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ORIGINAL PAPER

Spatial and temporal changes in flooding and the affecting factors in China

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Abstract Spatial and temporal changes in flood events in China are becoming increasingly important due to the rapid climate warming that is occurring. This study was conducted to consider changes in flood events and the factors affecting such changes. To accomplish this, China was divided into natural and social-economic flood regions: north China, northwest China, northeast China, southwest China, central China, east China, south China, and Taiwan, Hong Kong and Macau. Spatial and temporal changes in flood patterns were rebuilt during 1980–2009, and Fast Fourier Transform Filtering was then employed to stimulate the changes in floods during this period. The factors affecting flooding were then analyzed quantitatively. The results showed that, based on the time series for China as a whole, flooding was more serious during 1990–1999 than 1980–1989 and 2000–2009. However, in different regions, the trends in flooding differed greatly. Based on spatial changes, the areas hardest hit by floods were northeast China in the 1980s, northeast China, central China and east China in the 1990s, and central China after 2000. In China, the main flood-affecting factors were meteorological, ecological, population, water conservation facilities, and policy factors. However, the main affecting factors differed by region. Overall, the complex spatial and temporal features of flood variations and various affecting factors demand proper national and regional governmental action in the face of the changing flood patterns in China. The results of the present study provide valuable information to flood policymakers and flood disaster researchers.

Keywords Flood disaster · Spatial and temporal change · Affecting factors · China

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1 Introduction

Changes in flooding in response to global change have gained a great deal of attention in recent years (Schiermeier 2011). Indeed, flood disasters are occurring very frequently worldwide, with severe losses (Garcia-Castellanos et al. 2009; Blackmore 1999). Among global losses caused by natural disasters, floods accounted for 40%, tropical cyclones accounted for 20%, droughts accounted for 15%, earthquakes accounted for 15%, and all other factors accounted for 10% (Zhang and Li 2007). Accordingly, spatial and temporal changes in flood patterns and the affecting factors have caused widespread concern (Lecce and Pavlowsky 2004; Martinez and Le Toan 2007; Urgeles et al. 2002).

China is commonly affected by a variety of flood events because of its vast territory and the strong influence of the East Asian monsoon (Renyi and Nan 2002; Yu et al. 2009). Floods hit southern China nearly every year because of the abundant monsoon rainfall. In recent years, increases in extreme precipitation events have increased the occurrence of floods, and China has suffered from serious flood losses. The National Climate Center reported an economic loss of about $36 billion and more than 3,000 deaths owing to severe floods in the Yangtze River and Nenjiang–Songhuajiang valleys during the summer of 1998. Moreover, China is a populous country, and agriculture is the foundation of its national economy; accordingly, floods can directly influence food security in China. Although the State Council has promulgated and implemented national disaster prevention and mitigation plans, and a series of targeted measures on the role of flood control has achieved initial success, the risk of flooding in China remains high. Recognizing the spatial and temporal changes in flood disaster in different regions as well as the affecting factors is important for generating effective flood forecasting models and long-term and real-time flood hazard prediction systems (Bates and Anderson 1996; Hong et al. 2010); therefore, this has become an important prerequisite of flood disaster prevention and mitigation. Thus, strengthening the available research regarding the spatial and temporal changes in flood events and their affecting factors, as well as scientific management of disaster risk, has very important practical significance (Lecce and Pavlowsky 2004; Martinez and Le Toan 2007).

China is vast with significant geographical environment differences in each region. Regionalization is the basis of assessment, prediction, planning, and decision-making. The methods of regionalization in China are various (Byrnes and Storbeck 2000; Luo 1987; Xu et al. 2001), and the administrative boundary is not taken into account in most of the regionalization. In this study, we choose the regionalization based on regional geographic variations, economic and social differences, and the effective implementation of regional management.

In this study, the spatial and temporal changes in flood disasters were investigated and the contribution of the affecting factors in different regions was measured and discussed. China, which was used as the study area, was divided into eight regions characterized by different flood characteristics. The changes in flood disasters were then analyzed in two dimensions: temporal and spatial. There are many affecting factors of flood disaster; however, this study focused on the five most important factors: meteorological, ecological, population, water conservation, and policy. In this study, comparative and correlation analyses were used to investigate these factors in conjunction with GIS.

This paper is organized as follows. Section 2 describes our data sources and the case study area, as well as the design of the flood indicators, the regionalization of the study area, and the methodology. Section 3 shows and discusses the results of spatial and temporal changes in floods. Section 4 discusses the affecting factors in China. The conclusions are provided in Sect. 5.

