

Temporal–spatial variability of atmospheric and hydrological natural disasters during recent 500 years in Inner Mongolia, China

Yu Peng¹ · Jingyi Song¹ · Tiantian Cui¹ · Xiang Cheng¹

Received: 23 February 2017 / Accepted: 16 June 2017 / Published online: 24 June 2017
© Springer Science+Business Media B.V. 2017

Abstract Inner Mongolia, located in the northern China, is a natural disaster-prone region. This study is dedicated to making a comprehensive and quantitative analysis of the temporal–spatial patterns and its scale dependence of atmospheric and hydrological natural disaster frequency and intensity and its trend and correlation among them at 10-, 50- and 100-year cycle during recent 500 years by spatial statistics and geographical information system. The results indicated that the occurrence frequency and intensity were generally increased during last 500 years, with accelerating rate in recent one century, more obviously for drought and flood. The parts in southwest, middle and northeast region have suffered severe disaster pressure with an evident ascending trend. The scale dependence in temporal and spatial patterns of atmospheric and hydrological natural disasters was found. Totally, the disasters showed a clustered distribution during recent 500 years while snow dispersed during 1516–1615 and 1816–1915. By M–K test, the intensity of drought at 10-year cycle and flood at 50-year cycle, the frequency of hail and flood at 50-year cycle have significant increasing trend. Flood and hail mainly appeared in the middle, north and northeast parts, while wind appeared in most counties and snow scattered in the region. It is also found a close association among various disasters in either occurrence or intensity. Snow, hail and wind have significant opportunities to simultaneously happen at 10- and 50-year cycles. Hail has more chances to occur with flood, snow at all cycles, with drought at 10- and 100-year cycle, and wind at 10- and 50-year cycle. This study is anticipated to support the mitigation of natural disasters and to improve the management practices of environment system in a large-scale region.

Keywords Atmospheric disaster · Hydrological disaster · Frequency and intensity · Inner Mongolia · Long-term series · Temporal–spatial pattern

✉ Yu Peng
yuu.peng@muc.edu.cn

¹ College of Life & Environmental Sciences, Minzu University of China, Beijing 100081, China

1 Introduction

Climate change is influencing our earth, and natural disasters are found likely to become more frequent, more severe, and sustained along with climate change (Du et al. 2015; Easterling 2000). Within the context of natural disasters, variation and trends of extreme climate events, such as severe drought, instant flood, heavy snow, wind and hail, have recently received much attention, as they are more sensitive to climate changes than other disasters (Wang et al. 2013). Since the changes in the frequency or intensity of extreme weather and climate events would have more great impacts on both human society and natural systems than the mean climate variables (Easterling 2000; Hu et al. 2016), the behaviors of natural disasters have attracted more and more attentions.

The spatial–temporal patterns of natural disaster can strongly influence regional agriculture, raising livestock, population, consequently, economies determining the live level and society progress (Martins et al. 2012; Pfahl and Wernli 2012; Wang et al. 2015). Therefore, it is necessary to understand the spatial–temporal pattern change of natural disasters. However, most of the previous studies have concentrated on a certain type of natural disasters, and few studies have explicitly explored the spatial dynamics of natural disasters using a long-term sequence (Dahal et al. 2016; Yi et al. 2012). Still, it is found existed spatial dependence for analyzing the spatial pattern of some types of natural disasters (Bernard et al. 2013) in that extent and sample size used in analysis can influence the results of spatial calculation, indicating a cluster, random or scatter pattern at different scales (Wang et al. 2015; Weng et al. 2015). It is worthwhile to note that the scale dependence in time series can image the more detail dimension thus as to learn more of characteristics of natural disasters (Lopes et al. 2016; Wang et al. 2015). Although several attempts have been made over the past decade to analyze the spatial and temporal pattern of natural disasters in the earth (Afshar et al. 2016; Jia et al. 2016; Wang et al. 2014), or in arid/semiarid areas (Hu et al. 2016; Yi et al. 2012; Zarei et al. 2016), no comprehensive research has been conducted on temporal scale dependence of disasters during a period of 500 years. Hence, it is necessary to investigate the scale dependence in occurrences and its intensity along a time series; it would be more helpful if time sequences last longer.

