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Historical Changes and Future Trends of Extreme Precipitation and High Temperature in China

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Abstract: Extreme events have been occurring frequently in China due to global warming. Understanding the spatiotemporal variations in these extreme events and predicting their future trends could provide a theoretical basis for formulating regional strategies that can be adapted to climate change. Using the CN05.1 grid meteorological data and 11 global climate models based on the Coupled Model Intercomparison Project Phase 6 (CMIP6), we analyzed the evolution characteristics of extreme precipitation and high-temperature events in China from 1975 to 2014. Subsequently, we predicted the evolution of extreme events from 2015 to 2054, and proposed policy suggestions for dealing with these events. The results indicated that from 1975 to 2014, heavy precipitation exhibited an increase-decrease-increase pattern from the Northwest to Southeast regions of China, and that the risk and catastrophic ability of extreme precipitation in regions east of the Hu Line was significant. Under the SSP1-2.6 and SSP5-8.5 climate change scenarios, extreme precipitation in China would show a general increase, becoming stronger by 2054, with notable increases in North and Northeast China and a further increase in Northwest China. From 1975 to 2014, the number of warm days and nights in China increased significantly, whilst the increase in warm nights were greater than that of warm days. Furthermore, under the SSP1-2.6 and SSP5-8.5 climate change scenarios, extreme heat events in China will increase significantly by 2054, with the greatest increases occurring in Northwest, Southwest, and South China. To mitigate the impacts of climate change and cope with the risks of extreme events in future, China should further improve its response and emergency management capacity for dealing with floods and extreme heat risks, whilst strengthening international cooperation, and formulating strategies adapted to local conditions.

Keywords: Climate change; extreme event; CMIP6; extreme disaster response

1 Introduction

Since the Industrial Revolution, the concentration of carbon dioxide in the atmosphere has notably increased. The average annual concentration of carbon dioxide in 2021 was 414.7 ppm, approximately 2.3ppm higher than that in 2020. This is the highest value recorded with modern instruments [1]. Persistent emissions of greenhouse

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gases, such as carbon dioxide, have led to a substantial increase in the global average temperature, thereby, increasing the global risk of extreme climates. According to the *Global Climate Risk Index 2021* [2], approximately 11 000 extreme meteorological disasters have occurred globally over the past 20 years, which have resulted in approximately 475 000 deaths alongside economic losses of nearly 2.56 trillion USD. Global warming caused by greenhouse gas emissions has pronouncedly affected regional hydrological and atmospheric cycles, resulting in the frequent occurrence of disasters such as extreme drought, torrential rain and floods, high-temperature heat waves, rising sea levels, glacier degradation, and frozen soil melting. These disasters seriously restrict the balanced development of regional economic, social, and ecological environments [3,4].

According to the sixth assessment report of the United Nations Intergovernmental Panel on Climate change (IPCC), the global average temperature between 2011–2020 has increased by approximately 1.09 ℃ compared with that between 1850–1900. In the event of continued warming, the frequency and intensity of extreme weather events, such as extreme precipitation and high-temperature heat waves, will increase further [5]. According to the Clausius-Clapeyron thermodynamic equation, substantial atmospheric heating leads to an increase in atmospheric saturated water vapor pressure, thus increasing the frequency and intensity of extreme precipitation events [6]. The frequent occurrence of extreme precipitation events will then lead to regional floods, threatening the safety of life and property of urban and rural residents. Simultaneously, the reduction in food production caused by rainstorm disasters has aggravated the global food crisis and triggered a series of secondary disasters. Meanwhile, extremely high-temperature heat wave events increase the incidence of heat radiation, cardiovascular and cerebrovascular, respiratory tract, and nervous system diseases, directly threatening human health [7]. Therefore, to mitigate the impact of global warming, the *Paris Agreement* proposed limiting the range of global warming to 1.5–2 ℃ [8]. Notably, the rate of global average temperature increase from 2011 to 2020 was reported to be 0.24 ℃/10a [9]. A simulation of limited amplitude impulse response (FalR) climate model showed that under the scenario of stopping carbon emissions immediately in 2021, the global average temperature still had a 42% probability of exceeding the target temperature control of 1.5 ℃ by approximately 2029 [10]. Based on various climate model predictions, global warming by 1.5 ℃ and 2 ℃ could occur by approximately 2030 and 2040, respectively, whilst the regional temperature change in China will be higher than the global average [11].

