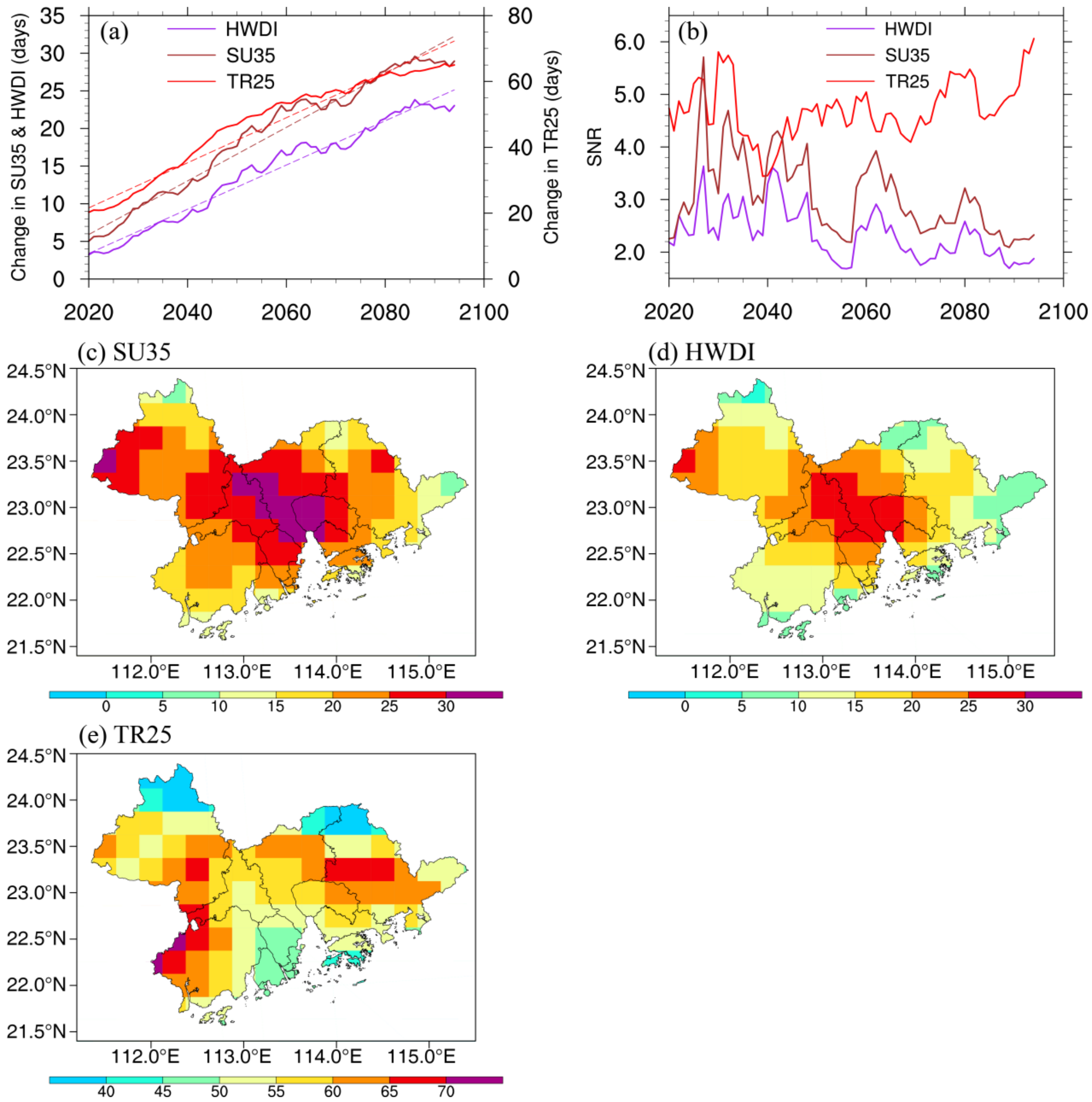


Figure 2.6 (a) Time series of area-averaged changes and (b) their SNRs during 2021–2099 and (c–e) spatial distributions of changes in temperature extremes during 2046–2065: (c) SU35 (units: d), (d) HWDI (units: d), (e) TR25 (units: d)

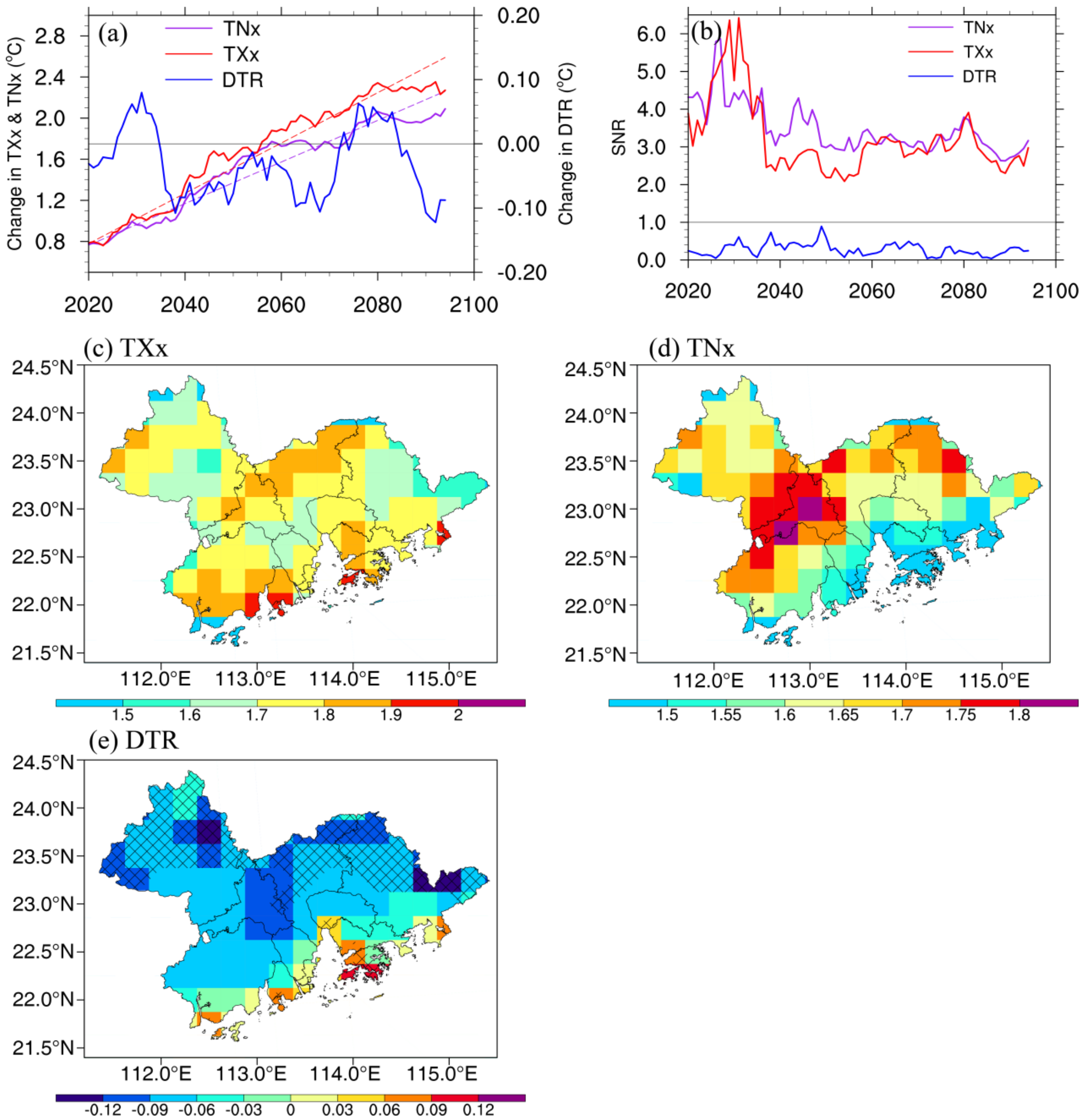
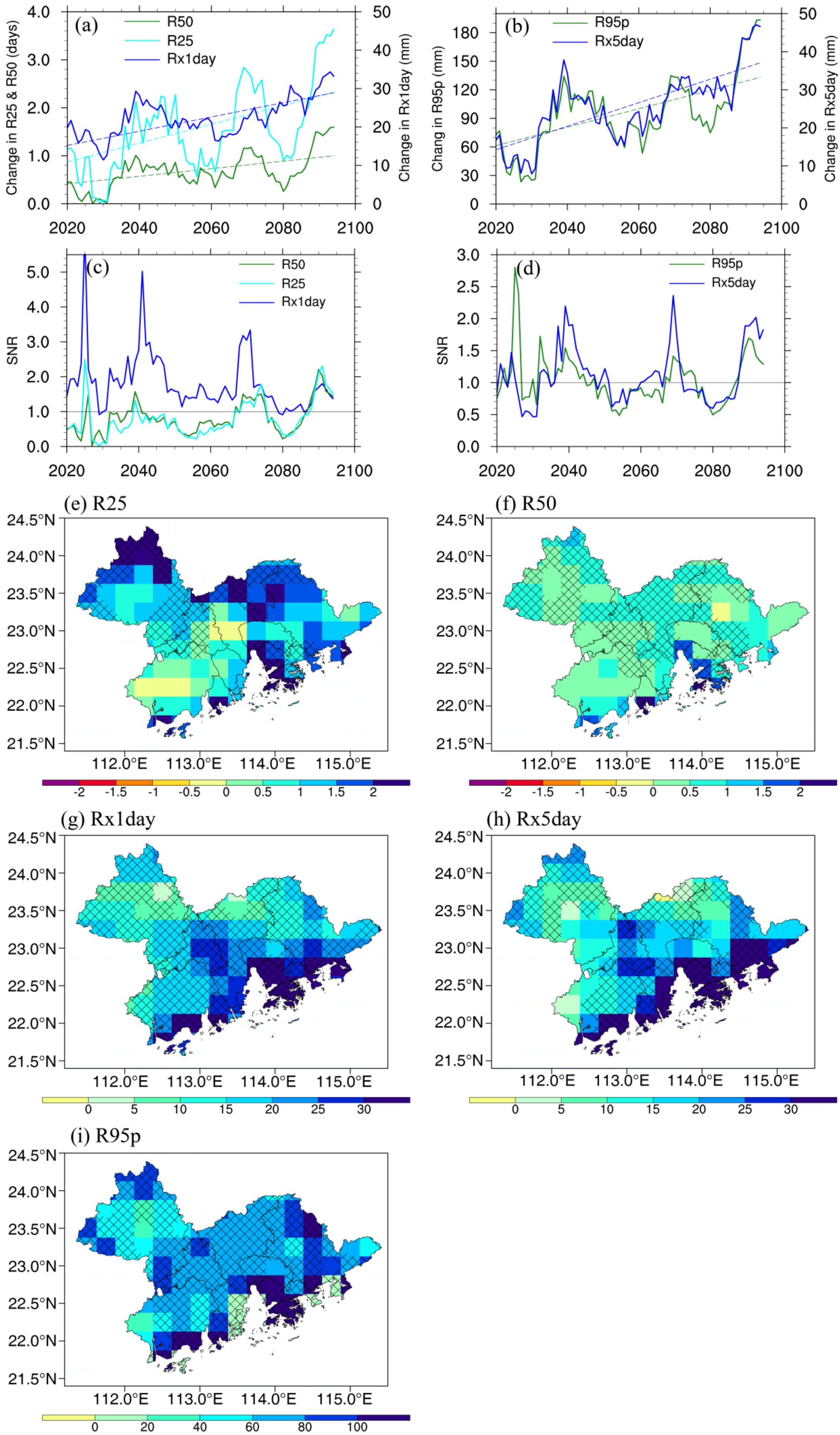


Figure 2.7 (a) Time series of area-averaged changes and (b) their SNRs during 2021–2099 and (c–e) spatial distributions of changes in temperature extremes during 2046–2065: (c) TXx (units: °C), (d) TNx (units: °C), (e) DTR (units: °C)

The ever-increasing extreme high temperature and heat island effect in the future will also exacerbate the human health risks in the Greater Bay Area. Compared with the period from 1985 to 2014, the incidence of both Plasmodium vivax and Plasmodium falciparum malaria will increase by 34.3% and 47.1%, respectively, by 2080 under the RCP4.5 scenario, and by 49.8% under the RCP8.5 scenario and 79.6%, of which the estimated result in South China is largely the same as that of the whole country (Hundessa et al., 2018).

(2) Heavy rains and floods and future risks of water resources security

With global warming, the frequency and intensity of future extreme precipitation events in the Guangdong-Hong Kong-Macao Greater Bay Area will further change. As shown in Figure 2.8, R25, R50, R95p, Rx1day and Rx5day are projected that to increase significantly by the end of 21st century, with magnitudes of 0.2 [0.0–0.4] d/10a, 0.1 [0.0–0.2] d/10a, 11.7 [3.2–19.1] mm/10a, 1.9 [0.7–3.2] mm/10a and 3.3 [1.1–5.1] mm/10a, respectively, with the areas of greater growth in the mid-21st century located along the coastal area of the GBA. River runoff simulations based on multiple hydrological models driven by CMIP5 global climate model outputs point to enhanced 5-year, 30-year and 50-year river flood intensities in the mainstream of the Pearl River under both RCP8.5 and RCP2.6 scenarios due to enhanced future extreme precipitation, and a high degree of consistency in the outputs between models (Li et al., 2016). In the future, the intensity and duration of drought in the Pearl River Basin will increase, while water demand may further increase and the contradiction between water supply and demand will further intensify. Therefore, future changes in total precipitation and water resources in the Greater Bay Area may be relatively small, but the relevant future estimates have greater uncertainty, and there is a greater chance of increased drought risk. If the future water demand increases at the same time, there will be an intensified conflict between water supply and demand.



(a)
R50
R25
Rx1day
Change in R25 & R50 (days)
Change in Rx1day (mm)
(b)
R95p
Rx5day
Chang in R95p (mm)
Change in Rx5day (mm)
(c)
SNR
(d)
(e) R25
(f) R50
(g) Rx1day
(h) Rx5day
(i) R95p

Figure 2.8 (a–b) Time series of area-averaged changes and (c–d) their SNRs during 2021–2099 and (e–i) spatial distributions of changes in precipitation extremes during 2046–2065: (e) R25 (units: day), (f) R50 (units: days), (g) Rx1day (units: mm), (h) Rx5day (units: mm), (i) R95p (units: mm).

(3) Future risks of typhoons, storm surges and sea level rise

The Guangdong-Hong Kong-Macao Greater Bay Area is located in the central coast of Guangdong. The typhoon hazard risk assessment shows that the risk is lower in Greater Bay Area than the western and eastern coasts of Guangdong, with the greatest typhoon hazard risk being Zhanjiang in western Guangdong among cities across the province, and the smallest being Dongguan within the Greater Bay Area (Shang and Li, 2015). However, the risk of economic losses caused by typhoon hazards differs, with higher risks in Guangzhou, Dongguan, Shenzhen, Zhongshan and Zhuhai within the Greater Bay Area, and a radiating weakening of risks inland from the Pearl River Estuary region (Yin et al., 2013). This is mainly due to the low terrain of the Guangdong-Hong Kong-Macao Greater Bay Area, its relatively dense population and a highly developed economy.

Storm surge risk assessment is mainly an assessment of the scale and frequency of future storm surges. The cities (districts) with the highest risk of a once-in-100-years storm surge disasters in the coastal areas of Guangdong are all within the Guangdong-Hong Kong-Macao Greater Bay Area, namely Zhuhai and Zhongshan,. with Zhongshan rising from a low-risk area to a very high-risk area, Guangzhou Panyu (including Nansha) and Taishan (a county-level city under Jiangmen) falling from a very high-risk area to a high-risk area, and Zhuhai's storm surge risk always remaining at a very high level (Li and Li, 2017).

The intensity of landing typhoons and the magnitude of sea level rise in the Guangdong-Hong Kong-Macao Greater Bay Area were estimated under the IPCC future emission scenarios. Under the RCP8.5 scenario, the peak intensity of a landfall typhoon (the maximum surface wind speed during its life cycle) is projected to increase by 3.1% in the near future (2015-2039), and storm surges are projected to increase about 8.5% in the long-term future (2075-2099) (Chen et al., 2020). Estimates of the relationship between global average and the sea level change in the Pearl River Delta indicate that a 1.0 m increase in global average sea level would correspond to a 1.3 m increase in the Pearl River Delta (with uncertainty of 1.25 to 1.46 m) (Xia et al., 2015). The Guangdong-Hong Kong-Macao Greater Bay Area is one of the most vulnerable regions to sea level rise along the Chinese coast. Under the RCP8.5 scenario, considering the extreme value of relative sea level change due to land subsidence (0.20m) and the extreme inter-monthly change (0.33m), it is estimated that the sea level of the Pearl River Delta will rise by 1.94m by 2100, with a potential submerged area of 8.57×103km^2. The study pointed out that at a sea level rises of 1.0m, the length of salt tide intrusion at the Four Eastern Gate of the Pearl River Estuary, Humen, Jiaomen, Hongqili and Hengmen will increase by approximately 21.37 km, 9.64 km, 9.75 km and 4.82 km respectively (Liu and Hong, 2019). In addition, the study also estimated the extent of damage to coastal mangrove and seagrass ecosystems and the erosion loss of wetland ecosystems caused by future sea level rise. In the future scenario, the proportion of inundated farmland and the loss of agricultural production in the Guangdong-Hong Kong-Macao Greater Bay Area will gradually increase, with a significant increase in inundated farmland in Yangjiang, Foshan and Dongguan in the Greater Bay Area, and a relatively slow increase in inundated farmland in Guangzhou and Zhuhai Relatively slow (Kang et al., 2016). Among the agricultural losses, vegetables will suffer the most production losses, followed by rice and peanuts (Kang Lei et al., 2015).