A major portion of the continent's land area on the earth is covered by arid regions. The natural disasters in arid or semiarid region to be believed are more sensitive to climate change than other humid regions in the world (Harrington et al. 2016; Tabari et al. 2012). Arid and semiarid areas in the continent have sparse vegetation, and small carrying capacity (Seo 2015). Rainfall variability and fluctuations are inherent to arid and semiarid lands, which have always displayed a tendency to show rapid land surface change in response to relatively slight environmental change (Modarres and da Silva 2007). Which makes it more vulnerable to atmospheric and hydrological natural disasters, especially for drought, flood, hail, frost and heavy snow as compared with other areas (Hu et al. 2016; Tabari et al. 2012; Tan et al. 2015). Still, arid and semiarid areas in the earth mostly are stroked in desertification and prone to poverty (Green 2016; Mu and Chen 2016). These fragile society and unsteady environments are vulnerable to atmospheric and hydrological natural disasters (Zhou et al. 2014). The more frequency and intensity of the disasters along undergoing climate changes, combined with vulnerability in society and environments, make it crucial necessary to be focused on the atmospheric and hydrological natural disasters in arid areas by researchers, politicians and related stakeholders.

In Inner Mongolia, located in the midlatitude belt of arid and semiarid regions of the earth, more than 75% of its area has been classified as arid or semiarid (Lin et al. 2011; Liu

et al. 2016). Inner Mongolia is an important production and processing base for livestock products and crop farming, and also one of the 13 major grain producing areas in China (Lin et al. 2011; Liu et al. 2016). Atmospheric and hydrological natural disasters in this region were identified as high-frequency risk (Jia et al. 2016) and have a high spatial and time variability (Hu et al. 2016), and disaster periods and their effects are of great concern to combat desertification and poverty alleviation (Li et al. 2014). Therefore, to explore the temporal–spatial variability of atmospheric and hydrological natural disasters using a long-term sequence in Inner Mongolia has great meaning in both practice and theory for natural disaster study.

Here, we analyzed the spatial and temporal pattern and its scale dependence for the main five atmospheric and hydrological natural disasters during 500-year period in the Inner Mongolia, northern China, in which the main objectives of the study were: (1) to identify the spatial distribution and temporal variability of five atmospheric and hydrological natural disasters in recent 500 years; (2) to discover the scale dependences at the 10-, 50- and 100-year cycles; (3) to detect the correlations among different atmospheric and hydrological natural disasters at various temporal cycles.

2 Study area and methods

2.1 Study area

Inner Mongolia Autonomous Region (hereafter as Inner Mongolia), China, is located between 37°24′–53°23′N and 97°12′–126°04′E with a mean elevation of 1014 m. As the largest grassland and the third largest province in China and an autonomous region, it covers an area of 1.18 million km², which accounts for 12.3% of the country's land territory. Inner Mongolia, with a temperate continental monsoon climate, has a cold and long winter with frequent blizzards and a warm and short summer. Except for the relatively humid Greater Hinggan Mountain area, most of the Inner Mongolia is arid, semiarid or semihumid from west to east. The average annual temperature is in the range of 1–15 °C, and the annual average precipitation ranges from 50 to 500 mm. The main land use categories are grassland, forest and arable land, accounted for 59.9, 16.4 and 7.3% of total area, respectively.

2.2 Data source

The raw data source utilized in this research includes the statistical data of five atmospheric and hydrological natural disasters and administrative map of Inner Mongolia in vector format. The atmospheric and hydrological natural disasters data from 1516 to 2015 in the present study were obtained from the printed books by Inner Mongolia Government: Historical Materials of Natural Disasters in Past Ages in Inner Mongolia (1982) (data of B.C. 244–A.D. 1949), Continued Edition of Historical Materials of Natural Disasters in Past Ages in Inner Mongolia (1988) (data of 1949–1986), and the published books: Annals of Natural Disasters in Inner Mongolia (2001) (data of 1986–1999), Meteorological Yearbook of China (2016) (data of 2000–2015), including start and end dates, affected areas, as well as losses on population, housing and the economy of every county. By analyzing all atmospheric and hydrological natural disasters, the disaster of drought, flood, heavy snow, heavy hail and strong wind (hereafter as drought, flood, snow, hail and wind)

was selected as the main ones in this study. The above books collected historical natural disaster data from B.C.244 to A.D.2015 by the specialized organizations of successive governments in different periods by following the principle of respecting historical fact, deleting the superstitious information and logging data in chronological order. Recording in a professional method by successive governments, with high consistent in standard, these can guarantee the authority of data quality for various atmospheric and hydrological natural disasters during 500-year period.