Global warming is an indisputable fact, and it has considerably impacted China's resources, ecology, economy, and society. The sub-project—"Water Balance and Evolution of Water Cycle Elements in Key Regions" (2020)—of the Chinese Academy of Engineering consultation project "Strategic Research on the Coordinated Development of Water Balance and Territorial Space (Phase I)" focused on the evolution of water balance elements and analyzed the impact of climate change on regional water balance. Among them, the change in extreme events under global warming was seen to directly impact the economic, social, and property security of China, revealed the law of historical evolution of extreme precipitation and high temperatures in China due to global warming. Predicting possible changes in extreme climatic events in the future is crucial for addressing the risk of climate change. Considering this, based on the CN05.1 grid meteorological data and the global climate model simulation climate data of the sixth International Coupled Model Comparison Plan (CMIP6), this study focused analyzing the extreme historical precipitation and high temperature changes, and future trends in China, and putting forward several policy suggestions to deal with extreme events and mitigate the effects of climate change.

2 Research data and methods

2.1 Research data

In this study, CN05.1 grid meteorological data (precipitation, maximum and minimum temperature) from 1975 to 2014 were used to analyze the changing trends and spatial characteristics of extreme historical precipitation and high-temperature events. CN05.1 meteorological data were generated by interpolation from more than 2400 meteorological stations in China and were provided by the National Climate Center. The data for future precipitation, maximum and minimum temperature were based on the prediction results from the global climate model, which was selected from the newly released CMIP6 plan, including ACCESS-CM2, ACCESS-ESM1-5, CanESM5, EC-Earth3, EC-Earth3-Veg, EC-Earth3-Veg-LR, GFDL-ESM4, KACE-1-0-G, MRI-ESM2-0, NorESM2-LM, and NorESM2-MM plans. These models have performed well in extreme precipitation and temperature simulations, whilst the ability of CMIP6 to simulate extreme climates has been improved compared with CMIP5 [12,13].

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CMIP6 provides historical climate simulation data from 1850 to 2014 alongside future climate prediction data from 2015 to 2100. To correspond with the time of historical observation information in China, this study considered 1975–2014 as the historical reference and 2015–2054 as the future forecast period whilst selecting two different shared socioeconomic path scenarios (SSP1-2.6, SSP5-8.5) for comparative analysis. The SSP1-2.6 scenario indicated that the radiation forcing stability in 2100 would be 2.6 W/m^2 under the path of sustainable development. Meanwhile, the SSP5-8.5 scenario indicated that radiation forcing in 2100 would be as high as 8.5 W/m^2 under the traditional fossil fuel-dominated path.

2.2 Research methods

The resolutions of the historical and future climate prediction data involved in this study were different; therefore, bilinear interpolation was used to unify all historical and future prediction data resolutions to a 0.5°× 0.5°grid. There was a large deviation in the regional application of the original climate model prediction data. Based on historical data of CN05.1, the deviation correction method was used to correct historical and future climate model data [14].

Extreme precipitation and high temperature index selected strong precipitation (R95TOT), precipitation intensity (SDII), number of warm nights (TN90p) and warm days (TX90p) to analyze the changes in extreme climate events [15]. The definitions of the extreme indicators are listed in Table 1. The threshold of the extreme event index in the historical period was determined by the CN05.1 dataset from 1975–2014, whilst the threshold of the extreme event indicator in future was determined using the model data from 1975–2014 under different emission scenarios for the climate model selected above.

The evolution trend and significance of historical extreme climate indices from 1975–2014 were analyzed using the Theil-Sen trend estimation method and the MK nonparametric rank test [16]. For predicting the trend of future extreme events, it was characterized by the variation in multi-year average extreme index relative to the average value of historical reference period in the future forecast period, wherein the relative percentage of extreme precipitation and absolute change in extreme high temperature were adopted. Simultaneously, prediction uncertainty was considered based on the prediction results of different climate models. To facilitate the comparative analysis, according to the geographical position of the provincial administrative region, the entire country was divided into seven regions: Northwest China, North China, Northeast China, Southwest China, Central China, East China, and South China, with the regional extreme index difference being reflected by changes in the grid index in the statistical division.

Table 1 Determination of indicators for extreme weather events.

Indicators	Name	Meaning
R95TOT	Strong precipitation	Annual cumulative precipitation with daily precipitation greater than 95% percentile
SDII	Precipitation intensity	Ratio of total annual precipitation to wet days
TN90p	Number of warm nights	The number of days when the daily minimum temperature is greater than 90% percentile.
TX90p	Number of warm days	The number of days when the daily maximum temperature is greater than 90% percentile.