2 Data and methodology

2.1 Data sources

2.1.1 Disaster data

The disaster dataset, including crop areas covered and crop areas affected by flood disasters from 1980 to 2009, was obtained from the China Statistical Yearbook. Crop area covered refers to the sown area of crops for which the crop yield decreased by more than 10% as a result of flood disaster. If the same block repeatedly affected the same crop in the same season, only most affected crop area was counted. Crop area affected refers to the sown area of crops for which yield decreased by more than 30% in response to flood disaster.

2.1.2 Agricultural data

Agricultural data in this study primarily consisted of the sown area of crops from 1980 to 2009. These data were obtained from the China Rural Statistical Yearbook. The sown area of crops refers to the area of land sown or transplanted with crops regardless of being in cultivated or non-cultivated areas. The area of land re-sown because of natural disasters was also included. The sown area of crops is an important indicator that can reflect the utilization condition of the following categories of crops: grain, cotton, oil-bearing crops, sugar crops, flax crops, tobacco, vegetables and melons, medicinal materials, and other farm crops.

2.1.3 Meteorological data

A dataset of annual precipitation obtained from 752 meteorological observation stations was used in this study. This dataset was developed by the Climate Data Center of the National Meteorological Center of the China Meteorological Administration and has been subjected to the quality control procedures of the Climate Data Center. This dataset has also been popularly used in studies of climate change in China. Data collected from 608 stations during 1980−2009 were used to maintain spatial consistence as well as temporal homogeneity of the precipitation records (Fig. 1). Weather and climate can be described in various ways, such as precipitation, the percentage of precipitation departure, and the precipitation intensity (Li et al. 1998). Precipitation, which is the most commonly used indicator, was used in this study.

2.1.4 Forest data

Over the past 30 years, the forest coverage rate in China has primarily been determined from the Chinese forest inventory data, which is a record of the areas and volumes of different forest types at the provincial (autonomous regions) level. However, these data have not been maintained continuously in recent years; thus, the interpolation method based on the average growth rate was employed to obtain successive estimated data.

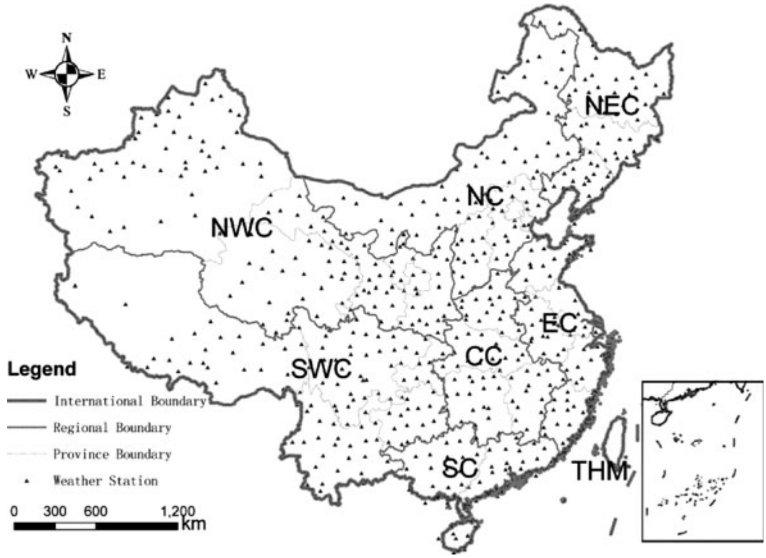

Fig. 1 Geographical distribution of the stations used in this study and the eight regions. Northeast China (*NEC*), north China (*NC*), northwest China (*NWC*), southwest China (*SWC*), central China (*CC*), east China (*EC*), south China (*SC*), and Taiwan, Hong Kong and Macau (*THM*)

2.1.5 Water conservation facilities

Water conservation facilities are an important method of regulating and storing water; therefore, improved water conservation facilities can prevent the occurrence of floods or reduce flood losses. Here, data on the capacity of reservoirs from 1980 to 2009 were obtained from the China Rural Statistical Yearbook and applied to the provincial-level administrative regions.

2.2 Study area

China ranges from mostly plateaus and mountains in the west to lower lands in the east (Fig. 1). Principal rivers in China flow from west to east. Mountains, plateaus, and hills take up about 67% of the land area, while basins and plains comprise the remaining 33%. From south to north, the climate zones include tropical, subtropical, temperate, and boreal regions owing to large differences in the regional distribution of temperature and precipitation. As a result, the climate of China has three characteristics: a monsoonal pattern, obvious continental climate, and a variety of climate types. There are also obvious wet seasons and dry seasons, which influence the frequency of floods in certain areas, such as Hubei, Sichuan Basin, Yunnan, and Liaoning provinces. The frequency of flooding can reach 30–50% per year, with some being subject to frequencies greater than 50% (Bureau 2010).