In this study, county level was taken as basic unit to analyze the spatial–temporal characteristics and evolutionary trend of natural disaster. The county-level civil affair departments in China are the grassroot units responsible for the prevention of natural disasters and the implementation of relief work. The data source from the mentioned books of natural disasters also has used the county as the smallest statistical unit, and therefore, we used the county as the unit for spatial pattern analysis.

To establish the natural disaster database of Inner Mongolia, this study inputted statistical data of every disaster in each county from 1516 to 2015 including frequency, intensity, location and date as an attribute of administrative map of Inner Mongolia in 2015 by GIS technology. The intensity of each kind of disaster was classified into three degrees: light, moderate and severe according the original records, quantified as 1, 2 and 3, respectively, as to make further statistical analysis. The annual total intensity value of each disaster in one county is equal to the intensity multiplied with frequency and then summed. The annual total intensity value of all disasters in one county is the sum of intensity values of every disaster.

In order to guarantee the spatial accurate, by maintaining the integrity and consistency of administrative boundaries, the administrative boundaries in the above materials during different dynasties were converted to the administrative boundaries in 2015 according to historical evolution of the administrative boundaries of Inner Mongolia.

2.3 Changing trend analysis

The Mann–Kendall (M–K) test is acknowledged as an effective tool for identifying whether or not trends exist in the time series data, and has been widely used in natural disaster analysis (Du et al. 2015). In this study, the M–K test was employed to analyze the atmospheric and hydrological natural disaster changing trend.

2.4 Spatial pattern analysis

The spatial distributions of disasters are uneven; thus, it is necessary to quantify the spatial pattern changes of disasters. Moran's I is the most commonly used to measure the degree of spatial concentration or dispersion of disasters at a global scale (Du et al. 2015), the index of which ranges from -1 to 1 , indicating clustered to dispersed pattern. In our study, Moran's I was employed to evaluate the spatial pattern of disasters and the analysis was conducted by geographical information system software: ArcGIS 10.2.

2.5 Cluster analysis

Cluster analysis is a statistical technique in which structure in an unlabeled data set is identified and data are objectively organized into homogeneous groups, where the within-group-object dissimilarity is minimized and the between-group-object dissimilarity is

maximized (Wang et al. 2015). Clustering analysis was used in this study to identify the zoning of all counties of Inner Mongolia. Hierarchical cluster analysis (flexible β linkage, $\beta = 8 \sim 15$, squared Euclidean distance, data relativized by maximum) of total atmospheric and hydrological natural disaster intensity of every county in Inner Mongolia was performed with the Statistical Package for the Social Sciences (SPSS, Chicago, Illinois, USA) to determine the zoning of atmospheric and hydrological natural disaster at county level.

2.6 Correlation analysis

Correlation analysis was employed to examine the relationships among various atmospheric and hydrological natural disasters. The correlation coefficient, which is known as R^2 , is between 0 and 1, indicating the strength of the association between two types of disasters. Pearson's significance test was performed at 0.05 and 0.01 level by the Statistical Package for the Social Sciences (SPSS, Chicago, Illinois, USA).

3 Results

3.1 The temporal variability

Figure 1 indicates that the frequency and intensity of atmospheric and hydrological natural disasters in Inner Mongolia increased with accelerating speed from 1516 to 2015. After 1915, all disasters increased with booming rate than before. Among all disasters, drought and flood have the high happening frequency and intensity, hail and wind followed, and snow has the lowest value.

The changes of atmospheric and hydrological natural disasters at time scale of 10-, 50- and 100-year cycle showed different patterns (Fig. 2). At 10-year cycle, both the frequency and intensity of all disasters waved sharply, yet it has a smooth increased trend within recent 50 years. At 50-year cycle, the happening frequency of all disasters displayed a smooth increase trend, while the intensity waved at the middle stage except drought has a steady increase during 500 years. At 100-year cycle, both the happening frequency and its intensity of all disasters have a linear increase trend except that of snow intensity.