(4) Future risks of air pollution from climate change

Air pollution is strongly affected by weather and climatic conditions, making it sensitive to climate change. The IPCC predicts that the air quality in cities will continue to deteriorate in the future, which may be attributed to an increase in anticyclonic weather conditions (IPCC, 2014). In the near future (2030-2039) and the long-term future (2090-2099). Changes in various air pollutants (O3, PM10 and SO2) in the Guangdong-Hong Kong-Macao Greater Bay Area under RCP 4.5 and RCP 8.5 emission scenarios point out to a decrease in June to August, but an increase in pollutant levels in all other seasons. In particular, the estimated change in average concentrations are more significant in the forward RCP8.5 scenario. The study also found that the frequency of high pollution levels will increase from December to February and from March to May. The proportion of pollution events is expected to increase by 6.4% to 9.6%. In the future, climate change alone will have a significant ongoing impact on air quality in the Guangdong-Hong Kong-Macao Greater Bay Area (Tong et al., 2018).

The air quality model also assessed the risk of future ozone pollution from a combination of climate change and emission changes (Liu et al., 2013). Radiation and ground temperature changes caused by climate change will result in a significant increase in isoprene and monoterpene emissions from the early 21st century to the 2150s; while ground temperatures above 40°C may inhibit biological emission events. Due to climate change, the average ground-level ozone concentration in the afternoon is expected to increase by 1.5 ppb; and due to changes in anthropogenic emissions, the overall average concentration of ozone in the Greater Bay Area will increase by 6.1 ppb, even if the ozone in the southern part of the Greater Bay Area will decrease. The combined effects of climate change and anthropogenic emissions would increase afternoon ground-level ozone concentration in the Greater Bay Area by 11.4ppb. The current assessment highlights the impact of climate change on ozone despite the great impact of changes in anthropogenic emissions.

2.3.3 Qinghai-Tibet Plateau

The Qinghai-Tibet Plateau is one of the most sensitive areas in response to global climate change. It is also an area with a fragile ecological environment. It is an important water source and ecological barrier area in China.

(1) The climate on the Qinghai-Tibet Plateau has become significantly warmer and more humid, and extreme weather and climate events have increased

From 1961 to 2020, the annual average temperature of the Qinghai-Tibet Plateau showed a significant upward trend (Figure 2.9), reaching 0.35°C/10 years, slightly lower than the Arctic region's warming rate (0.51°C/10 years) during the same period, and exceeding the global warming rate during the same period (0.16°C/10 years) twice. The Qinghai-Tibet Plateau is an area with the most significant climate change in China. 1961 to 2020 saw a significant increase in annual precipitation on the Qinghai-Tibet Plateau, with an average increase of 7.9 millimeters every ten years. Among them, the three-river-source in the central part of the plateau became the most humid, with annual precipitation increasing by 5-20 millimeters on average every ten years. Especially since 2016, precipitation in the Tibetan Plateau region has continued to be abnormally high, with an average precipitation of 539.6 mm in 2016 to 2020, an increase of 12.7% compared to the 1961-1990 average (478.6 mm) (Figure 2.10).

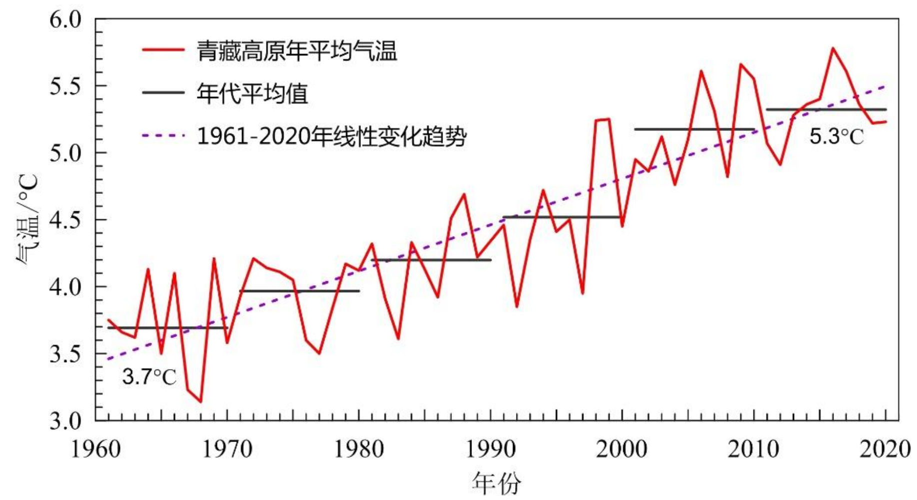


Figure 2.9 Changes in the average temperature of the Qinghai-Tibet Plateau from 1961 to 2020

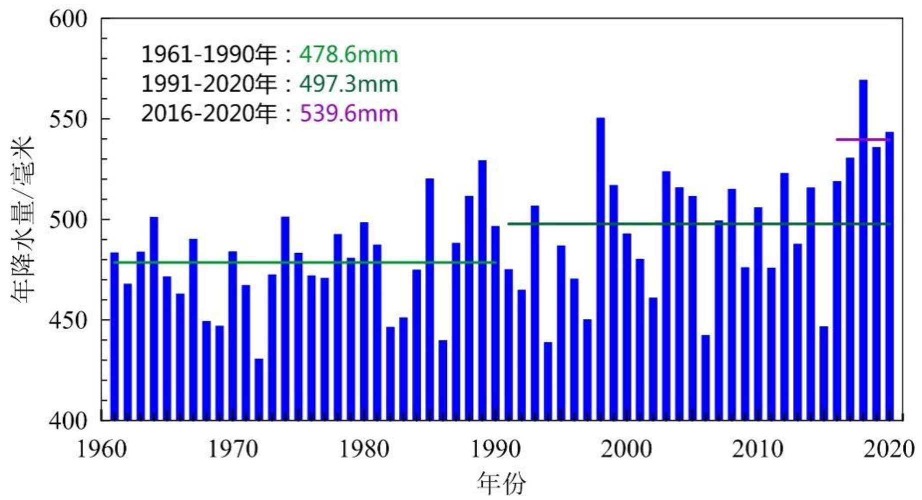


Figure 2.10 Changes in the average precipitation on the Qinghai-Tibet Plateau from 1961 to 2020

Meteorological hazards and derivative disasters have increased on the Qinghai-Tibet Plateau. In the past 40 years, the frequency of extreme heat events and extreme precipitation events has increased significantly in most parts of the plateau against the backdrop of warming and humidification, and meteorological disasters such as heavy rainfall, snowstorm, hail, thunder and lightning and strong winds have increased, as well as the number of derivative disasters such as mudslides, landslides, avalanches, and glacial lake outbursts. Since 1983, there have been 1244 severe meteorological disasters in Tibet, with an increasing frequency of 5.6 times per year. For example: In late January 2019, the daily minimum temperature (–21.7°C) in Nyalam County, Tibet, exceeded the historical extreme low temperature; in late July 2019, the maximum temperature at numbers national weather stations in Tibet broke the historical extreme since local meteorological records were kept.

(2) Climate change on the Qinghai-Tibet Plateau significantly affects water resources and ecological environment

Glaciers on the Qinghai-Tibet Plateau are retreating strongly, and the instability of the function of the "water tower" has increased. In the past 50 years, glaciers retreat has accelerated, with reserves decreasing by 15% and the area shrinking from 53,000 square kilometers to 45,000 square kilometers. Of these, the glacier area in the Himalayas, Hengduan Mountains, Nyainqentanglha and Qilian Mountains has decreased by 20%-30%, which is higher than the 10%-20% reduction of the glacier area of the Pamir Plateau, Tanggula and Karakoram Mountains. The strong retreat of glaciers and the short-term large-scale release of water resources stored in glacier "solid reservoirs" will increase the runoff of most of the glacier-fed rivers in the near and short term; but, with the continuous retreat of glaciers and the long-term loss of glacier water reserves, there will be a tipping point where glacier runoff reaches a peak and then turns into a gradual decrease, eventually aggravating the reduction in glacier runoff and increasing the instability of the "water tower" function, with significant implications for the sustainable use of regional and downstream water resources.

The accelerated melting of permafrost on the Qinghai-Tibet Plateau affects the safe operation of the Qinghai-Tibet Railway and Qinghai-Tibet Highway. Over the past 50 years, the permafrost area of the plateau has been reduced from 1.5 million square kilometers to 1.26 million square kilometers, a 16% decrease. From 1981 to 2019, the thickness (maximum melting depth) of the active layer in the permafrost zone along the Qinghai-Tibet Highway increased significantly, with an average thickness increase of 19.6 cm every ten years (Figure 2.11); from 2004 to 2019, the temperature at the base of the active layer increased significantly and perennial permafrost degradation is significant. The accelerated melting of permafrost poses a threat to the safe operation of the Qinghai-Tibet Railway and Qinghai-Tibet Highway.

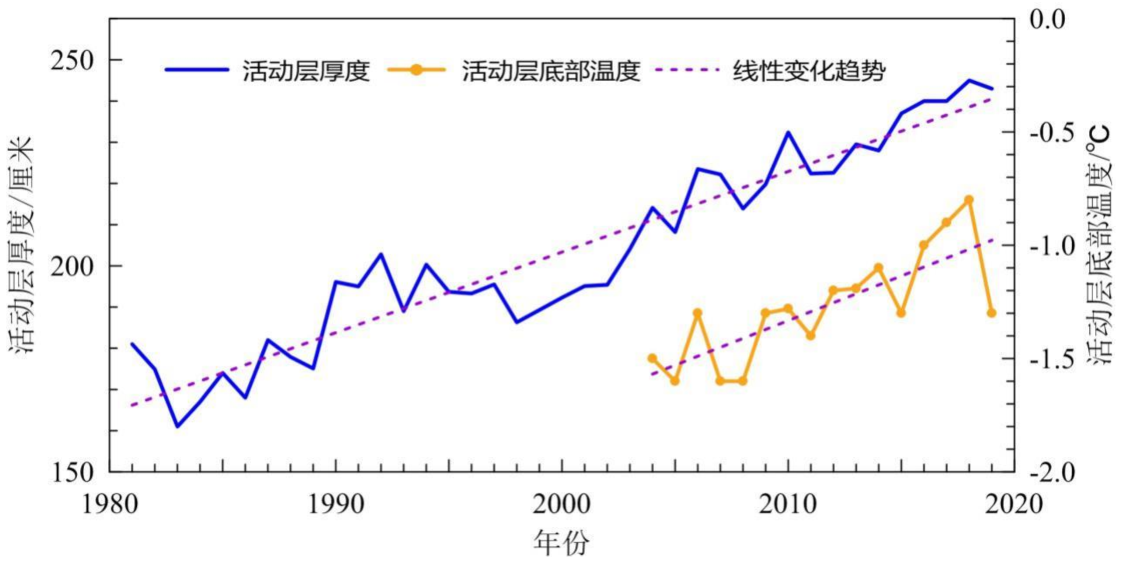


Figure 2.11 Changes in the thickness of the active layer and the temperature at the bottom of the active layer in the permafrost area along the Qinghai-Tibet Highway from 1981 to 2019

The number and area of lakes on the Qinghai-Tibet Plateau have increased. Over 80% of the lakes on the Qinghai-Tibet Plateau are in a state of expansion due to precipitation, evaporation and changes in snow and ice melt caused by regional warming. In the past 50 years, the area of lakes has increased by 5676 square kilometers, and the number of lakes larger than 1 square kilometer has increased from 1081 to 1236, an increase of 14%. Among them, from 1987 to 2019, the water area of Selin Co expanded from 1,634 square kilometers to 2,413 square kilometers; since 2005, due to the warming and humidification of the basin, the water level of Qinghai Lake has recovered steadily, reaching 3196.34 meters in 2020, recovering to the water level of the early 1960s.

The overall ecosystem of the Qinghai-Tibet Plateau is generally improving. In the context of climate warming and humidification, the plateau ecosystem has undergone significant changes, with the return of the vegetation phenology to green earlier, the withering period later and the growing period longer. Grassland net primary productivity and ecosystem carbon sink show an overall increase, and the productivity of alpine grassland increases, thereby changing the cropping system in the agricultural areas, expanding the potential areas suitable for two-rotation crops, increasing the multiple cropping index, extending the frost-free period, expanding the space for structural adjustment of agriculture and livestock, and increasing the income of farmers and herdsmen; forest resources have changed significantly, with forest area and accumulation decreasing until the late 1990s, and continuing to increase thereafter, and increasing forest carbon sinks .

(3) The Qinghai-Tibet Plateau will continue to warm up in the future, and the risks of climate and environmental disasters will further intensify

The Qinghai-Tibet Plateau will continue to warm in the future. The climate model projections of the National Climate Center indicate that under a future moderate greenhouse gas emissions scenario, relative to the base period (1986-2005), , the annual average temperature of the Qinghai-Tibet Plateau will rise by about 1.5°C by 2050, with a maximum winter temperature increase of more than 2.2°C; annual precipitation will increase, but by less than 10%, extreme precipitation in the Qinghai-Tibet Plateau will also increase significantly, and the number of days of heavy precipitation in the Hengduan Mountains will increase by 2-4 days.

The cryosphere in the Qinghai-Tibet Plateau will continue to shrink in this century, aggravating the compound risk of climate and ecological environmental disasters. Glacial retreat and multi-year permafrost degradation will reduce the stability of mountain slopes and increase the number and area of glacial lakes, leading to frequent landslides and floods; degradation of permafrost will increase the risk of instability of Qinghai-Tibet railway and highway foundation projects; at the same time, along with the sharp regional warming and the intensified human activities, glacial lake outbursts on the Qinghai-Tibet Plateau have increased, glacial debris flows have become more active, and the frequency of mega-hazards and catastrophes has increased.

Natural hazard assessment in the Qinghai-Tibet Plateau is very limited, due to the lack of historical observation data and related technical indicators. Based on numbers field investigations, the team constructed an index system for the risk assessment of major meteorological hazards on the Qinghai-Tibet Plateau, systematically identified the historical evolution process of the four types of high-risk areas of meteorological hazards on the Qinghai-Tibet Plateau, including drought, heavy rain, snow disaster and hailstorm, mapped the comprehensive hazard-causing intensity distribution of meteorological hazards (Figure 2.12), and analyzed the potential risk levels of each type of hazard in conjunction with population exposure indicators.

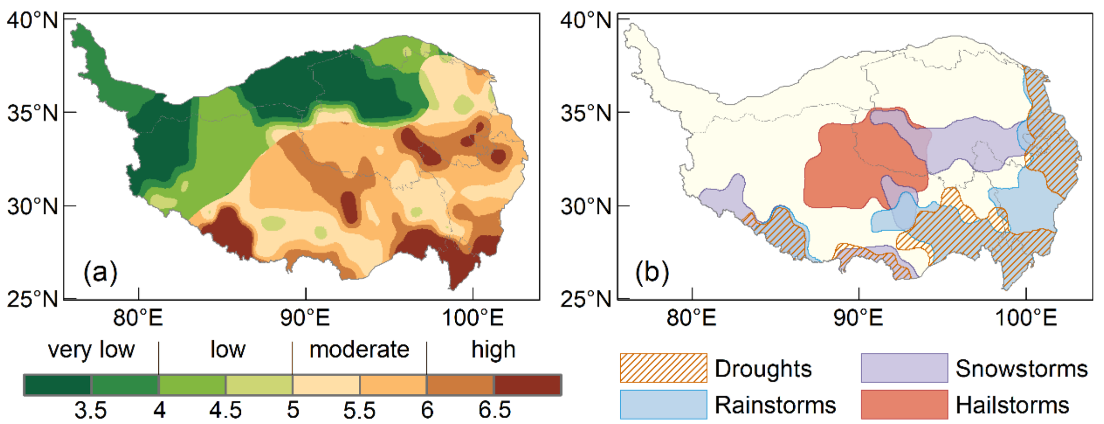


Figure 2.12 The distribution map of the comprehensive disaster-causing intensity of the main meteorological disasters on the Qinghai-Tibet Plateau (a) and the schematic diagram of the high-risk area (b)

2.3.4 The Yellow River Basin

Most of the Yellow River Basin is located in the north-south climate transition zone of China, with significant interannual and interdecadal variability in precipitation.

(1) Extremes and climate change trends

From 1961 to 2018, the extreme maximum temperature in the basin was 44.4°C in Yichuan, Henan (1966), and the extreme minimum temperature in Maduo, Qinghai was -48.1°C (1978). Since 1961, the annual average temperature, average maximum temperature and average minimum temperature of the Yellow River Basin have all shown an increasing trend, with warming rate of 0.28°C per decade (Figure 2.13). Among them, the upper reaches of the Yellow River will increase by an average 0.36°C per decade, while the middle and lower reaches have increased by 0.35°C and 0.25°C per decade, respectively. The number of high temperature days in the Yellow River Basin showed an increasing trend, with a perennial average of 5.6 days, a maximum of 14.4 days (1997) and a minimum of 1.2 days (1984). Since 1961, the number of high-temperature days in the Yellow River Basin has generally shown an increasing trend, with an increase rate of 0.4 d per decade.