The majority of China's population and agriculture is located in the southeast monsoon region, where the climate is relatively comfortable, and the economy is more developed. As the economy has developed and the living conditions have improved, management of flood disaster in China has improved significantly; however, it still has one of the most serious incidences of flood disaster in the world.

2.3 Methodology

2.3.1 Design of the flood indicator

In this study, we took crop area covered and crop area affected by flood disaster as the flood index because only these datasets can satisfy the demand for spatial and temporal change over such a long time series in China. Flood damage is influenced by the frequency and intensity of floods. As a result, flood frequency is widely used in studies of spatial and temporal changes in flood events (Kjeldsen et al. 2002; O'Connell 2005; Ouarda et al. 2006), although some researchers use the flood impact. In this study, we used the flood intensity.

Flood disaster can cause mortality, housing collapse, property damage, ecological damage, and health risks (Khatibi 2011; Plate 2002; Posthumus et al. 2008; Treby et al. 2006). In this study, we focused on agricultural losses by investigating the crop area covered and crop area affected by flood disaster. Crop areas covered and crop areas affected by flood disaster are direct reflections of flood damage to the agricultural industry. Agriculture is the foundation of China's national development, because it can provide food and habitat to population and provides raw materials for manufacturing. Therefore, it can indirectly reflect the effects of flood damage on society, the economy, and human health. In this study, the spatial scale was provincial, and the time scale was 30 years. The dataset describing the crop area covered and crop area affected by flood disaster can meet the data requirements of spatial and temporal changes analysis. The agricultural disaster records in China have good continuity over decades and are consistent among regions, which is beneficial for vertical and horizontal comparisons. To comprehensively reflect the extent of flood disaster losses, a comprehensive flood index was designed as follows:

$$F = \frac{C + A}{2 \times \mathrm{SA}} \times 100\%$$

where F is the comprehensive flood index, C is the crop area covered by flood disaster, A is the crop area affected by flood disaster, and SA is the sown area of the crop.

2.3.2 Regionalization of the study area

Because of its size, China has an extremely complex geographical environment, with significant differences occurring between regions. In this study, the flood data are based on administrative districts. We chose the regionalization which divided China into eight different regions (Fig. 1): northeast China (NEC), north China (NC), northwest China (NWC), southwest China (SWC), central China (CC), east China (EC), south China (SC), and Taiwan, Hong Kong and Macau (THM) (Ge et al. 2001). EC included Shandong, Jiangsu, Anhui, Zhejiang, Fujian, and Shanghai; SC included Guangdong, Guangxi, and Hainan; CC included Hubei, Hunan, Henan, and Jiangxi; NC included Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia; NWC included Ningxia, Xinjiang, Qinghai, Shaanxi, and Gansu; SWC included Sichuan, Yunnan, Guizhou, Tibet, and Chongqing; NEC included Liaoning, Jilin, and Heilongjiang. THM included Taiwan, Hong Kong and Macau. THM was not considered in this study. The regionalization is based on regional geographic variations, economic and social differences, and the effective implementation of regional policy.

2.3.3 Spatial and temporal changes

Changes in flood disaster were analyzed by SPSS and ArcGIS at the temporal and spatial scale. The entire country and seven regions were taken as the assessment unit when the temporal changes were analyzed. The time series ranged from 1980 to 2009, and FFT (Fast Fourier Transform) filtering was used to simulate the change process. Provinces were taken as the assessment units when the spatial distribution and changes were analyzed. The time series (1980–2009) were divided into three periods: 1980–1989, 1990–1999, and 2000–2009, to provide insight into the decadal variability of flood disasters among provinces. In the three periods, the comprehensive index is the average of 10 years.

2.3.4 Affecting factor analysis

There are many affecting factors of flood disasters; however, this study only considered the most important factors which are meteorological, ecological, population, water conservation facility, and policy. To accomplish this, comparative analysis and correlation analysis were employed.

3 Spatial and temporal changes in floods in China

3.1 Temporal changes in floods

Figure 2 shows the temporal variations in annual flood disaster in China and the seven regions from 1980 to 2009, which reflect the extent of disasters in the last three decades. The FFT filtering line can be used to identify the trends in different regions.