3 Historical climate change trends in China

3.1 Historical extreme precipitation changes

Fig. 1. shows a box diagram of the rate of change in R95TOT and SDII and the trend value of MK in different regions from 1975 to 2014. Between 1975 and 2014, the spatial pattern of the R95TOT trend change was similar to that of summer precipitation in China (Fig. 1 (a)). Overall, this showed the characteristic pattern of an initial increase, followed by a decrease, and then increasing again from the northwest to southeast [17]. These results demonstrated that more than 75% of the regions in Northwest China showed an increasing trend, with an increase rate of 0–30 mm/(10a); the increase rate of R95TOT in Northeast, Central, East, and South China east of the Hu Huanyong Line was the greatest, with an increase rate of 10–80 mm/(10a) being observed in more than 75% of the regions, whilst the decrease rate of R95TOT was 0–40 mm/(10a).

Considering the spatial trend of MK, the change in R95TOT index in most areas of China was not markable, whilst the area with confidence level below 95% (MK value was ±1.96) accounted for 81.4% of the study area (Fig. 1 (b)). The area where R95TOT increased substantially accounted for 17.2% of the total area, most of which was distributed in the Northwest and Northeast China; while, heavy precipitation in the dense area east of the Hu Huanyong Line generally increased, with a greater risk and harmfulness of extreme rainstorms. The area covered by R95TOT considerably decreased to less than 2% of the total area and was distributed throughout Southwest China.

For the SDII index, the change was similar to that of R95TOT, and generally showed the spatial pattern of “two additions, one decrease” (Fig. 1 (c)). Specifically, more areas in Northeast, East, and South China showed an upward trend, whereas more areas in North and Central China show a downward trend. The area of SDII showing an upward trend accounted for approximately 47.0% of the total area of the country, wherein the area with a change rate of more than 0.2 mm/ (d. 10a) accounted for an estimated 5.1% of the total area, whilst the area with a change rate below –0.2 mm/ (d. 10a) accounted for approximately 10.9% of the total area. Considering the MK trend value, the change in trend of the SDII in most areas of China was unremarkable. The area of MK value between ±1.96 accounted for approximately 85.5% of the total study area (Fig. 1 (d)). The area where the SDII substantially increased and decreased accounted for 6.3% and 8.2% of the total area. Overall, the intensity and total amount of extreme precipitation in the dense coastal areas of eastern China have increased, with an increased risk of extreme precipitation, which was consistent with existing research [18].

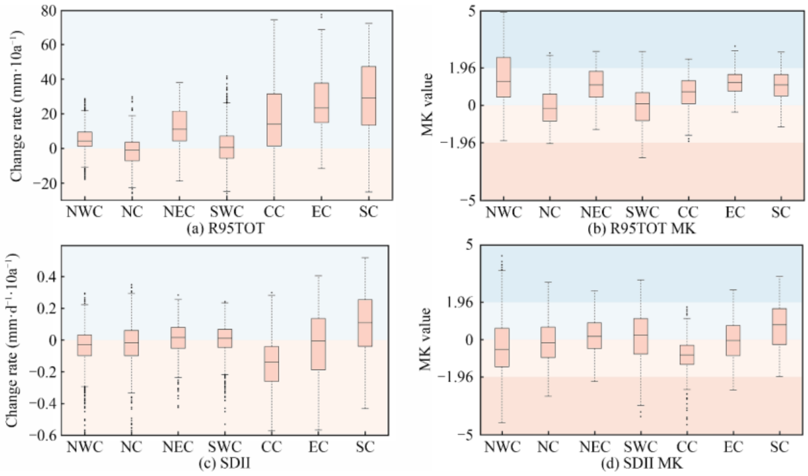

Fig. 1. Change rate and MK value of R95TOT and SDII index of extreme precipitation in China from 1975 to 2014.

Note: 1. The critical value of MK trend corresponding to 95% confidence level is ±1.96. The MK value was negative, indicating a downward trend; however, it was considered an upward trend, as shown below. 2. The box body in each area was composed of the grid statistical results, and the distribution of the box body represented the spatial difference in this area, which was the same as that in the same area. 3. NWC, NC, NEC, SWC, CC, EC, and SC refer to Northwest China, North China, Northeast China, Southwest China, Central China, East China, and South China, respectively.

3.2 Historical extreme high temperature changes

Fig. 2. shows the rate of change in the TN90p and TX90p indices and a box diagram of the MK value in different regions of China from 1975 to 2014. The changes in the TN90p and TX90p indices represented the frequency of extreme high-temperature events at night and during the day, respectively. Considering From the perspective of the rate of change, the TN90p and TX90p indices in most areas of the country increased to varying degrees, whilst their area ratios increased to 99.4% and 97.3%, respectively. The spatial distributions of the rates of change of TN90p and TX90p were generally similar, both of which were large in Northwest, North, Southwest, and South China, but small in Central and Eastern China. Overall, the rate of change in the TN90p was higher than that in the TX90p. The average rates of change for TN90p and TX90p in China were 5.9 d/10a and 4.0 d/10a, respectively. The spatial characteristics of the TN90p and TX90p rate of change were consistent with [19]. The rate of change of TN90p in Northwest, Qinghai-Tibet, and Southwest China were larger, while the rate of change of TX90p in Sichuan, Chongqing, Gansu, Shaanxi, and coastal areas were larger.