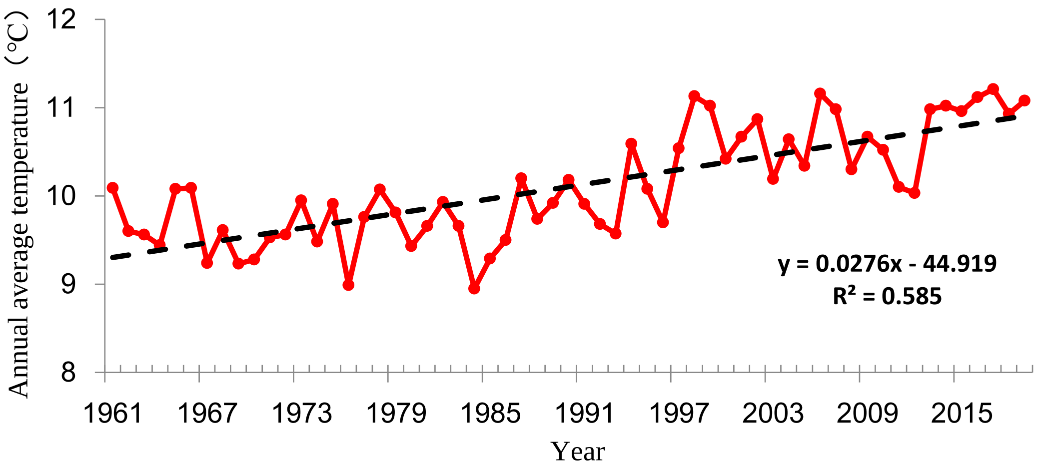


Figure 2.13 Linear change trend of annual average temperature in the Yellow River Basin

The precipitation in the Yellow River Basin varies with an increase in the north and a decrease in the south, with increased intensity and the inter-annual variability of extreme precipitation. The annual average is 465.6mm, the maximum annual precipitation is 697.8mm (1964), and the minimum annual precipitation is 336.8mm (1997). Since 1961, there has been a large inter-annual variability in the precipitation in the basin, with an overall decreasing trend. The precipitation in the basin is on a decreasing trend, with a decrease of 5.4mm per decade (Figure 2.14). Since the 21st century, precipitation has increased rapidly, with the average precipitation in 2003-2019 being 10.8% higher in the 1990s. Despite the decreasing trend in total precipitation in the middle reaches of the Yellow River, the intensity of extreme precipitation has increased. The number of precipitation days in the Yellow River Basin showed an overall decreasing trend, with a decrease of 2.5 days per decade. The annual average relative humidity of the Yellow River Basin is 60.7%, showing a weak decreasing trend. The largest year is 69.2% (1964), and the smallest year is 56.2% (2013).

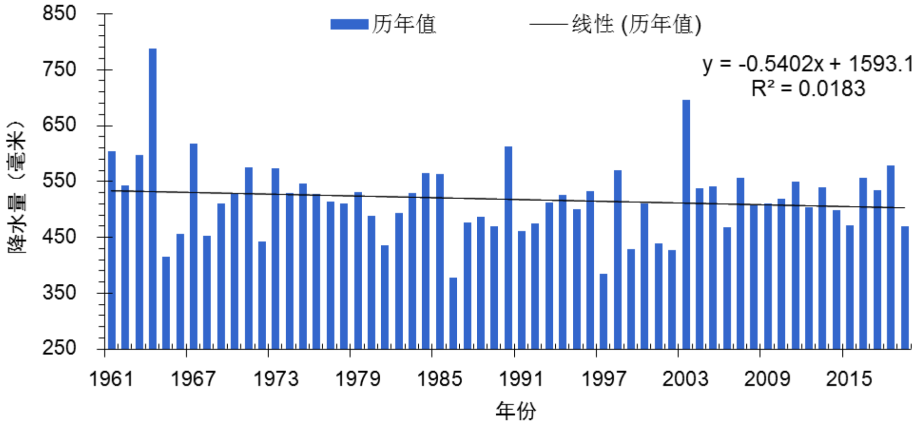


Figure 2.14 The characteristics of annual average precipitation changes in the Yellow River Basin since 1961 (unit: mm)

(2) Change trend of glacier area and water resources

Affected by regional warming, the area of glaciers in the upper reaches of the Yellow River showed a consistent trend of retreat, and an overall decreasing trend in the number of days of snow. The area of each main glacier showed a significant retreat, with the reduction in retreat range from 8% to 13%. The Xiaodong Kemadi Glacier, one of the iconic glaciers of the Three Rivers Source, had a cumulative material balance loss of 7.615mm from 1989 to 2015; in the Qilian Mountains of Qinghai, the glacier area has decreased by 198.44 km^2 (a decrease of 19.17%) in the past 50 years. Since 1961, the amount of surface water resources in the Yellow River Basin has generally shown a slight downward trend, with significant inter-decadal variation in the abundance and dryness (Figure 2.15), with the 1960s to the 1980s being the most abundant years, with the 1960s being 9.6% more than normal, and the 1990s being a dry period, with 5.2% less than normal.; the surface water resources have rebounded over the century, with a significant increase of 8.2% since 2011. 2003 and 1964 were the two years with the greatest water abundance, 38.6% and 49.9% above normal respectively.

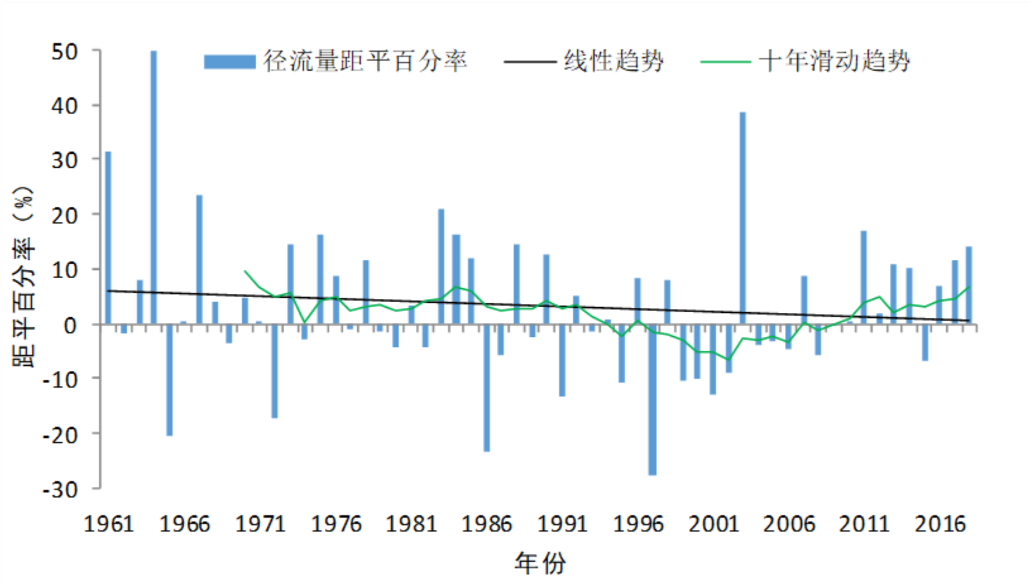


Figure 2.15 Changes in the percentage of surface water resources anomaly in the Yellow River Basin over the years (unit: %)

(3) Projections of future climate change and climate risks

In the context of global warming, the temperature in the Yellow River Basin will continue to rise and precipitation will increase in the future. Rainfall and heavy rainfall in the middle reaches of the Yellow River have increased, and the task of soil erosion prevention and control is still arduous; The continued rise in the temperature and increased precipitation in the upper reaches of the Yellow River will have an important impact on glaciers, snow, frozen soil, etc., and will further affect the change of runoff, water resources and the ecological environment.

The temperature in the Yellow River Basin will continue to rise in the future. As shown in Figure 2.16, during the period 2021-2035, the regional average summer increase is higher than the annual average, while the winter increase has wide interdecadal fluctuations; the annual, winter, and summer multi-year average warming values are 1.01℃, 1.09℃ and 1.12℃, respectively; the warming trend is generally increasing from east to west throughout the region, generally between 0.9 and 1.2°C. Around 2050, the annual average temperature in the Yellow River Basin shows a consistent upward trend, with a gradual increase from east to west in the entire region, generally between 1.4 and 2.0°C.

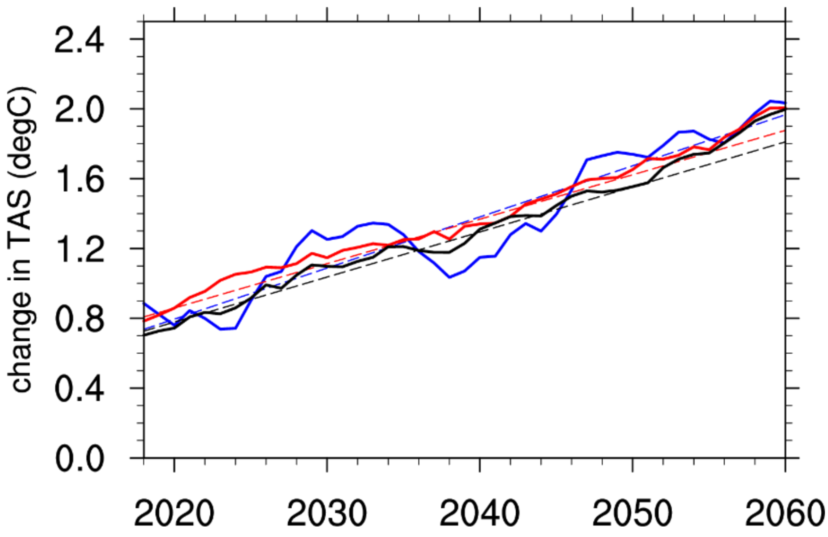


Figure 2.16 Prediction of the change trend of annual average temperature in the Yellow River Basin around 2050

(Black is the annual moving average, blue is winter, red is summer)

In the future, the overall precipitation in the Yellow River Basin will increase. Under the medium emission scenario, the precipitation in the coming years, winter and summer will be predominantly increased, and the increase will have obvious interdecadal characteristics and increasing over time. The annual precipitation increase rate is 0.9%/10 years. As shown in Figure 2.17, during the period of 2021-2035, the increase in summer precipitation is more consistent with the variability of annual precipitation, but the increase is slightly smaller, while the winter precipitation itself is less, so the percentage of increase is relatively large. The multi-year average increases for annual, winter, and summer are 3.9%, 8.4% and 3.4% respectively. Around 2050, the annual average precipitation in the Yellow River Basin will mainly increase by 5.5% on average. The average regional precipitation increase in winter and summer is 15.9% and 3.9% respectively. Around 2050, the overall increase in the number of heavy rain days in the Yellow River Basin is relatively small, not exceeding 2 days in most areas. Areas with large increase rates are mainly distributed in the middle reaches, with an increase rate of 0.5-1.5d; while the upstream and downstream areas mostly do not exceed 0.5d.

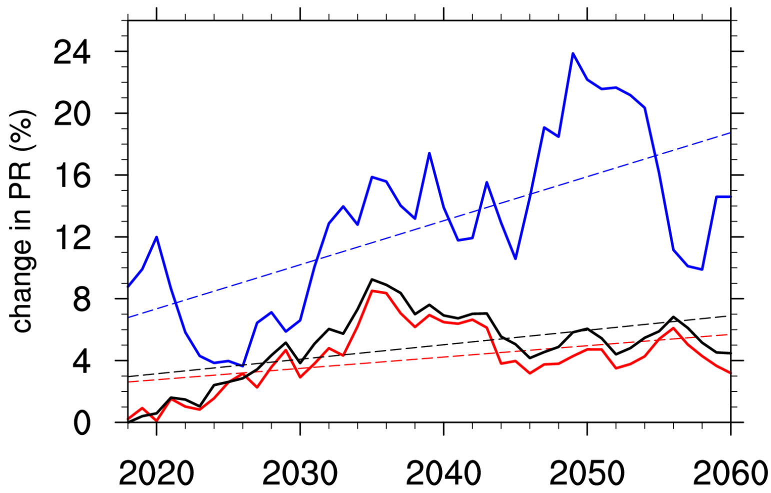


Figure 2.17 Prediction of the change trend of annual average precipitation in the Yellow River Basin around 2050

In the future, the risk of drought in the basin will increase and the runoff will change significantly. Under the medium emission scenario, the number of consecutive days without precipitation in the 2021-2035 multi-year average is mainly decreasing in the Yellow River Basin; most of the decrease in the upper reaches can exceed 4d, while a few areas in the middle and lower reaches are increases, but the increase generally does not exceed 2d. In the future, a significant increase in temperature in the upper reaches of the Yellow River, especially at its source, will have an important impact on glaciers, snow, frozen soil, etc., and will further affect changes in runoff, water resources and the ecological environment. In the future, the number of snow cover days and snow water equivalent in the headwaters of the Yellow River in the Qinghai-Tibet Plateau will be reduced, with the largest reductions being above 25d and 10mm water equivalent respectively; the future increase in temperature may also cause significant changes in the frozen soil environment in the source area of the Yellow River, with a 19% loss of multi-year permafrost if the temperature rises by an average of 1.1°CIf the climate warming trend continues, glaciers, snow and frozen soil in the Yellow River Basin may continue to change in the coming decades. The reduction in snowpack will reduce or disappear the snowmelt runoff in spring, and the ability of snow to regulate river runoff will be significantly weakened. The spring drought will become more serious, the drought situation will intensify, and the ecological environment will face severe risks.

2.4 Climate Change Risks in Typical Cities: Taking Shenzhen as an Example

Under the dual influence of global warming and rapid local urbanization, Shenzhen will become one of the cities with the greatest climate risk among the global megacities.

(1) Increased risk of typhoon storm surge

In the past 10 years, the number of typhoons affecting Shenzhen has increased, the typhoon season has gradually lengthened, and the intensity of typhoons affecting Shenzhen has become stronger. From the end of August to the beginning of September 2017, the typhoon hit the Pearl River Delta in three consecutive times within ten days, causing serious impact on Shenzhen. During the period under the influence of “Heavenly Dove”, the maximum wave height of offshore oil platforms was 10.5 meters, while the typhoon caused flooding in some local sections of the drainage river and Yabian swell in the western part of Bao'an, and the backflow of seawater in Shangdong Village, Tuyang, Dapeng New District. In 2018, the super typhoon "Mangosteen" caused 140,000 trees to fall in the city, with the largest wave reaching 14.2 meters, and a large number of coastal facilities were washed away. In 2018, the typhoon "Iyunni" superimposed on the monsoon and brought continuous heavy precipitation. The maximum process rainfall recorded at the station reached 568.9 mm. Typhoon Weipa in 2019 caused severe wind and rain effects on Shenzhen, and the combined rainfall impact of typhoon ranked sixth since 2008.

(2) The impact of heavy rain is getting bigger and bigger

The frequency of extreme (or abnormal) precipitation events has increased. Statistics show a clear trend towards increasing daily rainfall extremes. Since 1992, there have been 8 years where the extreme daily rainfall exceeded 300 mm, of which 6 occurred after 2008, and the extreme daily rainfall exceeded 300 mm in each of the past three years.

At the same time, short-duration rainstorms are becoming more frequent. Since 2007, the average hourly rain intensity is 113.8 mm/h, which is 54% higher than the average in the 1990s. The rain intensity of short-duration precipitation has also continuously refreshed its historical extreme value, with the 1-hour rainfall extreme value of 136.5 and the 2-hour rainfall extreme value of 189.8 recorded in 2019 already setting historical records.

(3) Strong convective weather is more and more frequent

Strong convective weather has become the most catastrophic weather in Shenzhen in terms of the disaster risk. The instantaneous wind caused by strong convective weather such as squall lines, downbursts, and tornadoes can often reach level 10 or more, and is usually accompanied by hail and short duration extreme heavy rainfall, which can easily cause serious damage. In particular, strong convective weather is highly localised, high sudden, rapid in coming and going, and has a short warning timeframe. Shenzhen recorded 4 squall line processes in April 2019, the frequency of which was the highest in the past 10 years, and the same as in 2008.

(4) Frequent high temperature and heat waves, sudden cold and warm winter

The temperature in Shenzhen has increased significantly since the 1980s. The average temperature in the past 10 years has increased by 1.6°C over the 1960s, which is more than double the global average increase in the past 100 years (0.85°C).

Shenzhen currently has an average of about 39 high temperature days per year above 33°C, much higher than the average of 25 days per year in the 1960s. The frequent occurrence of heat waves in summer puts forward increasingly high demands on urban power load. In July 2019, the coordinated load of the Shenzhen power grid exceeded the 19 million kilowatt mark for the first time, hitting a record high for the fourth time during the year. The average temperature in the winter season is generally increasing and warm winters have become the norm. There have been 10 warm winters since 2000, and only one warm winter has occurred in the 1950s and 1970s. Nevertheless, Shenzhen has become unpredictable in cold and warm in winter, with extreme or abnormal cold air processes often occur.

(5) Sea level rise has increased the disaster risk of typhoon

From 1980 to 2016, the sea level in the Guangdong-Hong Kong-Macao Greater Bay Area showed a fluctuating upward trend, with the average annual sea level rise of 6.8 mm and 4.8 mm in Hong Kong Victoria Harbor and Tai Po Jiao Tolo Harbor respectively, both significantly higher than the average level of coastal sea levels in China during the same period (3.2 mm/year), which will aggravate the impact of typhoon storm surges and expose the safe operation of coastal power, roads, underground pipeline networks and other infrastructure. In addition, the probability of coastal erosion and salt tides has increased. In October 2016, the Pearl River Estuary salt tides invaded for 45 days and the maximum upward distance exceeded 33 kilometers, which seriously affected the urban water supply in the Greater Bay Area.

(6) The development of urbanization has exacerbated climate risks

In the context of increasing climate risks, the characteristics of Shenzhen's own development are also worthy of attention. Firstly, the surface area has hardened extensively. In recent years, the built-up area has been expanding, and the road area has also increased year by year. In 2017, the road area increased by 14% compared with 2012, making it difficult for heavy rainfall to infiltrate and it is easy to form urban waterlogging. The second is the increase in underground space. Shenzhen has built a large number of subways, underground passages and underground commercial complexes. From 2000 to 2012, the development of underground space in Futian district increased by an average of 345,000 square meters per year, with an average annual growth rate of 10.7%. These underground spaces are interwoven with a large number of underground rivers and canals in Shenzhen, which are densely distributed underground. However, there is a lack of integrated, comprehensive and systematic assessment of the safety risks of these underground spaces in the context of climate change. This year's 4.11 disaster caused by short-lived extreme heavy rainfall s that occurred in this context. The third is the increase in high-rise buildings. Shenzhen currently has 15 super high-rise projects over 300 meters under construction and capped, ranking first in the country. With so many high-rise buildings in the context of the gradual increase in typhoon intensity, the durability and safety of the building structure against the wind and the glass curtain walls is a matter of concern. Fourth, there are a large number of houses built by cutting slopes. Affected by the topography, there are a large number of urban villages in Shenzhen built on hills or have slope cuts to build houses. These areas are densely populated and have a high risk of geological hazards. Strong convection, rainstorms, and typhoons will become important factors threatening the public safety of Shenzhen in the future. In addition, the warming of the climate and the increase in extreme high temperature weather will significantly increase the energy consumption of refrigeration, which will put greater pressure on the total electricity consumption of Shenzhen. The above characteristics must be attached great importance; the risk of climate change to the city is immeasurable, if the concern left unaddressed.