For China as a whole, the comprehensive flood indexes fluctuated between 5 and 10, and flood disasters were more serious in the 1990s than in the 1980s and the first 10 years of the twenty-first century. In NEC, the comprehensive flood indexes fluctuated widely between 0 and 40, and all of the indexes showed a statistically significant decline with time over the three decades. In NWC, the comprehensive flood indexes ranged from 1 to 8, and these indexes did not change greatly with time. In NC, the comprehensive flood indexes ranged from 0 to 10, with more serious flood disasters being observed in the 1990s than in the 1980s or the first 10 years of the twenty-first century. In CC, the comprehensive flood indexes all ranged from 0 to 20 in the end of the twentieth century, and in the beginning of the twenty-first century, flood disasters were more serious than during the other years considered. In EC, the comprehensive flood indexes primarily ranged from 1 to 10. In 1991 and 2003, flood disasters were serious, although there was not much variation among the other years investigated. In SWC, the comprehensive flood indexes varied greatly between 2 and 9 and increased significantly with time. These findings reflect the region experiencing more serious flood disasters in the latter two decades considered in the present study. In SC, the comprehensive flood indexes ranged from 0 to 20, with flood disasters being very serious in 1994. However, there was not much change in the indexes with time in SC.

3.2 Spatial changes in floods

Figure 3 shows the spatial variations in the average comprehensive flood index, which can reflect the extent of disaster in the last three decades throughout China.

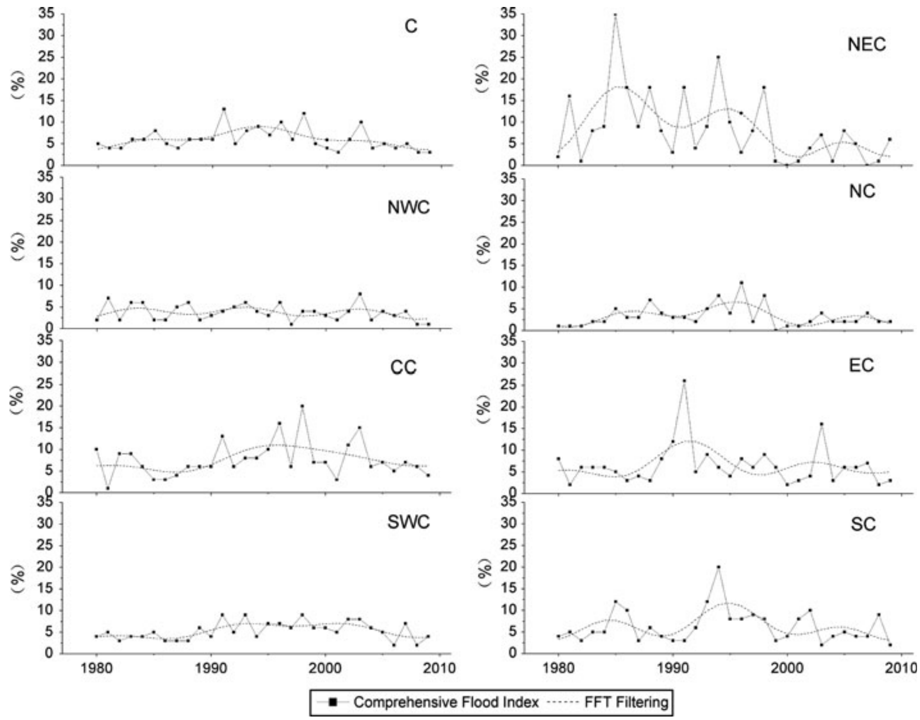

Fig. 2 Comprehensive flood index in China and the seven individual regions from 1980 to 2009. Northeast China (*NEC*), north China (*NC*), northwest China (*NWC*), southwest China (*SWC*), central China (*CC*), east China (*EC*), and south China (*SC*)

During the 1980s, the most serious areas of flood disaster were in NEC and CC, including Heilongjiang, Jilin, Liaoning, Hubei, and Anhui. Flood occurred is least in NWC and SWC. During the 1990s, the most serious areas of flood disaster were in NEC, CC, and EC, including Heilongjiang, Jilin, Liaoning, Anhui, Hubei, Hunan, Jiangxi, Jiangsu, Zhejiang, and Fujian. After 2000, the most serious areas of flood disaster were in CC, including Anhui, Hubei, and Hunan. Flood occurred is least in NWC, NC, and NEC.

Over the study period, the occurrence of floods in NEC, NC, and EC was significantly reduced, while CC and SWC became serious flood centers, and there was a little change in NWC and SC.