Considering the MK trend value, the rates of change of TN90p and TX90p were consistent, and the higher the change rate, the higher the significance level, with the areas of significant upward trends accounting for 82.8% and 72.2%, respectively. It is worth noting that the overall trends of the two extreme high-temperature indices in northwest Xinjiang were quite different from those in the entire northwest region. The change rates of TN90p and TX90p in these areas were 0–5 d /10a and −2–3 d /10a, respectively, which were much lower than the average change rates in Northwest China (the increase ranges of TN90p and TX90p change rates were 5–13 d /10a and 3–7 d /10a, respectively), whilst the TX90p index in a few regions showed a significant downward trend (Fig. 2 (d)).

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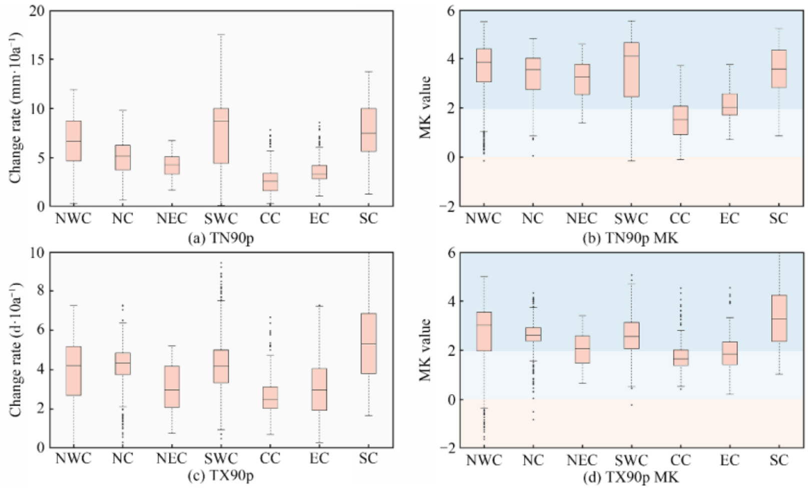

Fig. 2. Index change rate and MK value of warm night days (TN90p) and warm day days (TX90p) in China from 1975 to 2014.

4 Forecasting extreme climatic events in China

4.1 Future extreme precipitation estimates

Fig. 3 shows the percentage variations in R95TOT and SDII relative to the reference period in different regions of China. The percentile value was determined using the 50% quartile of the model set, whilst each box was composed of the 50% quantile prediction results for each grid in the region. As shown in Fig. 3, the R95TOT of heavy precipitation in China would increase under different scenarios, with most regions showing this increasing trend. Under scenario SSP1-2.6, the increase in R95TOT in the Northwest and Southwest Qinghai-Tibet Plateau would be the largest over the next 40 years, with the increase in R95TOT in most areas reaching more than 15%, followed by North and Northeast China, with a 10 – 20% increase in R95TOT. The growth rate of R95TOT in Central China was 5–15%, compared with 0–10% in East and South China. Yunnan, Guangxi, and Guangdong showed the smallest increases in strong precipitation, at 0–5%.

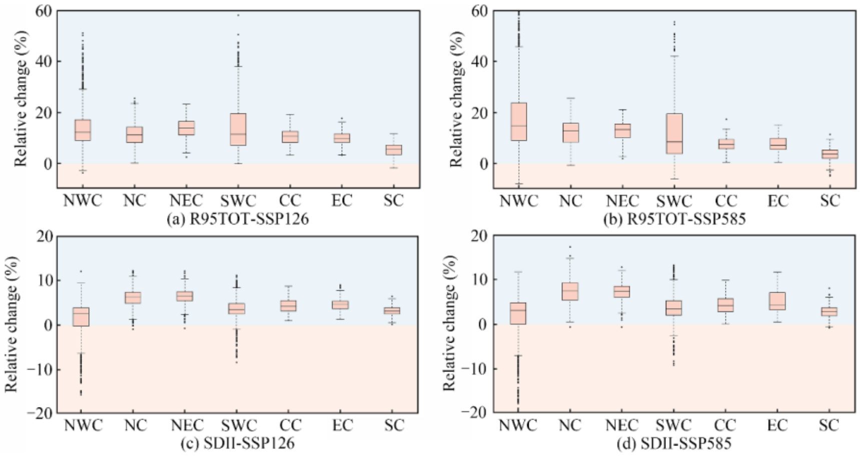

Fig. 3. Percentage of relative variation in extreme precipitation in China under SSP1-2.6 and SSP5-8.5 scenarios from 2015–2054 (relative to 1975–2014).