(7) Forecast of future climate risk

Affected by external forcing such as anthropogenic greenhouse gas emissions, the temperature in Shenzhen will continue to rise in the future, with a slightly greater increase rise in summer temperatures than in winter. Taking 1986-2005 as the base period, by around 2050, the annual average, summer and winter temperatures will rise by nearly 1.2°C, 1.4°C and 1.3°C respectively, and by 2100, the temperature will rise by nearly 1.7°C, 2.0°C and 1.8. °C (Figure 2.18 left). Future interdecadal variability in winter, summer, and annual average precipitation will fluctuate significantly, with increase dominating by 2100 and higher values of relative variability in winter precipitation than that of summer. By 2050, the annual average, summer and winter precipitation will increase by about 10%, 7%, and 15%, respectively; by 2100, they will increase by more than 15%, 10%, and 35% respectively (Figure 2.18, right).

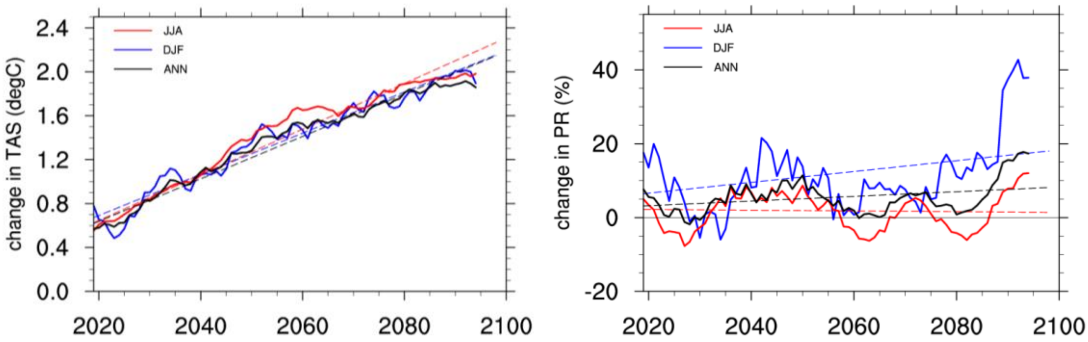


Figure 2.18 Future changes in Shenzhen's annual average, summer and winter average temperature (left picture, unit: °C) and average precipitation (right picture, unit: %) (relative to 1986–2005)

There is an increase in future extreme heat events, an increase in daily maximum temperature extremes, a small increase in the number of heavy rain days, a significant increase in 5-day maximum precipitation and extreme heavy precipitation, and a very significant increase in heavy precipitation. Future extreme high temperature events will increase. By 2050, the number of high temperature days (the total number of days where the maximum daily temperature is greater than 35°C per year) will increase by 26 days, while the daily maximum highest temperature (the maximum daily highest temperature each year) will increase by 1.7°C. By 2100, the number of high temperature days will increase by nearly 36 days, and the maximum daily highest temperature will increase by 2.3°C (Figure 2.19).

Changes in future 5-day maximum precipitation show interdecadal fluctuations, with an overall increase, with a major increasing trend from 2025–2050 and after 2065, and a significant downward trend from 2020–2025, 2050–2065. The 5-day maximum precipitation will increase by about 50mm by 2050 and by about 80mm by 2100 (Figure 2.20). The changes in the number of heavy rain days show significant interdecadal fluctuations. Similar to the relative change trend of precipitation, there is a decreasing trend from 2020–2030, 2050–2060, 2075–2080, reaching the lowest value of about 2 days by 2030; 2030–2050, 2060– 2075 and after 2080followed by an increasing trend; an increase of about 3.4 days around 2050, and a peak around 2100 with an increase of about 3.6 days (Figure 2.20).

The changes in heavy precipitation and extreme heavy precipitation also show interdecadal fluctuations, and the trends of the two are similar. Both show a downward trend in 2020–2025, 2050–2065, 2070–2080, and in 2025–2050, 2065–2070, and 2080, and an increasing trend after 2025-2050. By 2050, intense precipitation will increase by about 170mm and extreme intense precipitation will increase by about 140mm. By 2100, intense precipitation will increase by about 260mm, and extreme intense precipitation will increase by about 190mm (Figure 2.21).

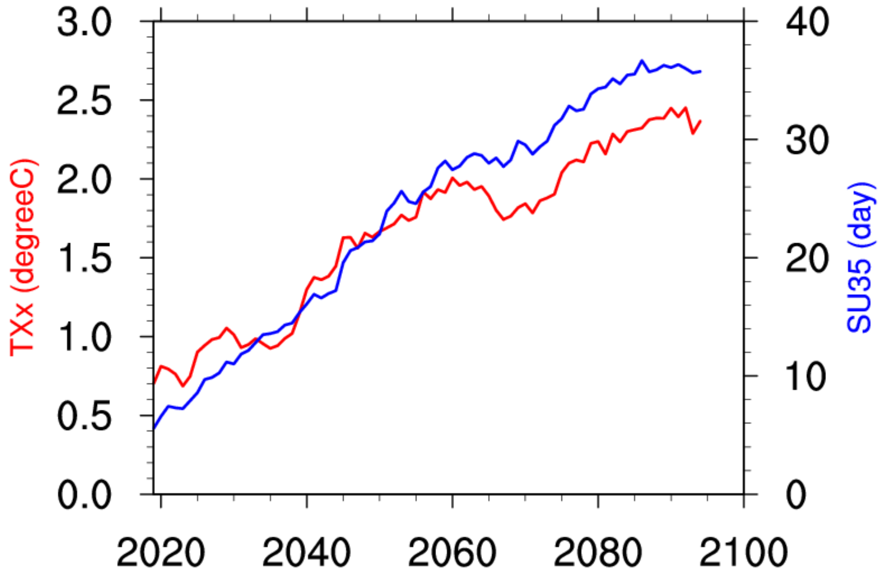


Figure 2.19 Future changes of extreme temperature in Shenzhen (relative to 1986–2005. Blue and red are the number of summer days (unit: days) and the maximum daily temperature (unit: °C))

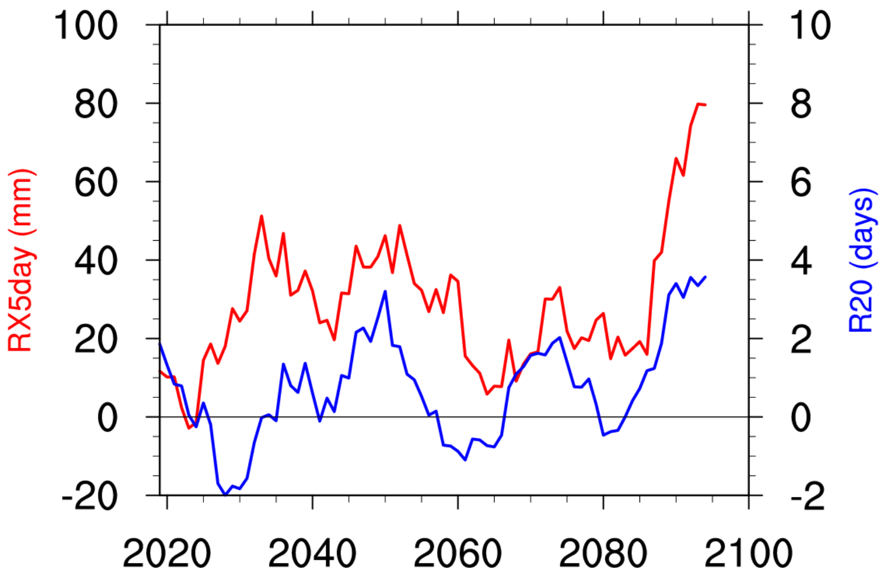


Figure 2.20 Future changes in extreme precipitation in Shenzhen (relative to 1986-2005. Blue and red are the number of heavy rain days (unit: day) and the maximum precipitation on the 5th (unit: mm))

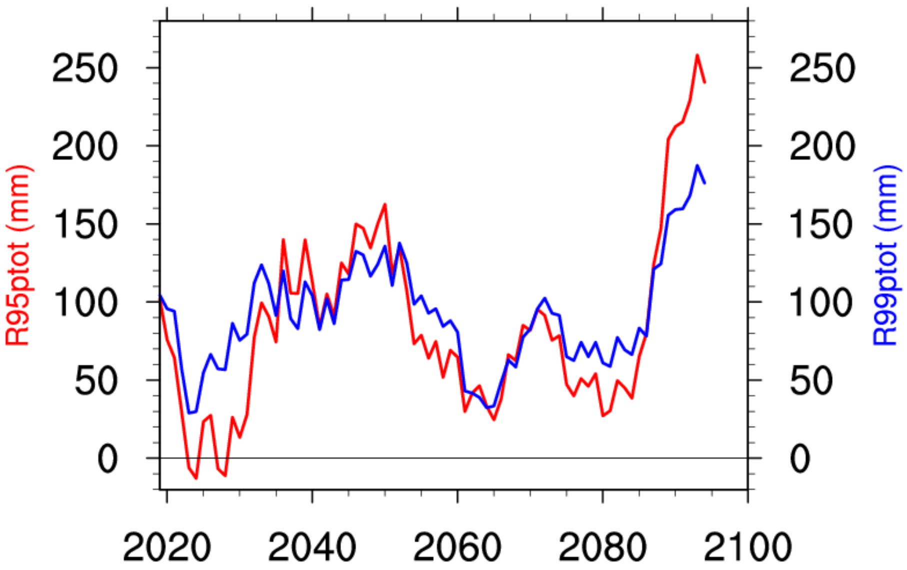


Figure 2.21 Future changes in extreme precipitation in Shenzhen (unit: millimeter, relative to 1986-2005. Blue and red are extreme heavy precipitation and heavy precipitation respectively)

2.5 Policies and practices

2.5.1 Policy issuance and implementation

China is a developing country with a large population, low level of economic development, complicated climatic conditions, fragile ecological environment, and vulnerable to the adverse effects of climate change. Climate change poses real threats to China's natural ecosystems and economic and social development, which are mainly reflected in the fields of agriculture, animal husbandry, forestry, natural ecosystems, water resources, as well as coastal and ecologically fragile areas. Adapting to climate change has become an urgent need for China. At the same time, China is at a stage of rapid economic development, facing multiple pressures to develop the economy, eradicate poverty, and reduce greenhouse gas emissions. The situation in tackling climate change is grim and the tasks are arduous.

As a responsible developing country, China attaches great importance to addressing climate change. Fully aware of the importance and urgency of addressing climate change, China has developed and implemented national plan for addressing climate change in accordance with the requirements of the scientific development concept, taking into account economic development and ecological construction, domestic and international, current and long-term, and has adopted a series of policies and measures. The main policy programs and actions in the past 10 years are as follows:

(1) 2007 "Comprehensive Work Plan for Energy Conservation and Emission Reduction"

(2) 2007 "China's National Climate Change Program"

(3) "China's Policies and Actions to Address Climate Change" in 2008

(4) 2011 "Comprehensive Work Plan for Energy Conservation and Emission Reduction during the Twelfth Five-Year Plan"

(5) 2011 "Work Plan for Controlling Greenhouse Gas Emissions during the Twelfth Five-Year Plan"

(6) 2012 "Twelfth Five-Year Energy-saving and Environmental Protection Industry Development Plan”

(7) 2012 "Twelfth Five-Year Plan for Energy Conservation and Emission Reduction"

(8) 2013 "National Climate Change Adaptation Strategy"

(9) 2016 "Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 13th Five-Year Plan"

(10) 2021 "Guiding Opinions on Coordinating and Strengthening Responding to Climate Change and Ecological Environmental Protection Work"

(11) 2021 "Opinions on the Complete, Accurate and Comprehensive Implementation of the New Development Concept to Do a Good Job in Carbon Peak and Carbon Neutrality"

(12) 2021 "Notice on the Carbon Peak Action Plan by 2030"

By formulating relevant policies and measures to deal with climate change, China has integrated the response to climate change with the implementation of sustainable development strategies, and accelerated the development of a resource-saving, environment-friendly society and an innovative country, and incorporated them into the overall national economic and social development plan and regional planning: On the one hand, it focuses on greenhouse gas emissions mitigation and on the other hand it focuses on improving the ability to adapt to climate change. China will adopt a series of legal, economic, administrative and technological measures to vigorously save energy, optimize the energy structure, improve the ecological environment, enhance adaptability, strengthen scientific and technological development and research capabilities, raise public awareness of climate change, and improve climate change governance mechanisms, gradually form a "Chinese solution" for climate change risk management and response.

2.5.2 Typical practical case: Shenzhen's response model to climate risk

Shenzhen has actively explored the implementation of policies and measures to address climate change risks, and has formed a relatively mature landing model.

(1) At the second meeting of the Standing Committee of the Seventh Shenzhen Municipal People’s Congress on June 29, 2021, “Regulations on Ecological Environment Protection in the Shenzhen Special Economic Zone” were adopted, with addressing climate change as one of the main chapters, providing for regular work on climate change, carbon peaking and carbon neutrality, and carbon emission rights trading. Among them, it is proposed: “The municipal and district governments should improve the climate change monitoring system and climate disaster monitoring, prediction, and early warning systems, formulate emergency plans for climate disasters, establish a data sharing platform, and regularly assess the impact of climate change on ecosystems, infrastructure, and key economies. and the health and property security of residents (article 100)” and “The municipal and district governments shall establish and improve climate risk management mechanisms, and improve the ability of major infrastructure to resist climate risks such as flood control and drainage, public transportation, and important industries and key areas (article 101)". The implementation plans, management and control mechanisms, standards and indicators have been developed in terms of promoting carbon peaking, carbon neutrality, and improving carbon emission trading mechanisms etc. to ensure carbon emission reduction and promote green and high-quality development.

(2) In August 2021, the National Development and Reform Commission issued the "Notice on Promoting the Innovative Measures and Experiences of Shenzhen Special Economic Zone" to promote 47 innovative measures and experiences of Shenzhen Special Economic Zone since the 18th National Congress of the Communist Party of China. Among them, in terms of innovatively promoting the modernization of the urban governance system and governance capabilities, the Shenzhen Meteorological Department’s experience in “creating a '31631' service model” was included as the recommended reference of “strengthening the construction of a disaster prevention, mitigation and relief system”. That is, before typhoons and heavy rains and other major weather , the meteorological department encrypts regional weather consultations 3 days in advance, and issues (major) weather information bulletins, giving process wind and rain forecasts, risk estimates, warning signal release rhythms and defense suggestions in advance; 1-day in advance forecast is detailed to district wind and rain areas, specific magnitudes and key impact periods, encrypts multi-departmental joint consultations with emergency management, three defenses, water affairs, ocean and other multi-sectoral joint consultations; 6 hours in advance to enter the state of refined meteorological warning for disasters, positioning high-risk areas; 3 hours in advance to issue zone warnings and zone risk warnings, and roll-over update

rain information such as the falling zone, cumulative rainfall in the process, maximum rain intensity, maximum wind speed, etc.; 1 hour in advance to release detailed quantitative forecasts to the street. The "'31631' service model" has improved Shenzhen's risk prevention capabilities in response to extreme weather events.

2.6 Key messages and suggestions

2.6.1 Key Information

With global climate change, the extreme trend of temperature and precipitation in the future will be more obvious, and, the timing, intensity, frequency, and regional characteristics of extreme disasters such as high temperature heat waves, rainstorms, floods, and droughts in China under the state of high climate variability will change significantly, and the risk of future compound disaster in key areas is increasing. The risks of climate change to China's key socio-economic systems are mainly manifested in key industries such as agriculture, transportation, energy, tourism, and urban human settlements, population health, and major projects, with great spatial differences. The risk research in key regions shows that the climate risk characteristics of each region are prominent, with large differences between the east and the west. The Yangtze River Economic Belt and the Guangdong-Hong Kong-Macao Greater Bay Area are dominated by extreme high temperature, precipitation, and sea level rise, while Qinghai-Tibet Plateau in the west is dominated by water resources risks caused by warming and humidification and glacier melting, and the Loess Plateau region in the centre has prominent risks of extreme precipitation and drought are outstanding. Therefore, under the carbon peak/carbon neutrality goal, national and local governments should develop relevant policies in response to climate change based on regional characteristics, integrating the synergistic benefits of environment, climate, health, energy, economic and social development.

2.6.2 Recommendations for climate risk response in China and key regions

The risk of climate change is a global common challenge, and China suffers from a relatively high level climate risk in the world, and the adverse effects of climate change have penetrated into the economic and social system. China actively promotes global green, low-carbon, and sustainable development, and building a community with a shared future for mankind. In recent years, series of tasks of climate change adaptation have been carried out in a number of areas with positive progress step forward in which the National Climate Change Adaptation Strategy is centered. Recommendation to improve the ability to respond to climate change are as below:

(1) Pay attention to and improve the ability to adapt to climate change, especially to respond to extreme weather and high-impact climate events.