3.2 The spatial variability

The atmospheric and hydrological natural disaster not only exhibited highly temporal variability, but also exhibited an uneven pattern in spatial distribution (Fig. 3). Drought disaster mainly happened in the west southern of Inner Mongolia, slightly in the northern and northeastern. Flood and hail mainly distributed in the southeastern and southern Inner Mongolia. Snow clustered in the middle region. Wind prevailed in the southeastern and western region. The total frequency of all disasters was relatively higher in the middle region.

By considering the intensity, the spatial distribution of atmospheric and hydrological natural disasters was slightly differed from those of frequency (Fig. 4). Drought disaster has almost same distribution, differed in that it more clustered in several western and southwestern counties. Flood mainly focused on several middle counties. Snow scattered in northeast region, indicated a pattern of lower in frequency and higher in intensity. Wind

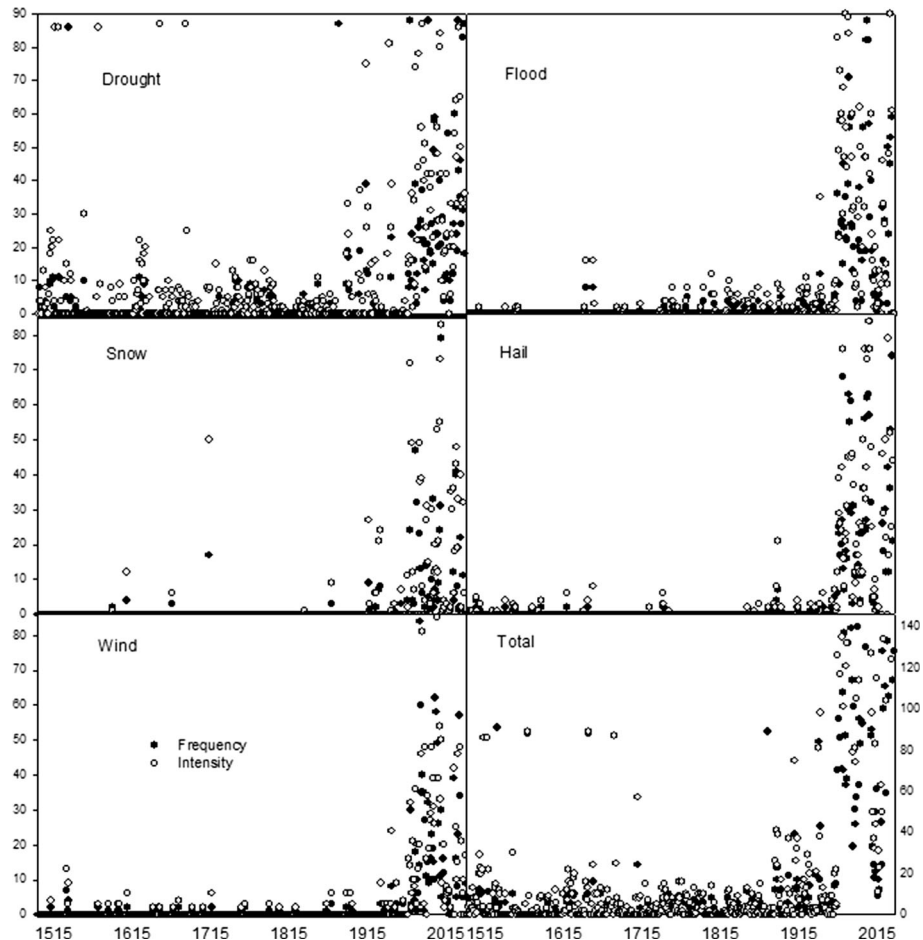


Fig. 1 Frequency and intensity changes of every and total atmospheric and hydrological natural disaster in Inner Mongolia, China, during 1516–2015

and hail were almost same with that in frequency, respectively. The overall intensity of disasters is more distributed on southwest, middle and northeast region of Inner Mongolia, China.

3.3 The spatial patterns

Table 1 shows the Moran's I varied among different atmospheric and hydrological natural disasters during 500-year period. The value of Moran's I ranges from 1 to -1 indicates that the spatial pattern was either clustered, random or dispersed. It is noticed that the values of all disasters showed positive, indicating slight clustered pattern. Among them, snow has a relative higher clustered pattern, drought followed, and then were hail and wind, and flood has the least value. All values passed the significant test at 0.05 level.