4 Affecting factors

Disaster is the product of the interaction between hazards and hazard-affected bodies. From the systems theory point of view, flood hazards and flood-affected bodies interact and influence each other, forming certain characteristics, structures and functions, and complex variation systems on the surface of the earth. The characteristics of disaster are uncertain, open, dynamic, and nonlinear (Huang 2004). The intensity of flooding does not depend entirely on rainfall, and it also depends on hazard-formative environments, such as topography, geographical factors, soil conditions, and vegetation, as well the vulnerability of hazard-affected bodies, such as agricultural farming systems and policy factors. In

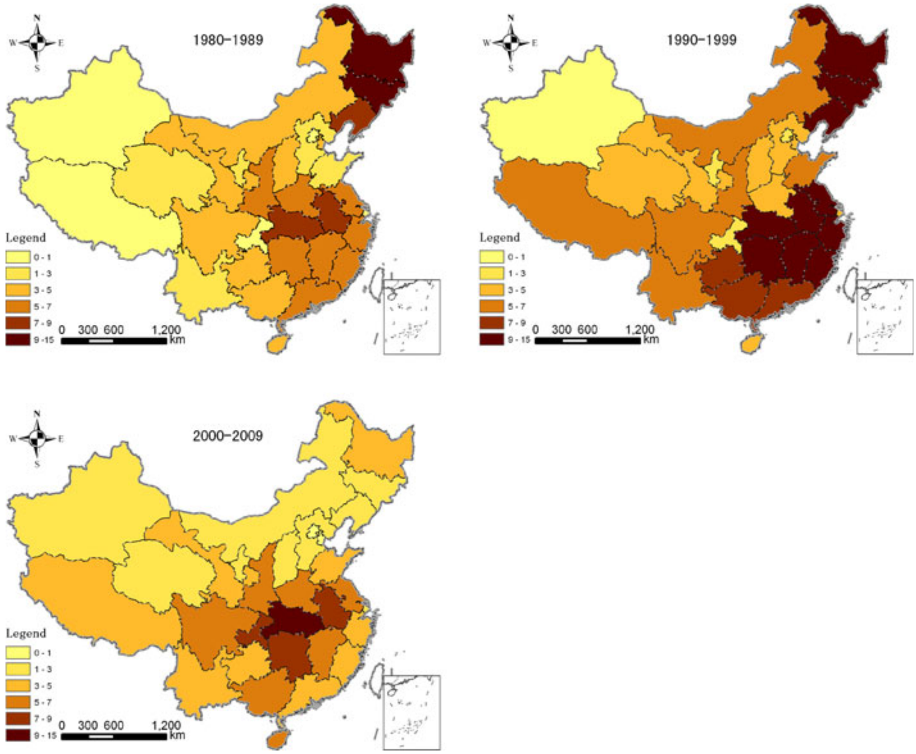

Fig. 3 Spatial dislocation of the average comprehensive flood index in the provinces of China during *1980–1989*, *1990–1999,* and *2000–2009*

addition, these factors interact and affect flood disasters. The major affecting factors are summarized as follows.

4.1 Meteorological factor

Meteorological factors that affect flood disaster include precipitation, the percentage of precipitation departure, and precipitation intensity (Li et al. 1998). This study selected precipitation as the meteorological factor to analyze the meteorological force behind flood damage (Feng et al. 1998). Analyses of the temporal change patterns in flood events and the variations in precipitation (Fig. 4) revealed that the variations in flood patterns are similar to those in precipitation. For example, in NWC, flood intensity varied with precipitation during the last three decades, while in NC, the flood curve agreed well with the precipitation curve. Moreover, more in-depth analysis revealed that trends in precipitation were positively correlated with those of floods in NEC, NWC, NC, CC, and SC. These findings imply that the changes in floods in these regions have primarily been caused by changes in precipitation. In EC and SWC, precipitation and floods sometimes appear to be dislocated, and the two factors were not correlated, which implies that precipitation is not the primary factor influencing changes in flood events in these areas (Zheng 1995).