In recent years, China’s ability to adapt to climate change changes, especially to respond to extreme disasters, has been significantly improved, and the proportion of deaths and direct economic losses to GDP has shown a clear downward trend. However, as China is currently undergoing rapid urbanization, the further concentration of population and wealth, and to some extent uncontrolled construction, will exacerbate the risk of extreme climate disasters. In order to further improve the ability to respond to extreme weather and high-impact climate events, it is necessary to develop a "National Climate Change Adaptation Strategy" for the new-period, to address extreme climate disasters as the core content of climate change adaptation, strengthen extreme climate disaster risk prevention measures, and further enhance the capability for precision monitoring and accurate prediction of extreme weather and climate events,, and strengthen the risk management of meteorological disasters. Carry out ecological and environmental meteorological services, carry out climate change impact assessments in key regions and characteristic industries, strengthen risk response to agriculture, water resources, ecology and health related to extreme climate events and disasters, and research and propose relevant measures to adapt to climate change, improve the resilience of the socio-economic system.

(2) Improve climate change risk response capabilities s, and carry out application demonstrations and technology promotion for disaster prevention and mitigation in key regions.

Give full play to the multi-departmental linkage mechanism, carry out research on key technologies in disaster risk response according to the daily operational needs of disaster prevention, mitigation and relief, continuously promote the application of the latest technological achievements to the daily natural disaster response operational system, strengthen the expansion of service areas, and improve the capability of refined service; make use of multi-disciplinary and integrated research means and methods to further study on the state, process and driving factors of disaster change, assess the impact and risk of climate change on the regional ecological environment and major engineering construction, and improve the defense against disaster risks; carry out natural disaster risk assessment and risk zoning in areas with high-risk areas of natural disasters, contiguous poor areas and areas where major strategic are implemented etc., , promote the standardization and institutionalization of disaster risk assessment and zoning, and apply demonstration and technology promotion.

(3) Innovate mechanisms, models and content to improve the financial system for disaster loss sharing and climate change adaptation.

Incorporate climate change-related risks into the macro-prudential management and micro-prudential supervision of financial institutions, and improve the green finance assessment system and information disclosure mechanism. Strengthen the awareness of environmental and social risk prevention in financial services, enhance the scientific and technological support for green finance in an all-round way, promote the application of frontier technologies such as big data, artificial intelligence, and cloud computing to help the development of green finance, and accelerate the independent innovation and research and development of financial risk analysis models to support risk simulation and stress testing in various scenarios of climate change, and prevent the occurrence of systemic financial risks in the process of responding to climate change risks. Under extreme weather, giving full play to the "covering" role of weather disaster insurance has become an important subject that urgently needs to be explored and practiced. Based on the warning information of weather hazard, meteorological departments and the insurance industry should combine insurance coverage and risk management measures to further strengthen cooperation in the areas of refined disaster prevention and loss prevention, personnel evacuation, and property transfer. In particular, the impact of global climate warming on the occurrence of natural disasters, biodiversity, and economic growth should be studied, and model prediction and solution design should be made in a forward-looking manner. China's catastrophe insurance is still in the exploratory stage, and the attempts and applications of risk securitization and other related derivatives are not yet mature. Further explorations should be made in the innovation of catastrophe insurance sharing mechanism, model and content. Strengthen the adaptability of energy facilities, including targeted measures to deal with climate change such as wind resistance, pressure resistance, and freeze resistance modification of power transmission and transformation facilities, as well as the design of financial instruments to improve the adaptability of population health.

(4) Pay attention to the construction of climate change risk management system and safeguard measures

Focusing on carrying out institutional development for climate change risk management system, and incorporate climate change risk management on extreme events and disaster legislation. Among them, the Ministry of Emergency and Disaster Mitigation jointly promoted the establishment of five-levels natural disasters emergency response plan at the national, provincial, prefecture, district, and township levels at, including conditions for starting natural disaster relief, organization and command systems, responsibilities and tasks, emergency preparedness, early warning, forecasting, emergency response, post-disaster relief and recovery and reconstruction shall be clearly stipulated; the meteorological department shall formulate emergency plans for meteorological disasters at all levels, and make detailed regulations on the monitoring and early warning of meteorological disasters, emergency handling, recovery and reconstruction, and emergency protection. In response to problems in key aspects in the process of disaster risk management under climate change, such as early warning and forecasting, emergency response, recovery and reconstruction, disaster reduction and relief, strengthen top-level design, overall layout, strengthen weak links, and gradually establish and improve a national disaster risk management scientific and technological support system. Strengthen the development of scientific and technological emergency mechanism, establish a national scientific and technological emergency mechanism for public emergencies; strengthen the disaster risk management personnel training system, gradually establish a national education system and training platform, and carry out targeted emergency rescue capacity training for various groups; strengthen the establishment of a risk management publicity and education system to enhance the awareness of disaster prevention and mitigation of the whole people.

2.6.3 Typical City - Shenzhen's Climate Risk Response Suggestions

(1) Establish a mechanism for continuous research, judgment and assessment of

climate risks

It is recommended to further emphasize the importance of multi-sectoral coordination to improve the awareness of adapting to climate change risks, and establish a working mechanism for urban climate risk tracking analysis, rolling research and evaluation of urban climate risks, so as to continuously track changes in Shenzhen city conditions. At the same time, in accordance with the comprehensive monitoring requirements of the multi-hazard disaster chain, meteorological, hydrological, marine and other disaster monitoring systems of Shenzhen shall be further improved.

(2) Organize systematic research and defense planning for climate risk hazards

It is recommended that the planning, water affairs and meteorological departments jointly conduct systematic research on climate risk hazards and develop comprehensive defense plans from a macro perspective, especially for the actual situation of the increasing number of underground spaces and high-rise buildings, and propose climate risk defense measures to achieve a long-term perspective, take precautions before they occur.

(3) Upgrade urban natural disaster defense standards

It is recommended that the preparation or revision of urban natural disaster prevention standards be carried out in a coordinated manner, and that standards for natural disasters, especially meteorological disasters, be prepared in response to the characteristics of urban development that requires space in the sky and underground, so as to enhance the resilience of cities in the context of climate change.

(4) Shenzhen urgently needs to strengthen its adaptation to climate change

Since the implementation of the 13th Five-Year Plan to address climate change in Shenzhen, the innovative concept of "double compliance" has been put forward in mitigating climate change. On the one hand, it meets air quality standards, on the other hand, it achieves the carbon emissions targets. However, Shenzhen needs to continue to strengthen its research on climate change adaptation.

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Chapter 3: Systemic Risks of Climate Change to China

3.1 Introduction

Cities are the major location where the economy and people clustering. In 2020, China's urbanization rate is 63.9%, and the resident urban population has reached 902 million. Under the impact of extreme weather such as heat wave and urban waterlogging, urban populations face serious threats to their public health, and infrastructure such as electricity and transport is greatly damaged and further transmitted to households, businesses and financial systems. In the context of climate change, disasters' chain, amplification, and agglomeration effects will be more pronounced, thus causing huge losses to urban operations, urban safety, and urban economic development. In addition, the level of vulnerability of different groups to climate change varies greatly, raising issues of social inequality and social exclusion. The systemic risks caused by climate change pose serious challenges for policy implementation and actions to address and adapt to climate change.

Given the complexity of the socio-economic system, the research does not fully cover the impact of climate change and its knock-on effects. First, the research is based on the vulnerability assessment framework, i.e., a qualitative and comprehensive assessment of the systemic risk of climate change due to heat waves and floods in the Yangtze River Economic Zone, using multiple indicators in terms of Hazard, Exposure and Vulnerability. Yangtze River Economic Belt Secondly, the research focuses on Wuhan, a pilot climate resilient city in China—and analyses the city-level health heat vulnerability and population mortality risks under heat waves, rotating power outages and transportation accessibility from three channels: the impact of high-temperature heat waves on public health, the impact of high-temperature heat waves on power facilities, and the impact of urban waterlogging on transportation facilities, and look into the risk of heat wave damage to the entire economic system. . In particular, the research focuses on the distinguishing impact of heat waves on vulnerable groups such as patients with cardiopulmonary diseases, the elderly, women, and those with low education, and provides a detailed zoning and classification of the social system risks in Wuhan due to urban waterlogging based on four aspects: submerged area in the spatial unit, population exposure, distribution of vulnerable groups, economic development level. Finally, the study puts forward policy recommendations to address and adapt to the systemic risks of climate change. The research helps local government decision makers to better understand the importance of climate change systemic risks and incorporate them into government policies and decisions to take effective measures to deal with and adapt to climate change systemic risks, and promote the inclusiveness of cities, to reduce social inequities and social exclusion caused by climate change. The research idea is shown in Figure 3.1.

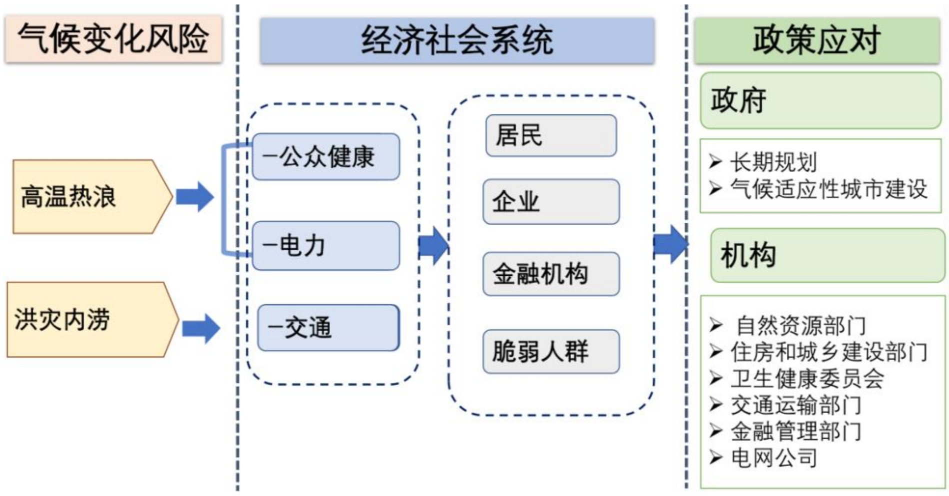


Figure 3.1 Framework for systemic risk analysis of urban climate change

3.2 Systematic risks of climate change in the Yangtze River Economic Belt and Wuhan City

3.2.1 Systematic risk assessment of climate change in the Yangtze River Economic Zone

The Yangtze River Economic Belt straddles the three-level ladders of mainland China. It connects 11 provinces and cities including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou, with the main stream and tributaries of the Yangtze River as the link, with an area of approximately 205.23. 10,000 square kilometers, accounting for 21.4% of the country's total area, and population, food production and gross production value exceeding 40% of the country's total.

Climate change risks in the Yangtze River Economic Beltare mainly reflected in two areas: Firstly, regional temperature rise has become increasingly pronounced. The "China Meteorological Yearbook" shows that the temperature in the Yangtze River Economic Belthas generally risen since 1961. Secondly, the precipitation in the upper, middle and lower reaches of the Yangtze River showed an uneven increase. Since 1956, the precipitation in the upper reaches of the Yangtze River has generally shown a downward trend, but the precipitation in the middle and lower reaches of the Yangtze River has shown an increasing trend. In 2020, the overall precipitation in the Yangtze River Basin reached the highest level since 1961, and it suffered the most severe flooding since 1998, with severe torrential rainfall and floods. Hubei Province experienced major flooding basically every three years or so during the period 2004-2018, with2016 being the peak year of the population affected by floods and deaths in Hubei Province, with approximately 20.8 million people affected and 110 deaths. The year 2013 was the worse year for drought over the years, in the worst year, the number of people affected by the disaster reached 15.79 million people affected and 3.67 million people having difficulty in drinking water due to drought.

Under the combined influence of temperature and precipitation, water resources, human health, agricultural development, and urban economic development have become the main areas of direct and systemic risks of climate change in the Yangtze River Economic Zone. Under the framework of vulnerability assessment, the study selected 9 indicators to qualitatively assess the systemic risks of climate change in the Yangtze River Economic Beltunder high temperature heat waves and floods. The indicators and evaluation results are shown in Table 3.1 and 3.2.

Table 3.1 Systematic risk assessment indicators of climate change in the Yangtze River Economic Zone

index	High temperature heat wave	Flooding
Hazard	High temperature days, annual average temperature	Annual precipitation
	Number of high temperature extreme events	Number of extreme daily precipitation events
	Annual extreme maximum temperature	Number of extreme continuous precipitation days
Exposure	Urban construction land area	Drain pipe length
	The population density	The population density
	GDP per capita	GDP per capita
Vulnerability	Density of health facilities	
	ersonnel Density of Health Institutions	
	Public finance expenditure	

From the perspective of the systemic risks of climate change caused by heat waves, the upper reaches of the Yangtze River are generally less hazardous, with lower population density, economic development level, and urban construction land area than the middle and lower reaches, lower level of urbanization, and poorer government spending and health care conditions, thus showing overall characteristics of low harm, low exposure and high vulnerability. The middle reaches of the Yangtze River are characterized by a high degree of heat hazard, medium population density and economic development, and medium government financial support and health care conditions, which makes this region characterized by a high degree of hazard, medium exposure and vulnerability. A The lower reaches of the Yangtze River are characterized by a relatively low risk, high exposure, and low vulnerability, complemented by a higher level of economic development, higher population density, better government services, and better health care conditions.

In terms of the systemic risks of climate change caused by floods, the upper reaches of the Yangtze River receive less annual precipitation than the middle and lower reaches of the Yangtze River, and the extreme precipitation occurs on a more even basis, so the hazard of waterlogging is not too high; moreover, the mountains and hills are more conducive to drainage than the plains, hence the overall hazard degree of waterlogging disasters is relatively low, with low hazard, low exposure and high vulnerability.. However, the terrain of Sichuan Province is low and flat, most of which are located in basin areas, and the drainage conditions are extremely unfavorable under extreme precipitation conditions. The middle reaches of the Yangtze River have the highest annual precipitation, and the occurrence of extreme precipitation is relatively even and better economic development situation than the upper reaches of the Yangtze River, but the density of urban drainage pipes does not match the annual precipitation, especially in Hubei Province, which has a large plain area with unfavorable drainage conditions and a high probability of flooding in the face of extreme precipitation conditions. Regarding flooding, the middle reaches of the Yangtze River showed the characteristics of high damage, high exposure, and medium vulnerability. The lower reaches of the Yangtze River receive moderate rainfall throughout the year, with a low probability of extreme events, and a low hazard level of flooding. However, due to the low terrain is not conducive to drainage, and the density of urban drainage pipes is not able to respond in time under extreme conditions, the exposure of flood disasters is relatively high, and the overall characteristics are low hazard, high exposure, and low vulnerability.

Generally speaking, most of the Yangtze River Economic Belt belongs to the subtropical monsoon climate zone, where rain and heat coincide and climatic conditions are similar. At the same time, the Yangtze River Economic Belt is densely populated, and even economically developed areas such as Shanghai are also facing a situation of shortage of medical resources when extreme situations occur, making the Yangtze River Economic Belt, especially the middle and lower reaches, generally more vulnerable to heat waves and floods.

Table 3.2 Results of Systemic Risk Assessment of Climate Change in the Yangtze River Economic Zone

Area	Provinces	High temperature heat wave			Floods		
		Hazard	Exposure	Vulnerability	Hazard	Exposure	Vulnerability
Upper Yangtze River	Guizhou	Low	Low	High	Low	Low	High
	Yunnan	Low	Low	High	Low	Low	High
	Sichuan	High	Low	Middle	High	High	Middle
	Chongqing	High	Middle	High	Low	Middle	High
Middle Yangtze River	Hunan	High	Middle	Middle	High	Middle	Middle
	Hubei	High	Middle	Middle	High	High	Middle
	Jiangxi	High	Middle	High	High	Middle	High
Lower Yangt	Anhui	High	High	High	Low	High	High
	Zhejiang	High	High	Middle	Low	High	Middle

ze River	Jiangsu	Middle	High	Middle	High	High	Middle
	Shanghai	Middle	Extremely High	Extremly High	Low	High	High

3.2.2 Systemic risks of climate change in Wuhan

(1) Main climate changes in Wuhan

Located in the eastern part of the Hanjiang Plain, Wuhan is a megacity in the middle and lower reaches of the Yangtze River, with a resident population of 12.326 million in 2020. It belongs to the north subtropical monsoon (humid) climate, characterized by abundant rainfall, sufficient heat, rain and heat in the same season, light and heat in the same season, cold in winter and hot in summer, and four distinct seasons. The "China Meteorological Yearbook" shows that from 1910 to 2020, the annual average temperature in Wuhan showed a significant upward trend, with an average temperature increase of 0.06°C every 10 years. During 1910-1950, the temperature in Wuhan was mostly lower than the annual average. From 1950 to 2020, the annual average temperature in Wuhan increased by 0.3°C per decade, which was higher than the average annual temperature growth rate of China in the same period-0.25°Cper decade. From 1950 to 2020, the extreme maximum temperature in Wuhan reached 39.6℃, and the extreme minimum temperature was -18.1℃. Both the maximum and minimum temperatures show an increasing trend, with more pronounced increase in low temperatures (see Figure 3.2 and Figure 3.3). From an intra-city perspective, according to the analysis of the data from the Wuhan weather station, the temperature in the central city of Wuhan is higher than that in the peripheral areas. The high temperature area basically covers most of Hankou, Hanyang and Wuchang districts within the third ring road of Wuhan. The traditional main urban area of the district, as well as the newly-built Wuhan Development Zone, Gunaggu area, Wujiashan area in Dongxi District, these are the areas with a high population, relatively high GDP or the fastest growth rate in Wuhan.