The spatial mode of R95TOT strong precipitation predicted by SSP5-8.5, was consistent with that of SSP1-2.6. Overall, there was a large increase in the Northwest, North China, and the Northeast and Southwest Qinghai-Tibet Plateau, alongside a small increase in the southern region. Compared with the SSP1-2.6 scenario, extreme heavy precipitation in Northern China would increase further under the SSP5-8.5 scenario, especially in cold and arid areas such as the Northwest, Qinghai-Tibet, Northeast, and other cold and arid areas, indicating that high carbon emissions would further aggravate the risk of extreme events whilst threatening the security of fragile areas with cold and dry ecology and economic core areas in China.

Concerning SDII, the future precipitation intensity would increase in most areas of China under different development scenarios, whilst only the northwest and southwest regions would show a decreasing trend. The

SSP1-2.6 scenario showed that the increase in SDII in North and Northeast China would be the highest over the next 40 years, with an increase of approximately 6%, followed by Central and East China, with an increase of between 2–6%, and that of South China with the lowest increase of 0–4%. The spatial mode of the SDII precipitation intensity predicted by SSP5-8.5 was essentially the same as that of SSP1-2.6. Overall, the increase in precipitation intensity in North and Northeast China was the largest, with that in South China being the lowest, whilst that in the local area of Northwest China decreased. Compared with the SSP1-2.6 scenario, the precipitation intensity in Northern China would further increase under the SSP5-8.5 scenario, whilst the decreasing trend of the SDII precipitation intensity in Northwest China was more obvious. However, the predicted results of different climate models in Northwest China were quite different, and there remains a great deal of uncertainty in the prediction.

In recent years, the observation data have shown that the northwest region exhibited a warm and humidification trend, despite being wet since 1961, and that the eastern region exhibited a dry to a humid trend in 1997, which was related to the cooperative enhancement of the East Asian summer monsoon circulation of the westerly circulation in the 21st century [20]. The simulation of the climate model also showed that the northwestern region would continue to warm and humidify in the future, along with continuous increase and intensification of the precipitation events. Zhu Huanhuan et al. [21] previously showed that the continuous dry days in Northwest China would be substantially reduced at 2.0 ℃, especially in the Tarim and Chaidamu basins. SDII is the ratio of the total annual precipitation to the number of humid days. Due to drought, less rain, impact of climate change, and scarcity of precipitation events in Northwest China, the precipitation events and the threshold events above the 95% quantile would obviously increase, leading to a decrease in precipitation intensity relative to the reference period in the local areas of Northwest China in future.

4.2 Prediction of extreme high temperatures in the future

Fig. 4. shows the absolute variation in the extreme high-temperature indices (TN90p and TX90p) for different scenarios over the next 40 years relative to the base period. As shown in Fig. 4, the number of warm nights in China will increase in the future under different scenarios, and all parts of the country would show this increase. Scenario SSP1-2.6 showed that the increase in TN90p in Southwest and South China was the highest, with most regions increasing by more than 40 d, followed by the regions of Northwest, North, and Central China, where the increase in TN90p was between 20 and 45 d, whilst that of Northeast and East China was the lowest, at 20–30 d.

The spatial mode of TN90p predicted by SSP5-8.5 was the same as that of SSP1-2.6; overall, it showed the spatial characteristics of Southern, Southwestern, Northwestern, Northern, and Central China. Compared with the SSP1-2.6 scenario, the extreme high temperatures at night in China will be further aggravated, with the risk of night high temperatures notably increasing under SSP5-8.5.