As for the Moran's I of 100-year cycle, it has a different performance (Table 2). Drought and hail have a significant cluster pattern during 500 years. Flood also showed the

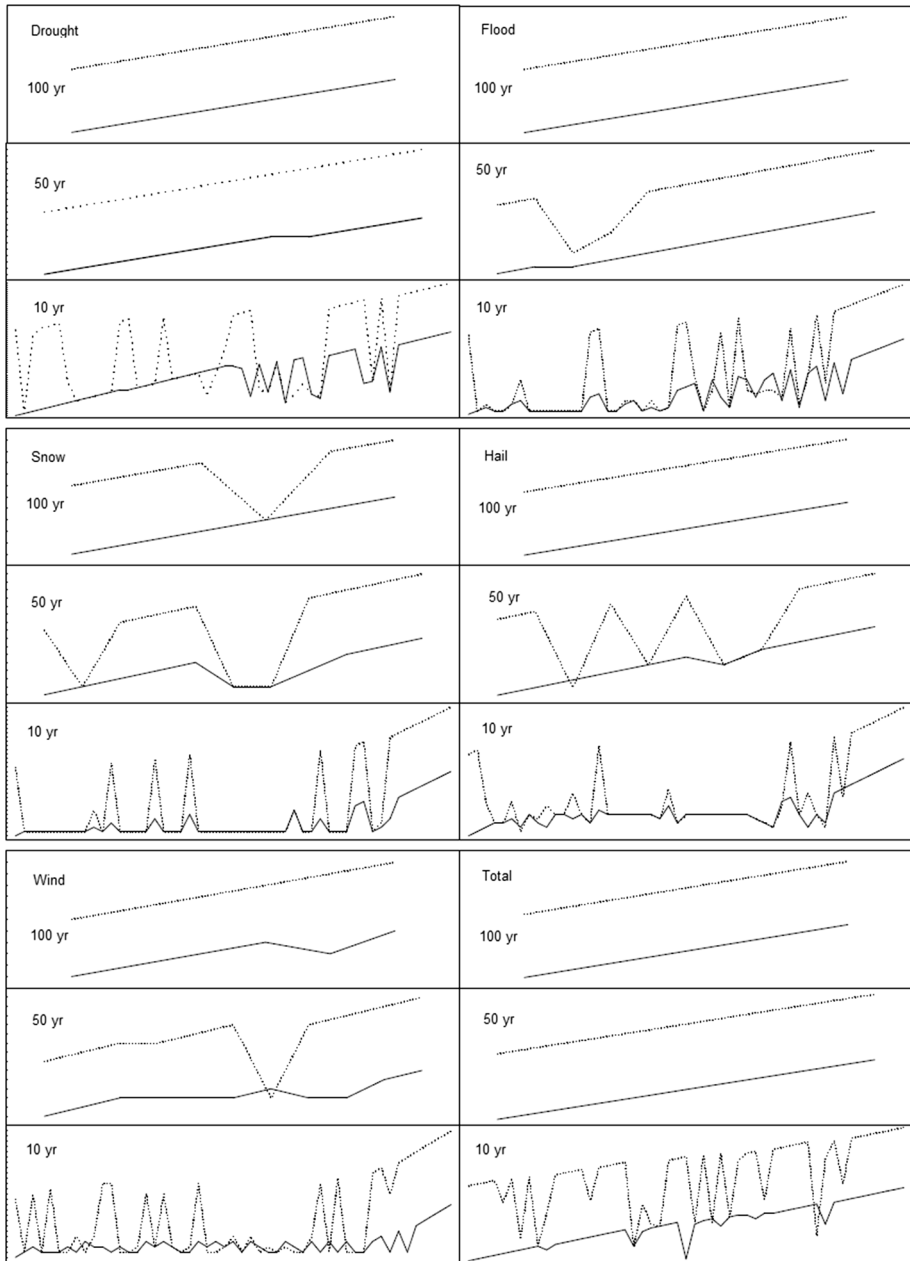


Fig. 2 Frequency and intensity series of every and total disasters at the time scale of 10-, 50- and 100-year cycle, respectively, in Inner Mongolia, China, during 1516–2015 (Dotted line indicates happening intensity, and solid line indicates happening frequency)

same pattern while it has not reached significant level ($p > 0.05$) during 1716–1815. As for snow, it has different pattern in different periods: a significant cluster pattern during the period of 1616–1715 and 1916–2015, a nonsignificant cluster pattern during 1716–1815