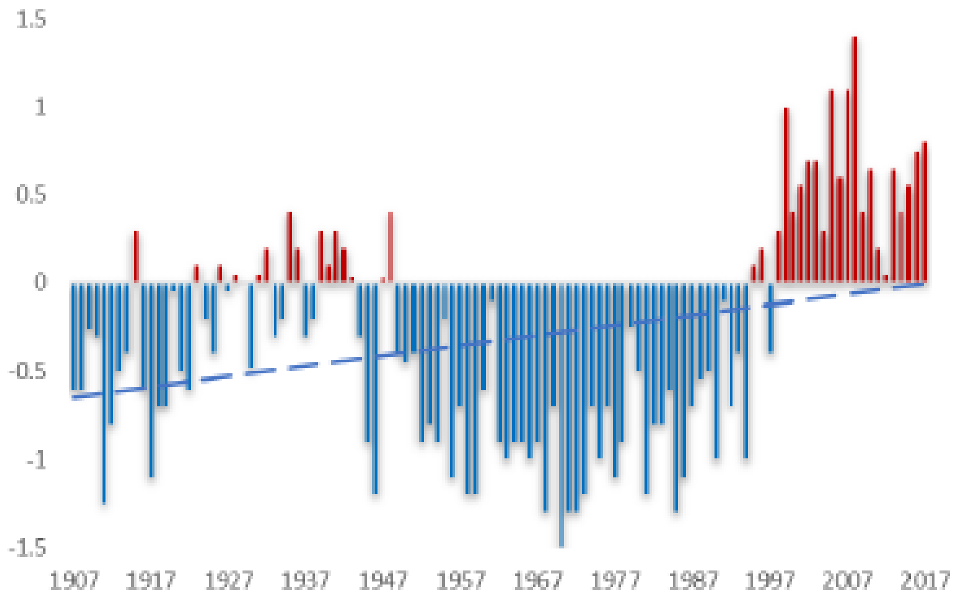


Figure 3.2 Changes in historical average temperature in Wuhan

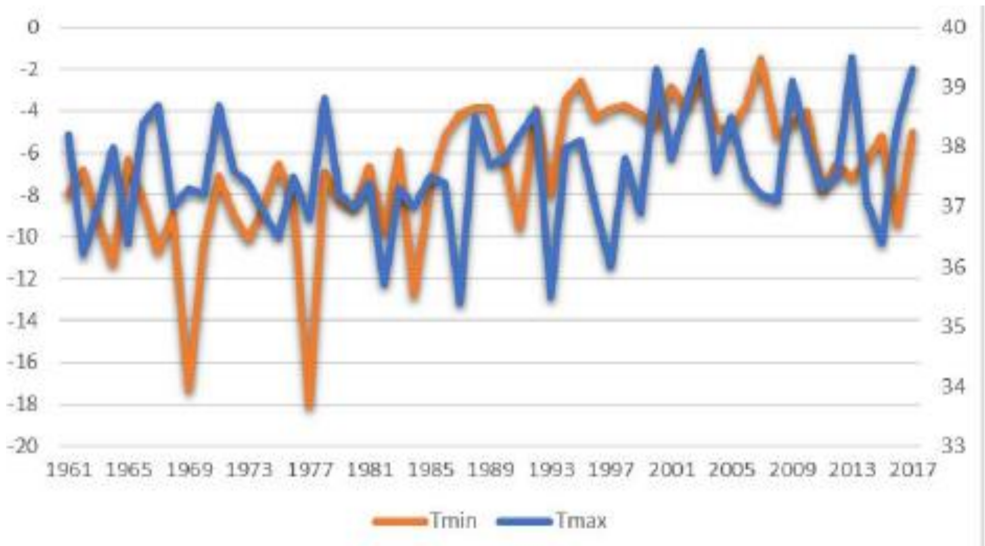


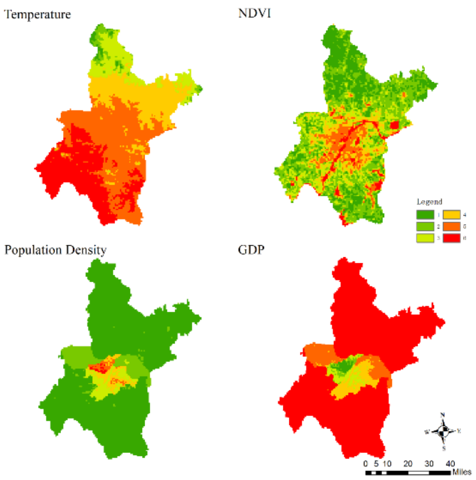
Figure 3.3 Changes in extreme temperature in Wuhan

Wuhan city has a relatively low and flat topography, which, combined with short-lived heavy rainfall weather events in summer, urban waterlogging is extremely easy to form. From June 30 to July 6, 2016, the super-strong El Niño event combined with the strong subtropical high pressure, the prevailing meridional circulation at mid-high latitudes at 500hPa, and the low polar vortex intensity index. Wuhan suffered continuous heavy rainfall during the Meiyu period, with a cumulated precipitation of 580mm, the highest value since meteorological records were available. This caused severe waterlogging and urban flooding. Data from the National Disaster Reduction Center of the Ministry of Civil Affairs of China showed that 1.06 million people were affected by urban flooding in Wuhan in 2016, disrupting urban traffic and causing direct economic losses of RMB 5.3 billion yuan.

(2) Health heat vulnerability assessment in Wuhan

From the public health perspective, thermal vulnerability refers to the degree to which the human body is sensitive to, or unable to cope with, the adverse effects of high temperature. The study uses average annual temperature to reflect hazard, population density to reflect exposure, and normalized vegetation index (NDVI) and GDP to reflect vulnerability. The different data were categorised into six levels according to the natural discontinuity method, with higher levels indicating greater health thermal vulnerability. Then, each dimension level is weighted equally and summed up as a health heat vulnerability index, which ranges from 4 to24, with higher levels indicating stronger health heat vulnerability. The results of Wuhan thermal vulnerability assessment are shown in Figure 3.4 and Figure 3.5.

In terms of the exposure to health heat vulnerability in Wuhan, it shows a spatial distribution characteristics of high in the southwest and low in the northeast, withthe annual average temperature in Caidian District and Hannan District being relatively high; while in terms of the exposure to health heat vulnerability in Wuhan , it shows the spatial distribution characteristics of high in the center and low periphery, with the central urban area showing higher exposure to heat due to its higher population density and lower vegetation coverage; the vulnerability presents the opposite characteristics of the spatial distribution of exposure, with a low level in the center and high level in the periphery. Due to the high level of economic development in the central city, its infrastructure, living environment, medical conditions, etc., compared with the peripheral areas, show higher adaptability and lower fragility under the same heat exposure. Therefore, in general, the overall spatial distribution of health heat vulnerability in Wuhan is characterized by a high level in the central urban area and a low level in the peripheral urban areas; among the peripheral urban areas, the southwestern part is higher than the northeast.



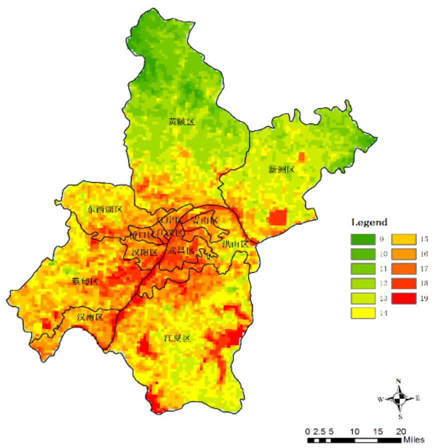


Figure 3.4 The level of thermal vulnerability in different dimensions in Wuhan Figure 3.5 Spatial distribution of thermal vulnerability in Wuhan

(3) Evaluation of heat-related mortality in Wuhan

The study uses a distributed hysteresis nonlinear model to establish the exposure response between temperature and mortality using day-by-day mortality data and climate data in Wuhan. The results show a "U"-shaped relationship (see Figure 3.6).

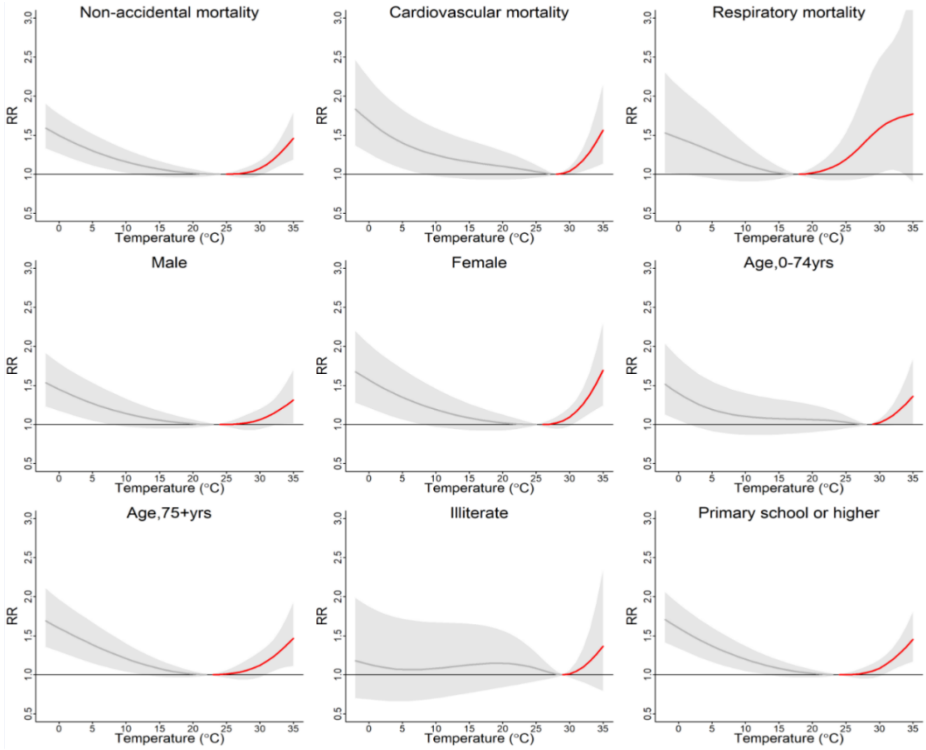


Figure 3.6 Baseline level of the relationship between temperature and mortality exposure in different populations in Wuhan

The temperature corresponding to the lowest mortality rate is the most suitable temperature for the population in this area, and the temperature range in Wuhan City is between 19-28°C. Outside of the minimum mortality temperature, any increase or decrease in temperature it can increase the risk of death in the population. At the same time, the relationship between the two exposure response varied between different causes of death, gender, age group, and education level etc.

The future temperature of Wuhan is estimated to increase by 2.08°C under RCP 4.5 and 4.33°C under RCP 8.5 by the end of the 21st century. The results of this projection of future heat-related mortality in Wuhan show that the local heat-related mortality will increase from 1.6% in the 2010s to 2.1% in the 2030s, 3.0% in the 2050s5.6% by end of this century under the RCP 8.5 scenario. At the same time, the heat-related mortality rate under the RCP 8.5 scenario is projected to be about twice that under the RCP 4.5 scenario by the end of this century, (see Figure 3.7, Table 3.3, and Table 3.4). With patients with respiratory diseases, women, and the elderly being the most vulnerable to temperature increases. Without any climate change response and adaptation policies, the heat-related mortality rate will therefore rise significantly, posing a great threat to the health of the population.

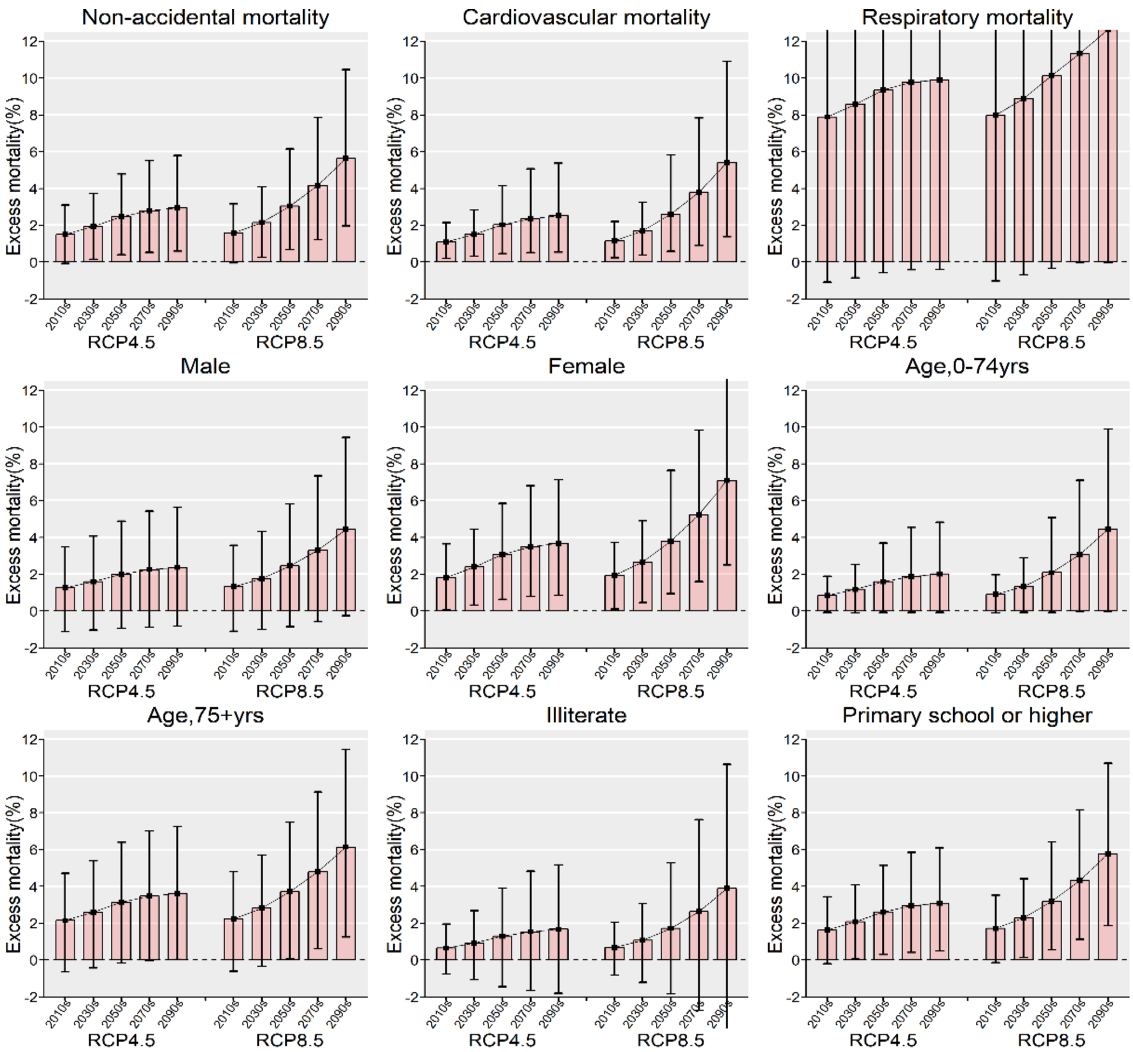


Figure 3.7 Estimates of future heat-related excess deaths in Wuhan under different emission scenarios

Table 3.3 Estimated heat-related deaths of different populations in Wuhan under RCP 4.5 scenario

RCP4.5	**2010s**	**2030s**	**2050s**	**2090s**
原因 Cause)				
非意外死亡（Non-accidental mortality）	1605 (-94,3314)	2075 (159,3988)	2638 (426,5134)	3149 (638,6190)
心血管死亡率（Cardiovascular mortality）	506 (96,999)	702 (149,1319)	945 (209,1943)	1178 (253,2514)
呼吸系统死亡率（Respiratory mortality）	847 (-118,1540)	920 (-93,1634)	1004 (-62,1769)	1064 (-42,1871)
性别（Gender）				
男性（Male）	786 (-697,2176)	997 (-638,2528)	1249 (-576,3038)	1475 (-519,3508)
女性	823	1076	1378	1653

（Female）	(23,1636)	(148,1994)	(285,2627)	(388,3202)
年龄(Age)				
0-74	391 (-39,879)	548 (-43,1177)	745 (-38,1720)	939 (-36,2245)
75+	1194 (-355,2623)	1449 (-237,2995)	1749 (-91,3561)	2006 (15,4038)
教育水平(Education)				
文盲 （Illiterate）	102 (-122,309)	147 (-171,427)	206 (-229,621)	265 (-288,822)
小学及以上 （Primary school or higher）	1399 (-170,2950)	1783 (37,3497)	2241 (255,4403)	2652 (427,5222)

Table 3.4 Estimated heat-related deaths of different populations in Wuhan under RCP 8.5 scenario

RCP8.5	2010s	2030s	2050s	2090s
原因(Cause) 非意外死亡 （Non-accidental mortality）	1695 (-52,3397)	2295 (274,4366)	3251 (711,6576)	6027 (2113,11200)
心血管死亡率 （Cardiovascular mortality）	545 (107,1031)	795 (175,1518)	1217 (273,2720)	2525 (645,5092)
呼吸系统死亡率 （Respiratory mortality）	858 (-110,1545)	955 (-75,1684)	1089 (-38,1906)	1357 (-4,2322)
性别（Gender）				
男性 （Male）	825 (-686,2217)	1095 (-620,2694)	1524 (-526,3618)	2755 (-157,5868)
女性 （Female）	873 (50,1672)	1195 (206,2203)	1705 (427,3431)	3185 (1123,5851)
年龄(Age)				
0-74	422 (-41,920)	624 (-40,1349)	970 (-36,2368)	2070 (-2,4610)
75+	1240 (-338,2669)	1568 (-191,3178)	2067 (32,4161)	3420 (702,6368)
教育水平(Education)				
文盲 （Illiterate）	110 (-132,327)	170 (-194,487)	274 (-292,840)	619 (-632,1689)
小学及以上 （Primary school or higher）	1473 (-129,3016)	1962 (127,3784)	2737 (478,5492)	4952 (1599,9159)

(4) Systematic risks caused by power shortages caused by high-temperature heat waves in Wuhan

Extremely high temperature weather can lead to a rapid rise in t demand for electricity in a short period of time and the power supply cannot be guaranteed. Under the basic policy of protecting people's livelihood, the grid will restrict the supply to industrial enterprises to protect the residential demand. During periods of continuous high-temperature weather, in order to ensure basic fairness, the grid will adopt measures of rotating area blackouts, which will lead to the interruption in production and thus economic losses.