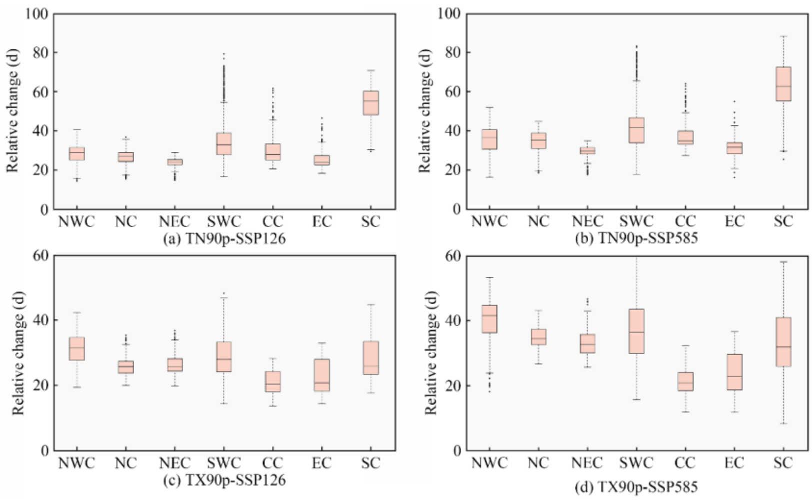

Fig. 4. Relative variation of extreme high temperature index in China from 2015–2054 under SSP1-2.6 and SSP5-8.5 scenarios (relative to 1975–2014).

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For TX90p, the number of warm days in China is expected to increase under the different development scenarios. The SSP1-2.6 scenario showed that over the next 40 years, the increase in TX90p in Northwest, Southwest, and South China will be the highest, ranging from 20 to 45 d, followed by North and Northeast China, where the number of warm days would increase by approximately 20 d. The Central and Eastern China among other regions showed the least growth between 15 and 30 d. Compared with the SSP1-2.6 scenario, the estimated TX90p spatial mode of SSP5-8.5 scenario was basically the same as that of the SSP1-2.6 scenario, which showed that the increase in the number of warm days in Central and Eastern China was the lowest. Compared with the SSP1-2.6 scenario, the risk of extremely high temperatures in China would further increased in SSP5-8.5, especially in Southwest and South China, where the daily number of warm days would increase by more than 50 d.

A comparison between the number of warm nights and days under different scenarios showed that the range of warm nights in different scenarios was larger than that of warm days, which was consistent with the change in law of historical extreme high temperatures. In the SSP5-8.5 scenario, with high carbon emissions, the extreme high temperature was more obvious, which indicated that the temperature rise at night in China was substantially higher than that during the daytime regarding global warming. Previous studies have shown that the historical minimum temperature was more remarkable than the maximum temperature and that the heating rate was faster [22]. This also meant that the impact of global warming on the regional minimum temperature was more obvious. Moreover, the synchronous increase in the risk of extreme high-temperature during the day and night, and the sustained high emissions of greenhouse gases will further aggravate the risk of high-temperature heat waves in the future; thereby, threatening human survival and the Earth's ecology [23].

5 Response and mitigation proposals for extreme precipitation and high temperature events

Against the background of global climate change, extreme precipitation and high-temperature events in China have shown temporal and spatial differences. Over the past 40 years, the spatial pattern of strong precipitation in China increased, decreased, and then increased again from the Northwest to Southeast, whilst the precipitation intensity and heavy precipitation in Northern, Northeastern, Eastern, and Southern China in northwest Tianshan increased. Over the next 40 years, due to global warming, extreme precipitation in China will further increase and intensify. The frequency of extreme high-temperature events at day and night in the country has noticeably increased over the past 40 years, among which the rate of change in the number warm days and nights in the North and Southwest was the highest, whilst high-temperature heat wave events were substantially enhanced. In the next 40 years, diurnal extreme high temperature events in China will increase further, with the increasing risk of high-temperature heat wave event; in particular, the synchronous increase in diurnal extreme high temperatures will further aggravate the degree of extreme climate events in future.

Global warming increases the probability of extreme precipitation and high-temperature events such as frequent floods and heat waves. Therefore, adequate mitigating responses to these extreme events must be conducted. The response should be developed considering two perspectives: engineering (infrastructure construction) and non-engineering measures (information construction and emergency management). However, climate change has a profound global impact, which is a common problem faced by all mankind. Disaster chains caused by climate change have a significant impact on human society. Therefore, Countries must work together to deal with climate change; thus, with combined with specific engineering and non-engineering measures, this study proposes the following suggestions for three prominent risk areas: flood disasters, high-temperature heat wave disasters, and climate change (Fig. 5).