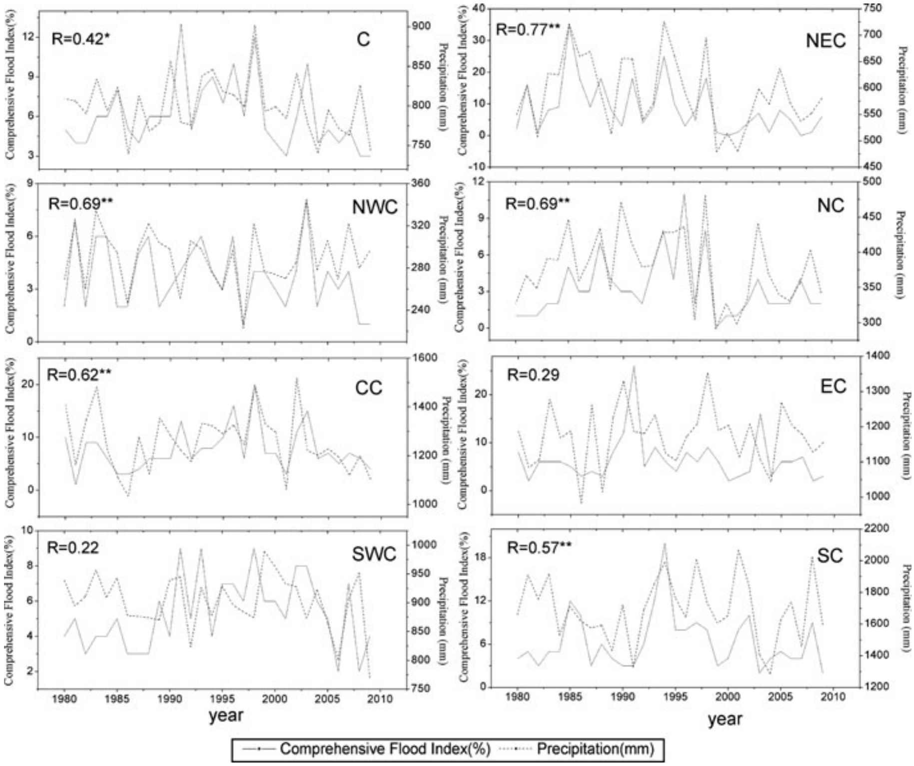

Fig. 4 Comprehensive flood index and precipitation in china and different regions during 1980–2009. *R*: Pearson correlations; *Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level

4.2 Ecological factor

As shown in Fig. 4, high precipitation values do not correspond to high losses in some regions, which reflects the vulnerability of hazard-affected bodies on the impact of floods, and the spatial differences in the hazard-formative environments. The distinct regional features of the variations in floods indicate different responses to hazard change throughout China. Ecological factors, which include land use, land cover, and soil erosion, play an important role in the process of flood variation. When rain falls, it does not become a flood disaster directly. Rather, floods are generated by a range of processes, such as catchment processes (i.e., intense rainfall, snowmelt, interception by vegetation, and absorption by soil), overflow stage, the vegetation interception and absorption of depression reaching saturation, a river beginning to flow into different rivers, and channel processes (i.e., ice jams, dam breaks) (Parajka et al. 2010). Among the catchment processes, interception by vegetation is very important because foliage can retain water, and roots and leaves in the earth can increase the saturation of water and reduce soil erosion. Forest as one of the most important ecological factors was taken as the example to illustrate the ecological factor in flood variation in this study.

In the past three decades, the forest coverage rate has increased regularly throughout China (Fig. 5), which has reduced the occurrence of flood disasters in some areas.

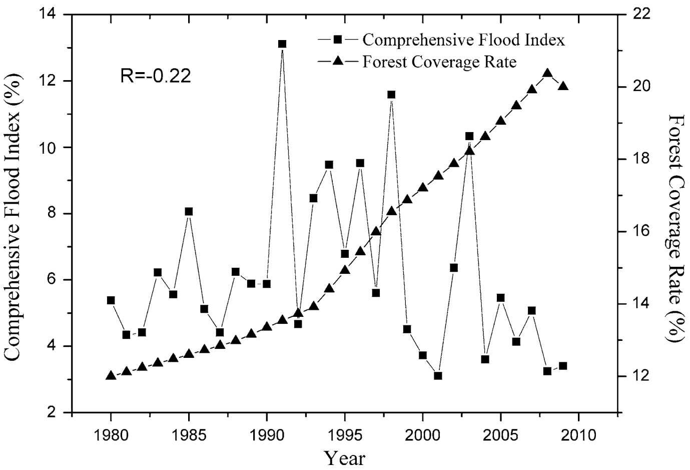

Fig. 5 Variation in the comprehensive flood index and forest coverage rate over China during 1980–2009. *R*: correlation coefficient

However, there are many serious floods in some regions because of the functional decline of the forest over the past three decades. For example, the flooding of the Yangtze River in 1998 (Fig. 4, CC) was one of the most serious floods over the 30-year study period, but the precipitation level was similar to that observed in 1980, 1983, and 2002, during which years flooding was much less serious. One reason for this is destruction of the forest, which has reduced the area's ability to resist flood disaster. In the 1950s, the forest coverage in the upstream portion of the Yangtze River was 30–40%, while it is currently only 10% (Ding and Zhang 2009).