In order to assess the systemic risks of climate change caused by power shortages due to high temperatures in Wuhan, the 2017 NPP-VIIRS night light remote sensing data to match Baidu API is used to analyze the specialization of the added value of the secondary industry in Wuhan and analyze the main industries in Wuhan Enterprise cluster area (see Figure 3.8). Further, the Monte Carlo simulation method is used, with equal probability for 10,000 simulations, the probability distribution of the economic loss of Wuhan's secondary industry caused by a high temperature was calculated (see Figure 3.9). The calculation results show that the economic losses of the secondary industry in Wuhan caused by a single high temperature are mainly distributed between 114,900 yuan and 294,900 yuan, with the highest loss in the range of 1.5549 million yuan - 1.73 million yuan. In recent years, Wuhan has maintained high temperature exceeding 35℃ for about 40 days per year, while each round of area blackout is about 15 areas. According to the simulation results, it can be found that economic losses incurred by the secondary industry in Wuhan due to power shortages caused by high temperatures wil be a minimum of 120 million yuan and a maximum of 1.28 billion yuan.

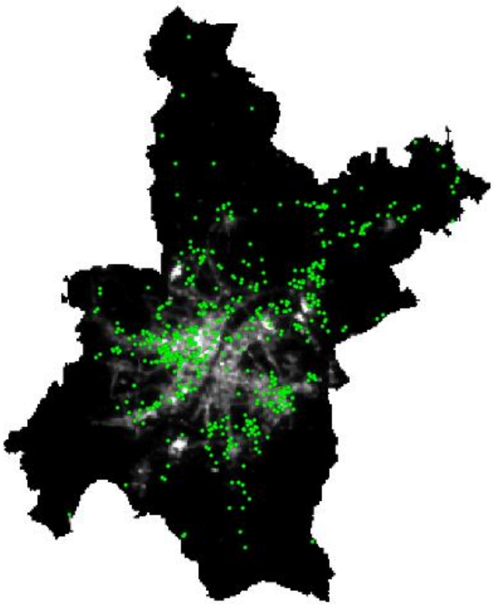


Figure 3.8 Spatial distribution of secondary industry enterprises in Wuhan (left)

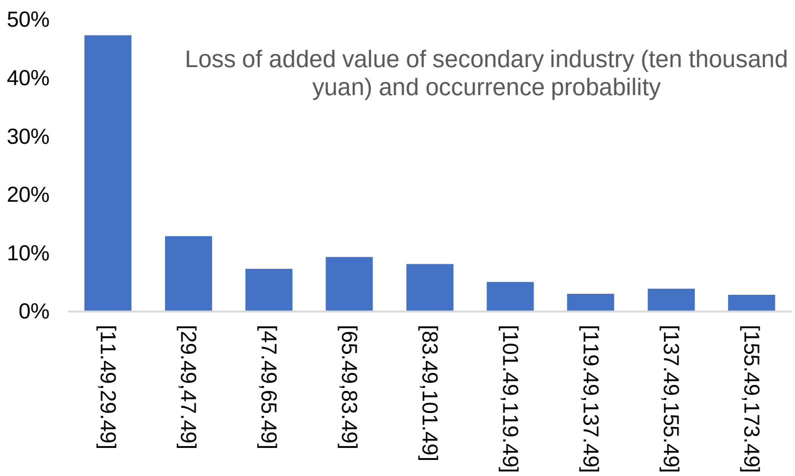


Figure 3.9 Losses and probability distribution caused by high-temperature power outages in Wuhan (right)

With the global warming, the number of days with extreme high temperature in Wuhan is expected to increase, and thus the risk of transmission through the power system to the economic system will further increase. By the end of the 21st century, under the RCP 4.5 scenario, the number of long-term high temperature days (from 2081 to 2100) and the daily maximum temperature in Wuhan will reach 54.7 days and 40.7°C, respectively. Under the RCP 8.5 scenario, the number of high temperature days and daily maximum temperature in Wuhan (from 2081 to 2100) will reach 78.3 days and 43.1°C, respectively in the long term. According to the medium and long-term development plan of Wuhan, according to the medium and high-speed development scenario, the per capita GDP of Wuhan will reach 336,000 yuan per person by 2050 (constant price in 2020, the same below), and the total population will reach 20 million; per capita GDP will reach 560,000 yuan per person and the total population will reach 30 million by 2100. Wuhan, as a major industrial town in China, has always stabilized its share of secondary production at around 40%, and the geographical location of the industrial parks is basically stable, but they have all achieved industrial upgrading. Based on the above scenarios, the average losses due to power shortages caused by high temperature in 2030, 2050, and 2100 are respectively 905 million yuan and 1.442 billion yuan, 21.03 billion yuan. Billion yuan and 3.417 billion yuan, 6.649 billion yuan and 11.07 billion yuan respectively under the RCP4.5 and RCP8.5 scenarios through Monte Carlo simulations. (See Figure 3.10).

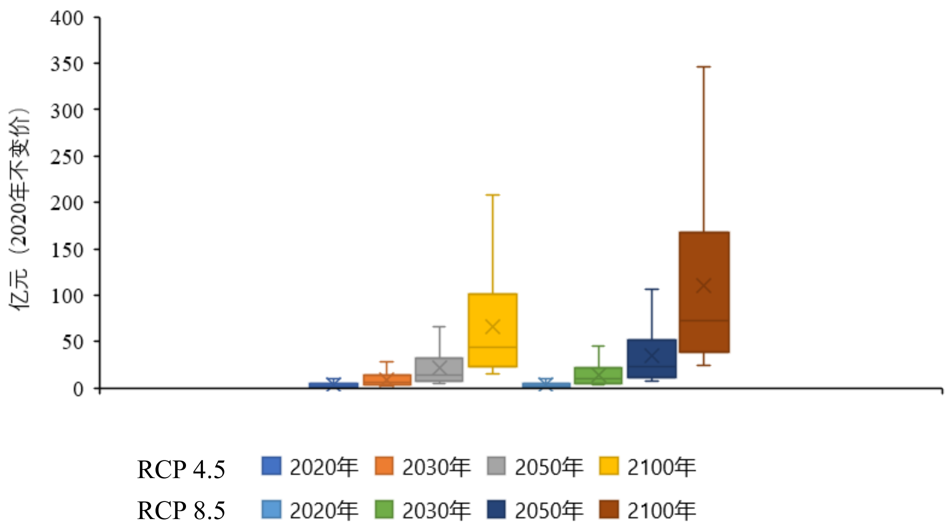


Figure 3.10 System loss and uncertainty interval of power shortage in Wuhan under different scenarios

(5) Economic systemic risks caused by traffic delays caused by urban waterlogging in Wuhan

The transportation sector is the infrastructure for the normal functioning of the economic system. Urban waterlogging caused by short-lived heavy rainfall will damage the transportation infrastructure and reduce the connectivity and accessibility of the street network which will not only cause direct economic losses in the transportation sector, but will also have a chain reaction and ripple effect on the economy through industrial linkages, which will lead to indirect economic losses, thus making the direct risks caused by urban waterlogging will develop into systemic risks for the entire economy.

The study uses four 24-hour heavy precipitation scenarios as the hazard indicator of urban waterlogging, Wuhan's transportation facilities as the exposure indicator, and the construction time and drainage capacity of the Wuhan pumping station as the vulnerability indicator. Using a combination of GIS remote sensing imagery, NPP-VIIRS nighttime light remote sensing annual synthetic imagery and gravity modeling tools for analysis, traffic disruptions caused by urban flooding and their delays were firstly assessed based on the spatial accessibility of the motor vehicle road network under the four 24-hour heavy precipitation scenarios.; second, the direct economic loss of the road transportation industry are estimated by estimating the increase in travel time caused by urban waterlogging; thirdly, the input-output model is used to simulate and calculate the industry-related losses caused by urban waterlogging, and finally the economic system risk due to traffic interruption caused by urban waterlogging is obtained.

- **Scene setting**

The study uses 2016 and 2020 as realistic scenarios, and extreme heavy rain events in Zhengzhou in July 2100 and 2021 as simulated scenarios.

- 2016 scenario: 24-hour maximum precipitation in Wuhan in July 2016 was 242mm, and the drainage capacity of the urban road network and pumping stations in 2016.
- 2020 scenario: maximum 24-hour precipitation Wuhan in July 2020 is 227mm, and the urban road network and drainage capacity of each pumping station in 2020.
- 2100 scenario: 24-hour precipitation of 384mm, urban road network and drainage capacity of pumping stations in 2020.
- Zhengzhou scenario: the historical extreme value of the 24-hour precipitation in July 2021 of 553mm, and the drainage capacity of the urban road network and pumping stations in 2020.

The adaptability of urban waterlogging in Wuhan has been greatly improved. In order to alleviate and adapt to the urban waterlogging problem and improve the resilience to disasters, Wuhan has put forward the concept of “four waters and co-governance”, namelyflood prevention, drainage, sewage treatment, and water supply, complied Wuhan Flood Prevention Emergency Plan, the Wuhan Sponge City Special Plan, the Wuhan Central City Drainage and Flood Prevention Special Plan (2012-2030)" and other special plans and planning documents on this regard, improved the construction of urban drainage facilities such as pumping stations, and at the same time comprehensively promoted the development of sponge cities and upgraded Wuhan's drainage pipes network and strengthened water storage function of the lakes. From 2010 to 2019, the per capita park green area in Wuhan increased from 8.89 square meters to

10.19 square meters, the urban green coverage rate rose from 38.2% to 40.02%, the length of drainage pipes increased by 3304 kilometers, and the overall drainage capacity of the central urban area increased from 2016's 958 m^3/s will be increased to 1960m^3/s in 2020.

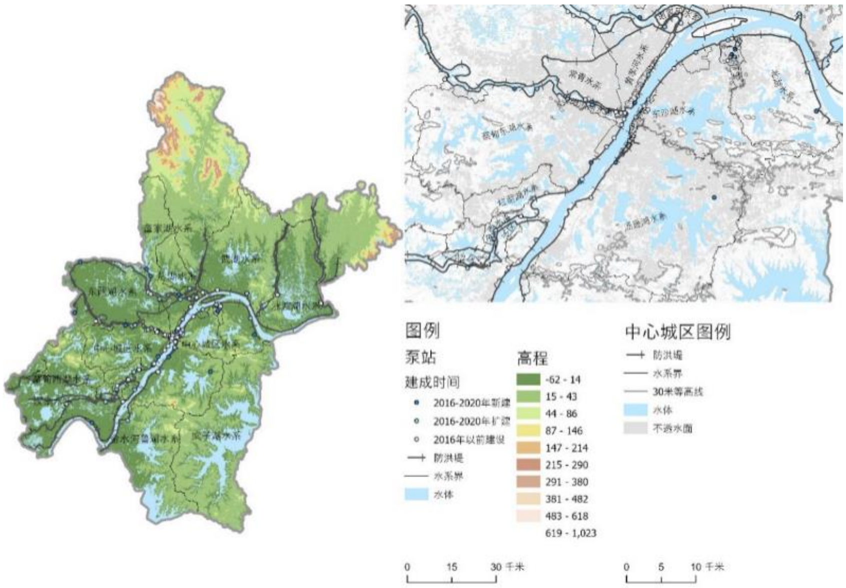


Figure 3.11 Topography, water system and drainage capacity of Wuhan city

- **Evaluation and analysis of inundated areas in Wuhan under different scenarios**

As shown in Figure 3.12 and Figure 3.13, the heavy precipitation in 2016 was slightly higher than that in 2020, it resulted in a much higher the inundation area in Wuhan than in 2020. In contrast, after the construction of the drainage system in Wuhan, the city effectively responded to the short-lived heavy rainfall in July of that year in 2020. Although there are still partially inundated areas, the total area has decreased by 10.05% compared with 2016. However, if the drainage capacity remains unchanged in 2020, the submerged area will expand by 76.64% for the 2100 heavy precipitation scenario, and 187.88% for the 2021 extreme precipitation scenario in Zhengzhou.

In addition, there are significant urban-rural and intra-urban differences in the exposure of transportation facilities and the adaptability of heavy rains and urban waterlogging in Wuhan, which leads to differences in the risk of urban waterlogging. First, the intensity of traffic activities in central urban areas is higher than that in remote urban areas, and the exposure to short-lived heavy rainfall will be higher. Secondly, the overall drainage capacity of Wuhan City has increased by 104.59% in 2016 to 2020. However, the construction intensity of the water system in the central urban area of Wuhan was higher than that in the outer urban area during the same period, with drainage capacity increasing by 108.28% and 46.02% respectively. Therefore, from the results of the inundation areas, compared with 2016, the inundation area in the central urban area and the outer urban area in the water system in 2020 will be reduced by 30.92% and 10.77%, respectively, and the inundated areas in Hankou, Hanyang and Wuchang in the central city decreased by72.55%, 36.22%, and 26.46% in the 2016 scenario, respectively, indicating that the three towns in Wuhan benefited from the improvement of urban drainage capacity and effectively responded to the challenge of short-livedheavy rainfall in 2020.

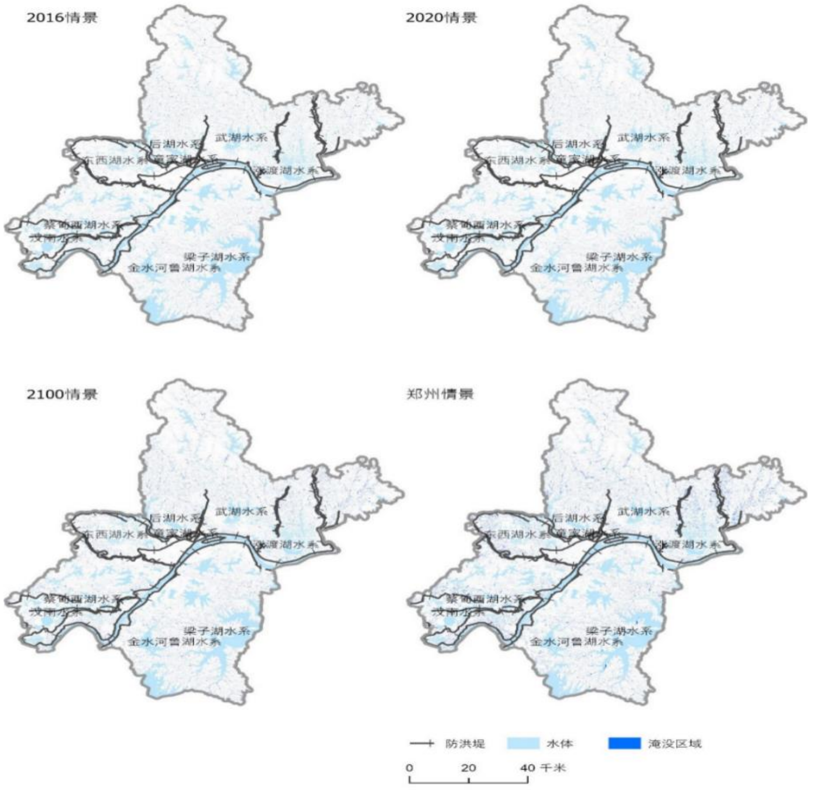


Figure 3.12 Simulation results of the flooded area in Wuhan under four different scenarios

However, if the drainage capacity is not further improved, the submerged area within the central urban area and the remote urban area will increase by 119.67% and 84.20% respectively under the 2100 scenario compared to 2020, with the flooded area of Hankou, Hanyang, and Wuchang will increase respectively by 608.62% 112.08%, 119.37%. Under the Zhengzhou scenario, the inundation area within the central urban area and the outer urban area will increase by 242.83% and 234.63% respectively compared to 2020, of which the flooded area in Hankou, Hanyang, and Wuchang will increase by 3464.89%, 216.14%, and 227.79%, respectively, and the areas with severe urban waterlogging are in Hankou.

In summary, although the urban drainage projects in Wuhan have improved the city’s ability to cope with short duration heavy rainfall, it is still difficult to respond more effectively to higher-intensity rainfall caused by future climate change based on the current drainage capacity. Considering the frequency and intensity of heavy precipitation due to climate change, the extent of inundation will be even greater.

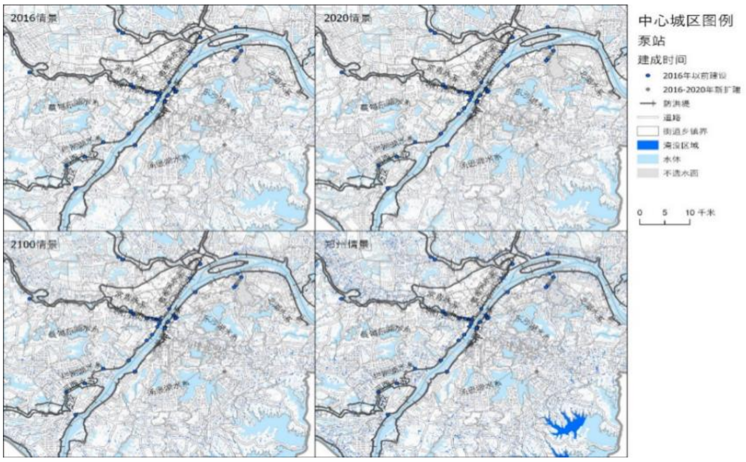


Figure 3.13 Simulation results of the submerged area in the central urban area of Wuhan under different scenarios

- **Evaluation and analysis of Wuhan's traffic delay under different scenarios**

Table 3.5 and Figure 3.14 show the distribution areas and delays of Wuhan's traffic delay under different scenarios. In 2016, the average traffic delay in Wuhan was 668.9 minutes and 621.9 minutes in 2020, a decrease of 7.03% compared to 2016. Keeping the drainage system construction unchanged in 2020, the traffic delay under the 2100 scenario would reach 887.2 minutes, an increase of 42.66% over 2020, and the traffic delays under the 2021extreme precipitation scenario in Zhengzhou would reach 1040.9 minutes, an increase of 67.37% over 2020. If the gravitational forces and link ages between the various regions of the city are considered, the average delay of a single trip, expressed as a weighted average delay, decreases by 58.57% in 2020 compared to 2016, and the 2100 and Zhengzhou scenarios will increase by 1439.08% and 2005.75%. Compared to2020.The results of modelling and analysis of the transportation system show that the increase in the intensity of short duration rainfall and the expansion of the inundated area lead to changes in the morphology of the urban road network, thereby further generating the correlation between traffic flows, path changes and delays.