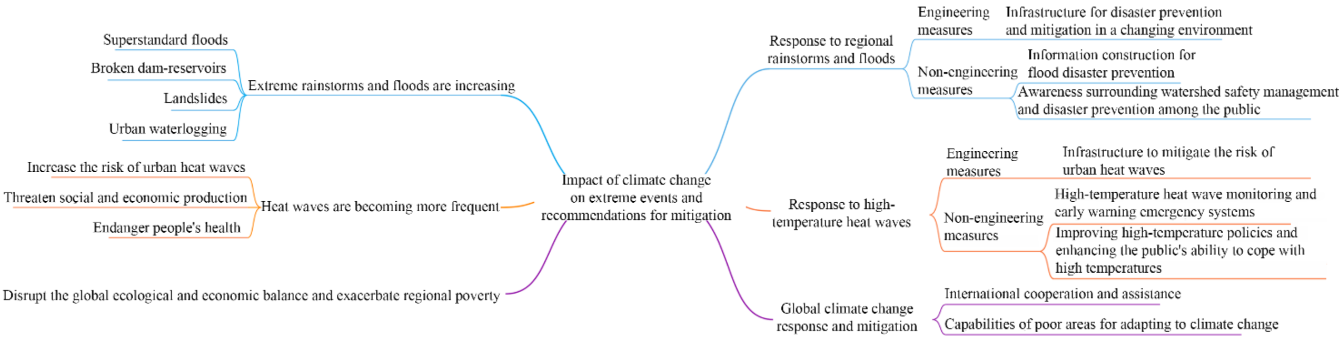

Fig. 5. Impact of climate change on extreme events and recommendations for mitigation.

5.1 Enhancing flood risk response and emergency management capacity

Global climate change will increase the probability of extreme rainstorm events in the regions, resulting in an increased risk of superstandard floods, broken dam-reservoirs, landslides, urban waterlogging, and other disasters that threaten national water security and public safety. In terms of flood disasters, we should first strengthen engineering measures such as engineering design, basin flood control engineering construction, and urban flood control infrastructure construction; second, we should strengthen non-engineering measures such as watershed, urban, and engineering disaster prevention information; and third, adequate watershed safety management should be introduced to comprehensively build resilient watersheds and cities.

We intend to strengthen the infrastructure for disaster prevention and mitigation in a changing environment. (1) We intend to strengthen the basic research of engineering hydrological calculations under the changing environment, comprehensively design floods of composite reservoir dams, consider the influence of extreme rainstorms and temperature events on water conservancy projects, and improve engineering design standards. (2) Based on the river basin and urban and rural areas as a whole, we should accelerate the construction of flood control projects and flood storage and detention areas in the river basin, strengthen the management of small- and medium-sized rivers, prevent and control mountain torrents, and accelerate the reinforcement of dangerous reservoirs in view of the built reservoirs. (3) To promote the construction of spongy cities in new and old urban areas, full mobilization of the urban water storage capacity by expanding the area of green space and construction of constructed wetlands must be considered and simultaneously realize source emissions reduction and rainstorm runoff storage for ecological protection [24]. Comprehensive investigation and resolution of flood drainage and blocking points, and construction of large-scale drainage facilities and profound urban projects in view of super-standard urban flood disasters to improve the capacity of urban drainage and waterlogging removal must be considered.

Strengthening information construction for flood disaster prevention [25]. (1) To improve the level of water conservancy informatization, advanced sensing, communication and other modern information technologies must be used to establish a three-dimensional hydrometeorological flood control and drought relief system. Similarly, big data and artificial intelligence technology, combined with multi-objective joint optimal operation of cascade reservoirs in river basins must be applied, to develop an integrated flood control forecasting and dispatching system in complex watersheds, and construct a command system integrating forecasting, early warning, planning, and preview. (2) It is necessary to perfect the mechanism of urban extreme weather research and judgment, realize the dynamic monitoring of the whole process of urban extreme rainstorm floods, establish an integrated cloud platform for urban rainstorm waterlogging forecasting and early warning, and strengthen the ability of forecasting and early warning information dissemination. (3) We should accelerate the information gathering process on water conservancy project safety monitoring to achieve real-time monitoring and timely reporting. Furthermore, the level of communication, calculation, and control, combined with big data systems must be improved; a digital twin platform for large-scale water conservancy projects must be established; improvements in information infrastructure for water conservancy project management and supervision platforms must be realized; the ability of a reservoir dam to ensure safety and withstand and respond to extreme rainstorm disasters must be realized and improved.

We will raise awareness surrounding watershed safety management and disaster prevention among the public. (1) We should strengthen the daily management and emergency rescue levels of reservoir dams and the compilation of emergency plans for flood control and waterlogging removal. Based on the basic principle of "safety first, prevention first, and all-round emergency," we should avoid risks and improve the ability to deal with emergencies in advance, to reduce the possible post-disaster impact overall. (2) We should strengthen urban planning and construction to adapt to floods; avoid and limit the development and construction in flood disaster-prone areas ahead of time; strengthen disaster prevention and repair of lifelines such as communication, traffic, power supply, and water supply; and ensure the normal operation of the city and the effectiveness of emergency and disaster relief. (3) We should strengthen the daily propaganda work of popularizing the science of disaster prevention and mitigation, and enhance the awareness of disaster prevention among the whole population.