Figure 5 shows the relationship between the comprehensive flood index and forest coverage rate over China for 1980–2009. The function of the forest is very important, but the correlation coefficient was −0.22, which is not significant. There are two reasons for this: the meteorological factor is the decisive factor that can be seen above and the ecological function of the forest is low, even though the forest coverage is showing an upward trend. According to the results of a study conducted by Wang et al. (2009), the forest function of conserving water/unit area was in decline from the 1970s to the end of the twentieth century. Although this function began to rebound slightly in the twenty-first century, it is still at a low level. Moreover, there has been a downward trend in the function of conserving soil/unit area since the 1980s. These decreases in forest function may have occurred for several reasons. According to seven forest inventories conducted in China from 1973 to 2008, the proportion of artificial forest area has increased sharply, while the proportion of natural forest area has decreased in the past 30 years. With China's rapid economic development, forest resource consumption has increased dramatically, rapidly reducing the area of mature forest, which has resulted in a younger forest age structure. Although the forest coverage rate has increased, the ecological function of young forests is limited; therefore, the trend of ecological deterioration has not been fundamentally reversed.

It is important to note that due to the lack of accurate provincial forest coverage data, quantity relationship between flooding and forest cannot be ascertained in each region. As the collection of data increases, more complete analysis will be possible.

4.3 Population factor

With the development of human society, the relationship between human activities and environmental change is becoming more apparent. Human activities geared toward transforming nature can meet our needs for survival in the short term. However, they often lead to greater destruction of the environment in the long term. In this section, we illustrate the impact of population factor on flood events as follows.

The human impact on environmental and flood disasters is growing. Specifically, increased population has led to greater demand for agricultural products and increased pressure on arable land. Before the well-known flood in 1998 in China, the crop sown area of the seven regions with the exception of EC showed a significant increase (Fig. 6). The demand for arable land has caused over-exploitation of land resources and unreasonable development. To obtain more arable land, forests and grasslands on steep slopes of mountains are often destroyed, while land is reclaimed from lakes and beaches in plains. These practices are capable of increasing food production within a short time but have seriously impacted the function of water regulation and storage in the environment. During the 1990s, the steep increase in crops sown areas corresponds to the serious flood in the same period (Figs. 2, 6), which demonstrates the population played an important role in the seriousness of flooding.

4.4 Water conservation facilities factor

In addition to forests, grasslands, soil, rivers, and lakes, reservoirs have also made a great contribution to water conservation. Figure 7 shows the variation and relationship between the comprehensive flood index and capacity of reservoirs in China from 1980 to 2009. The comprehensive flood index was found to be negatively correlated with the capacity of reservoirs across China, which indicates that water conservation facilities play an important role in flood prevention and reduction. In the past 30 years, the capacity of the reservoirs has increased regularly, but the level of water conservation facilities worldwide is still low. Furthermore, these facilities cannot meet the increasing demand for disaster prevention and reduction. Therefore, the construction of water conservation facilities

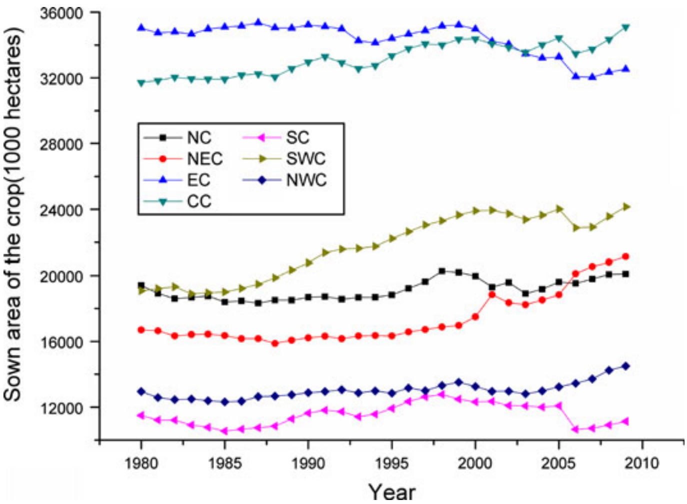

Fig. 6 Variation in the sown areas of the crops in the seven individual regions from 1980 to 2009