Table 3.5 Traffic delay results in Wuhan under different scenarios

	2016 scenario	**2020scenario**	**2100scenario**	**Zhengzhou scenario**
Mean	668.9Minutes	621.9Minutes	887.2Minutes	1040.9Minutes
Weighted mean	21.0Minutes	8.7Minutes	133.9Minutes	183.2Minutes

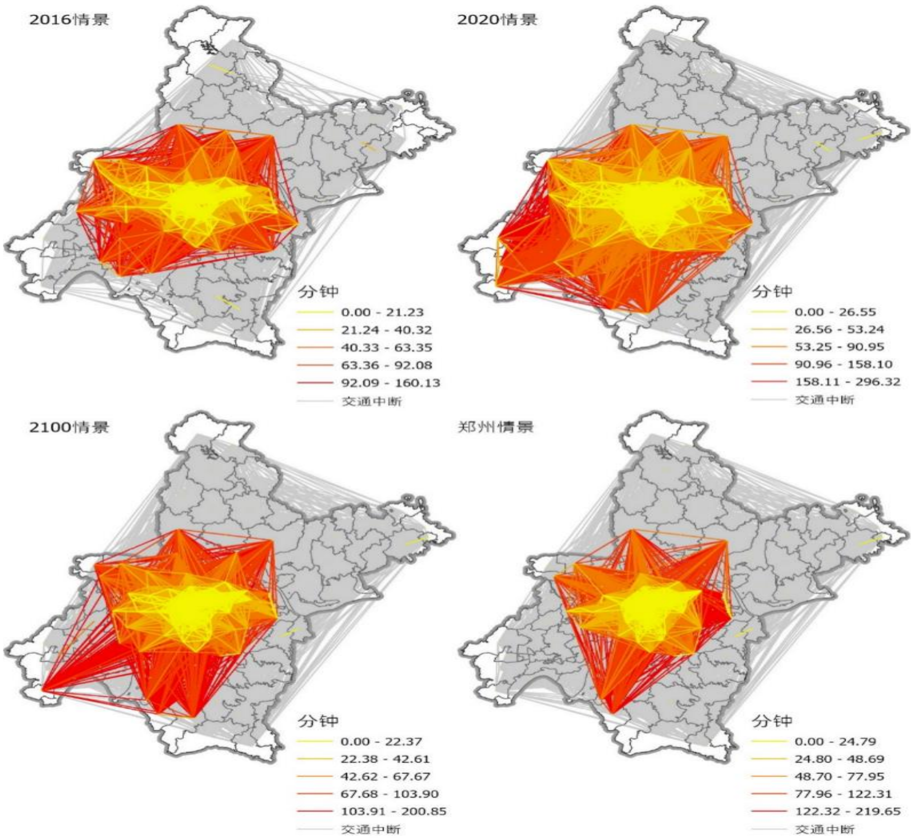


Figure 3.14 Traffic delay results in Wuhan under different scenarios

- **Evaluation and analysis of Wuhan's traffic delay under different scenarios**

The road delays caused by urban waterlogging first lead to a major loss of transportation infrastructure which is part of the direct risk caused by urban waterlogging. The indirect risk to the transportation sector is unable to operate normally due to damage to the infrastructure, the loss caused by the suspension of operation or traffic delays, and the economic damage to all sectors of society due to the delayed delivery of people and goods, so that urban waterlogging transmits risks through the transportation sector to the entire urban economic system, thereby causing systemic risks.

Based on the 2016 scenario, the study calculated the loss to the entire economic system of Wuhan due to traffic delays caused by urban waterlogging by using the input-output tables of Wuhan in 2017 (see Table 3.6). It can be found that when the maximum 24-hours precipitation reached 242mm in July 2016, the direct economic losses to the transportation sector reached 122.8375 million yuan, and the traffic delays caused the indirect economic loss in the transport sector amounted to by 14.9612 million yuan, mainly in the road transportation sector, reaching at 12.5106 million yuan, whilethe total indirect losses transmitted to various industries via the road transport amounted to 196.7830 million yuan. In terms of industries, the indirect losses in the primary industry were 441,900 yuan, the indirect losses of the secondary industry were 139,297,700 yuan, and the indirect loss of the tertiary sector were 5,704,434 yuan. From the industry perspective, the economic sectors with the greatest indirect risks were transportation sector, finance, construction, road/highway transportation, wholesale and retail, leasing and business service.

It can be found that in the context of increasing intensity and frequency of extreme weather events such as heavy rains, climate change risk will expand to the entire economic system and ultimately lead to large-scale systemic risks for the whole city if the key economic sectors where the risk transmission do not have adequate response and preventive measures to break the chain of risk transmission in time.

Table 3.6 Economic losses of various industries caused by traffic delay caused by urban waterlogging in Wuhan (unit: ten thousand yuan)

Number	Industry	Indirect Loss	Number	Industry	Indirect Loss
1	Agriculture, forestry, animal husbandry and fishery products and services	44.19	24	Electricity and heat production and supply	393.80
2	Coal mining products	0.18	25	Gas production and supply	337.08
3	Oil and gas extraction products	0.00	26	Water production and supply	17.76
4	Metal mining products	16.40	27	Architecture	1253.43
5	Non-metallic ore and other mining and beneficiation products	2.33	28	Wholesale and Retail	551.01
6	Food and tobacco	208.85	29	Railway transportation industry	41.75
7	textile	17.19	30	Road transportation industry	1251.06
8	Textiles, clothing, shoes, hats, leather down and their products	24.64	31	Water transportation industry	36.65
9	Woodworking products and furniture	16.62	32	Air transportation industry	51.16
10	Papermaking printing and cultural, educational and sporting goods	125.87	33	Other transportation industry	115.50
11	Petroleum, coking products and nuclear fuel	459.79	34	Accommodation and meals	314.01
12	processed products	242.78	35	Information transmission, software and information technology services	333.12
13	chemical product	40.39	36	Finance	1719.75
14	Non-metallic mineral products	189.08	37	Real estate	449.01
15	Metal smelting and rolled products	128.26	38	Rental and business services	542.58
16	General Equipment	363.25	39	Research and experimental development	0.00
17	Professional setting	66.53	40	Comprehensive technical service	38.55
18	Transportation equipment	9031.75	41	Water conservancy, environment and public facilities management	6.83

19	Electrical machinery and equipment	372.72	42	Resident services, repairs and other services	121.63
20	Communication equipment, computers and other electronic equipment	401.67	43	Educate	21.13
21	Instrumentation	54.30	44	Health and social work	21.58
22	Other manufactured products and scrap	38.02	45	Culture, sports and entertainment	63.47
23	Repair service of metal products, machinery and equipment	127.08	46	Public administration, social security and social organization	25.55
Total: 19678.3					

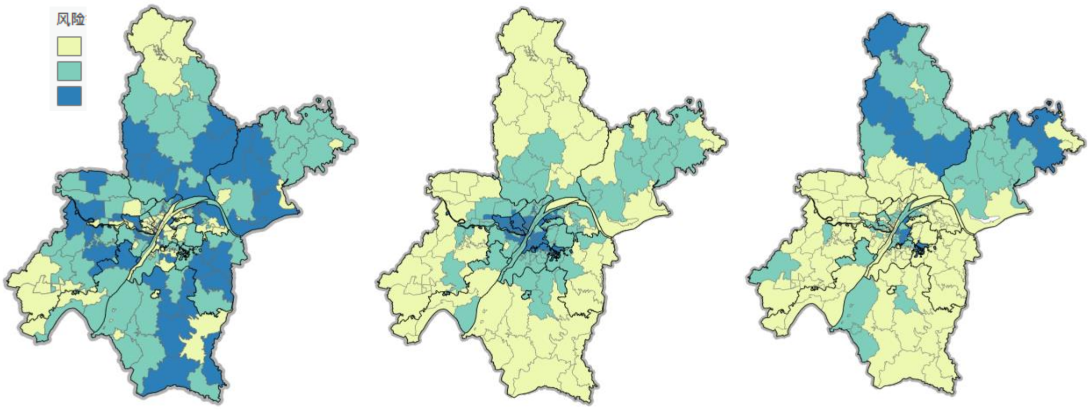
(6) Social risks under climate change in Wuhan

The results of simulation and analysis based on the road traffic system under different scenarios further confirm the correlation between the direct risks of climate change and the indirect risks of the transportation system. Considering a global temperature rise of at least 1.5°C all emission scenarios (IPCC, 2021), the frequency and intensity of extreme weather events caused by climate change will continue to increase. Cities are complex nonlinear system, and the existing adaptive capacity to respond can effectively and inclusively to future climate change and its systemic risks still needs further assessment. Therefore, the impact of climate change-induced heavy rains and waterlogging on urban economic and social systems can be modelled and assessed in terms of the waterlogging caused by extreme weather events and its delay effect on urban traffic.

The spatial heterogeneity of urban climate risk and adaptive capacity will also be transmitted and diffused to the urban social system through the spatial differentiation of urban social and the spatial differentiation of income and housing generated by the urban economic structure. Different social groups are exposed to climate risks differently where, and climate change may lead to a higher intensity of exposure of certain groups to climate change risks, resulting in the climate vulnerable populations, raising issue of social inequality, social exclusion in response to climate change based on climate risks, and leading to the social risks of climate change.

Taking into account the aging demographic structure of Chinese society, the study takes the elderly as an example, based on the vulnerability assessment framework, selects the inundated area in Wuhan as the hazard indicator, the population size as the exposure indicator, the elderly population aged 65 and over and GDP per capita as the vulnerability indicator, and using remote sensing data from Luojia-1 night lights (130m resolution), the 2018 Wuhan Statistical Yearbook and the data from the Census, the social system risk of urban waterlogging in Wuhan was regionally classified in terms of hazard, exposure and vulnerability, , and high, medium and low (H-M-L) levels, based on street-scale analysis (see Figure 3.15). The results found that the social systemic risk of urban waterlogging in Wuhan has significant characteristics of urban-rural and intra-urban heterogeneity. Figures 3.16 and 4-17 further show that the heterogeneity is mainly characterized by high-hazard-high-exposure-low-vulnerability areas in cities and medium-hazard-low-exposure-high-vulnerability areas in rural areas;

the intra-urban heterogeneity is mainly manifested as low-hazard-high-exposure-high-vulnerability areas in old town, and medium-hazard-high-exposure-low-vulnerability areas in new development areas.



Waterlogging risk level Exposure level Exposure level

Figure 3.15 The three-dimensional performance of the social system risk caused by urban waterlogging in Wuhan

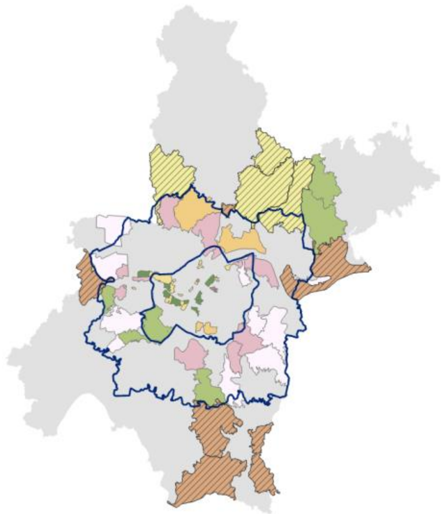


Figure 3.16 Urban-rural differences in the social risk of waterlogging in Wuhan

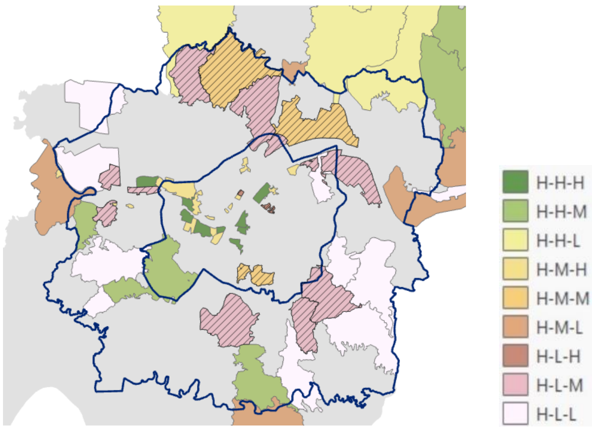


Figure 3.17 Differences within the social risk of urban waterlogging in Wuhan

3.3 Key messages and suggestions

3.3.1 Key information

Due to the high concentration of population, industry, and wealth, the impact of extreme disaster events caused by climate change on the health, life, and infrastructure of urban populations is becoming more prominent. Climate change interacts with urban human settlements and production environments, and the disasters' chaining, amplification, and clustering effects will be more pronounced driven by climate change.

Cities will become the most vulnerable areas to induce climate change system risks. The complexity of cities further increases the difficulty of responding to climate change risks. Local government decision makers need to therefore better understand the severity of systemic risks of climate change, incorporate them into government policies and decision-making, strengthen systematic planning to deal with systemic risks of climate change, and implement policy actions that reduce vulnerability, enhance participation and inclusiveness in decision-making, and adhere to the coordination of social, environmental, and economic effects.

3.3.2 Suggestions

(1) Suggestions for the health risks of climate change

The first is to establish a national and regional climate change health risk assessment system. The main types of climate change, health risks, and the characteristics of vulnerable areas and populations at the national level and in different regions need to be clearly identified, so that targeted adaptation strategies and measures can be adopted in accordance with local and seasonal conditions. The second is to establish national and regional climate change health risk adaptation systems, prepare adaptation plans and action guidelines based on the results of climate change health risk assessments, carry out regular assessments of adaptation capacity and the implementation of adaptation plan, dynamically assess the changes in adaptation capacity and update the adaptive capacity action plan. The third is to further improve the resilience of the medical and healthcare service system to climate change, and guidelines for assessing the vulnerability of the healthcare service system to climate change will be developed and evaluated, including vulnerability analysis and risk assessment of hospitals, public health institutions, medical staff, ambulances, and medicines and related industrial chains such as medicines, medical equipment and protective gear. Formulate reasonable response plans based on the assessment results to gradually improve the resilience of the healthcare system to climate change, especially extreme weather events.

(2) Suggestions for systemic risks under high temperature heat waves

The first is to co-ordinate the overall planning of power consumption. The region must coordinate the planning and construction of both the power supply and demand sides, develop diversified routes for the supply side power supply, and improve the resilience of power supply; second, the demand side should improve energy efficiency and establish a demand response system. Strengthen communication and guidance, map out the minimum production demand load of the enterprise, monitor the production and operation of the enterprise in real time, regularly count the output and power consumption of the enterprise, and grasp the production dynamics of the enterprise; third, establish a transformer parade system based on the load characteristics of the platform; fourth, establish an industrial peak tariff system to encourage industrial enterprises to rationally shift electricity load, cut peaks and fill valleys, reduce the power load rate during peak and valley periods, improve the utilization efficiency of system equipment capacity and save energy; fifth, recommend a comprehensive energy diagnosis for industrial enterprises, actively connect with the power supply department to understand the requirements for load reduction requirements, strengthen industrial operation monitoring, and strictly implement the regional orderly peak-avoidance power plan; sixth, establish a residential-side shift-peak and flat-valley power capacity market system.

(3) Suggestions for systemic risks under urban waterlogging

First is to comprehensively improve the city's ability to adapt to climate change. At first instance, climate risks should be fully considered in urban planning, and climate feasibility should be considered as a precondition for urban planning and functional layout; rainstorm intensity formula and drainage pipe network standards should be revised according to the new spatial and temporal distribution patterns and rain patterns of short-duration rainstorms. Secondly, further improve the early warning system for rainstorms and high temperature disasters, the capacity of rainstorms and high temperature monitoring and early warning should be improved, the emergency plans for sudden rainstorms in cities, mechanism for disaster prevention and mitigation, emergency release of early warning information and emergency response should be improved. Finally, all engineering measures should be adapted to the impact of climate change, the development intensity should be controlled, the development intensity and the layout should be rationally governed through planning and the surface runoff and heat island effect should be effectively controlled through engineering measures.

Secondly, priority should be given to promote. Nature based Solutions. Cities should increase the protection of lakes and wetlands, restore and improve the lake’s ecological water storage capacity; accelerate the development of sponge cities, and strictly control the growth of impermeable layers; and scientifically design rainwater utilization systems such as urban lakes, grasslands and permeable water based on the city’s waterlogging risk level zoning map.

Third, focus on the cross-regional division of affairs and financial authorities. Accelerate the improvement of cross-regional, cross-industry, and cross-departmental river and lake management mechanisms, and earnestly implement the main responsibility for river and lake protection; strictly implement the lake chief[①] system, develop the "one lake, one policy" tailored programme, and specify the responsibility of the lake chief to every meter of the lake shoreline. Explore the cross-regional ecological compensation mechanism, jointly build the Yangtze River ecological environment supervision platform, strengthen the development of risk prevention and control capabilities in key areas; establish a unified environmental risk emergency management platform in key areas to achieve disaster emergency information exchange and sharing; actively innovate investment and financing mechanisms, engage all stakeholders in the investment, construction and professional operation and management of drainage and waterlogging prevention facilities from multiple channels.

[①] The river/lake chief mechanism is an institutional innovation and started implementation in 2007 in China, it assigns each part of a river/lake to a certain official to deal with the ecological environmental crisis in the river basin/lake region. River/Lake chiefs also help coordinate between depts & regions.

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