5.2 Strengthening the mitigation and response measures for high-temperature heat waves

The continuous emission of greenhouse gases leads to a notable increase in global temperature, which causes abnormal atmospheric circulation, frequent occurrence of high-temperature heat wave events in the weather system, coupled with the heat island effect caused by urban construction. This causes urban areas with concentrated populations to experience higher heat storm exposure and risks under the heat wave disaster; subsequently, increasing the threat to the life and properties compared with other extreme events. To deal with high-temperature heat wave disasters, we should first optimize the urban layout and reduce the urban heat exposure risk using engineering measures; second, we should strengthen the information level on heat wave monitoring and early warning; and third, improve the high-temperature policy and other non-engineering measures.

Infrastructure should be trengthened to mitigate the risk of urban heat waves [26]. (1) Rational planning of urban construction layout, controlling population and building density, scientific planning of urban ventilation corridors, and introduction of cold suburban air into urban areas are suggested. (2) We should improve the coverage rate of urban greening and reduce the degree of urban thermal outbursts; construct a water system around the city and adjust the climate of the urban area; innovate the structural design of buildings; and popularize centralized cooling technology in public areas. (3) It is necessary to reduce artificial heat dissipation, improve energy efficiency, develop and utilize new clean energy sources, and improve the performance of building thermal insulation materials.

High-temperature heat wave monitoring and early warning emergency systems should be constructed [27]. (1) We should lay out the high-temperature weather observation network in general; construct a multi-source monitoring information channel for high-temperature weather; and realize multidirectional coverage, monitoring, and early warning for the general and key areas. (2) It is necessary to establish an integrated system for accurate and real-time high-temperature prediction and early warning; strengthen the capability of urban high-temperature prediction; and improve the timeliness of agricultural high-temperature prediction. (3) It is also necessary to open up the multi-source propaganda channel of high-temperature forecast information, giving full provision to the dissemination ability of network and communication technologies to achieve comprehensive and meticulous monitoring, accurate and timely predictions, and rapid and extensive dissemination.

Improving high-temperature policies and enhancing the public’s ability to cope with high temperatures are suggested. (1) We should improve the labor security and summer protection subsidy system during high-temperature heat waves, reduce heat exposure caused by outdoor work during high-temperature heat waves, and improve the high-temperature policy to protect human health. (2) It is necessary to strengthen the propaganda and education on the harm of high-temperature heat waves; popularize the scientific mitigation methods against diseases caused due to extreme heat exposure and the measures of self-rescue and mutual rescue; especially strengthening the propaganda of popularizing science among workers in high-temperature places. (3) We should also improve health care, strengthen personal heat-resistant exercises, and improve their ability to adapt to extremely high temperatures.

5.3 Global climate change response and mitigation

Climate change is a global challenge to human survival and development. Extreme events caused by climate change affect the global ecological environment and economic and social balance, resulting in increased livelihood costs in poor areas, which are most severely affected by climate change through chain effects on agriculture, animal husbandry, and fisheries [28]. Considering the general trend of global warming, we should first strengthen international cooperation and assistance from a national perspective; second, from a regional perspective, we should establish an adaptation strategy for areas vulnerable to climate change.

International cooperation and assistance should be strengthened. (1) Addressing climate change requires joint efforts from the international community, because it is difficult for any independent country or alliance to deal with it alone. Therefore, it is necessary to build a global community with a shared future, actively promote the objectives of the *Paris Agreement*, and strengthen the common responsibility for dealing with climate change. (2) Developed countries are mainly responsible for global climate change and historical carbon emissions, whereas developing countries are at the stage of unavoidable high carbon emissions. Developed countries have an international obligation to provide financial resources to help developing nations to better respond to climate change. Moreover, safeguarding climate justice could help in mobilizing the enthusiasm of a vast number of developing countries to participate in jointly addressing the effects of climate change and improving the effectiveness of international cooperation.

Capabilities of poor areas for adapting to climate change should be improved. (1) It is necessary to actively promote the Belt and Road Initiative, strengthen South–South cooperation, raise the economic level of poor areas, accelerate energy transformation, and enhance their ability to cope with climate change. (2) We should facilitate sharing of meteorological information services, train skilled professionals related to climate change and meteorological forecasts, and enhance the ability of extreme weather forecasts and early warnings in poor areas. (3) It is necessary to provide new ideas for water-saving and efficient agriculture, renewable energy technology, and water resource management and development plans for poor areas, whilst enhancing their ability to save energy and reduce emissions.

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