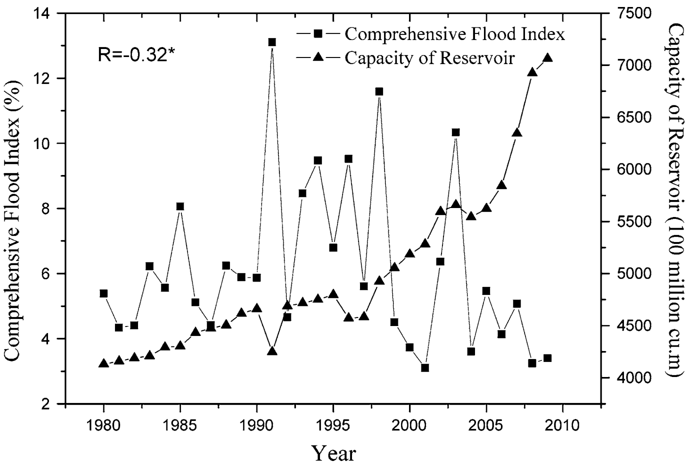

Fig. 7 Variation in comprehensive flood index and capacity of reservoirs in China during 1980–2009. *R*: correlation coefficient. *Correlation is significant at the 0.05 level

should be increased. Additionally, the quality of water conservation facilities is poor in China, especially in undeveloped area. Most conservation facilities were built during the 1950s and 1960s, but they were frequently vandalized and cannot perform the function of water conservation. In recent years, the investments in the water infrastructure have remained inadequate, and some of the investments were diverted. As a result, many reservoirs and rivers, especially small reservoirs and rivers have not been repaired for many years. This makes them prone to flooding when there is heavy rain fall. Finally, unreasonable project designation, vandalism, disrepair of water conservation systems, and poor management has increased the risk of floods (Deng et al. 2006; Qaiser et al. 2011).

4.5 Policy factor

In addition to individual activities to transform nature, policy factors also play a very important role. Such factors include agricultural, forestry, water, land, urban development, population policy, and disaster management policies. For example, the government implemented a policy of reconverting farmland into forest and grassland after the flood of 1998, so the sown areas decreased abruptly after 2000 (Fig. 6), which contribute to the decline in floods (Fig. 2). In addition, in the early 1980s, the conversion of the forestry management system resulted in greatly increased consumption of forest resources, particularly in the southern forests. This was because flood awareness was weak in some areas among both individuals and government officials. Moreover, there are still some cities that are subject to huge losses from flood damage because they are not adequately prepared following a low level of disaster management, inefficient officials, and imperfect management organization.

5 Conclusions and discussions

Only a few studies of regional spatial and temporal change have been reported in China. Most of these studies have used meteorological indexes instead of the actual flood damages and did not provide profound reasons explaining the changes that have been observed. Therefore, in this study, a direct and basic index to characterize flood impact was designed. In addition, a regionalization method to aid the government's flood disaster management efforts was used. Furthermore, the factors in this study are quantitative and have better precision than those used in previously conducted studies, which should lead to improved characterization of the flood-affecting factor field. The major conclusions of this study are summarized as follows.

1. The spatial and temporal change patterns of floods were assessed for 1980–2009. The results showed that, for China as a whole, flooding was most serious between 1990 and 1999, but these trends differed between regions. Spatially, the areas hardest hit by floods were northeast China in the 1980s, northeast China, central China and east China in the 1990s, and central China after 2000. Therefore, the complex spatial and temporal features of variations in flood disaster demand proper national and regional governmental action.
2. The results of this study revealed the affecting factors of flood disaster over the last three decades throughout China. The primary affecting factors were meteorological, ecological, population, water conservation facility, and policy. Interaction between these factors has caused the pattern of floods to change in China over the past 30 years. However, in different regions, the main affecting factors differ. In northwest China and north China, where annual precipitation is less, the flood hazard is the primary factor affecting flood damages. In central China and southwest China, in addition to the impact of meteorological factors, the hazard-formative environment and the vulnerability of the bodies influenced by the factors are also important (Ge et al. 2011). In China's coastal areas, including east China and south China, which are affected by storms and typhoons, water conservation facilities, flood prediction, and flood management can all influence the impact of floods (Zhang et al. 2011; Wang et al. 2011). Moreover, agricultural, forestry, land use, and water policies can affect floods in the regions. Therefore, proper national and regional governmental action should be taken to cope with the principal affecting factors of flood disaster.
3. In the system of flood disaster, floods are not influenced by each factor separately, but by a combination of all the factors mentioned as well as others not mentioned here. But, the factors are also interdependent. A sound ecosystem will lead to a decrease in the occurrence of extreme weather which will in turn result in fewer floods. If the relationship between humans and nature is not in perfect harmony, such as the human action of destroying the environment, adverse ecological events will result, which can lead to more floods. The policy factor can also indirectly influence flood occurrence, such as regulation of human activities. For example, land policy can determine the human change to land cover, and water resource policy can affect the water conservation facilities. Flooding is not only affected by the factors, but also affects the factors. A devastating flood can destroy the ecosystem and water conservation facilities (Tan et al. 2008). As a result, the response and feedback mechanism of the disaster system should gain attention. Moreover, flood disasters are related to social, economic, ecological, and human health systems and should be introduced to future flood analysis systems.

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