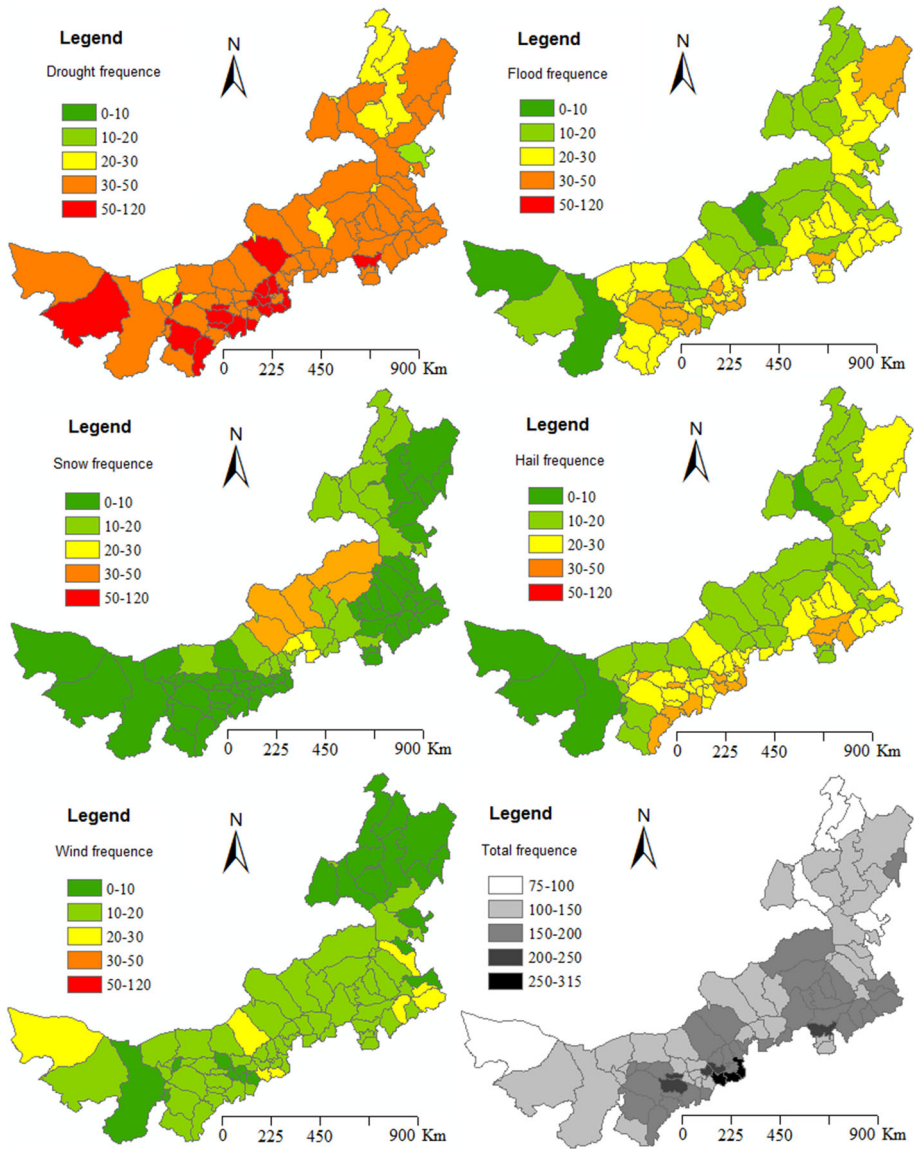


Fig. 3 Maps indicated the spatial distribution of total frequency in atmospheric and hydrological natural disaster in Inner Mongolia, China, during 1516–2015

and a disperse pattern during 1516–1615 and 1816–1915. Hail and wind have a significant cluster pattern during each period, except that of 1516–1615 which has not reached a significant level.

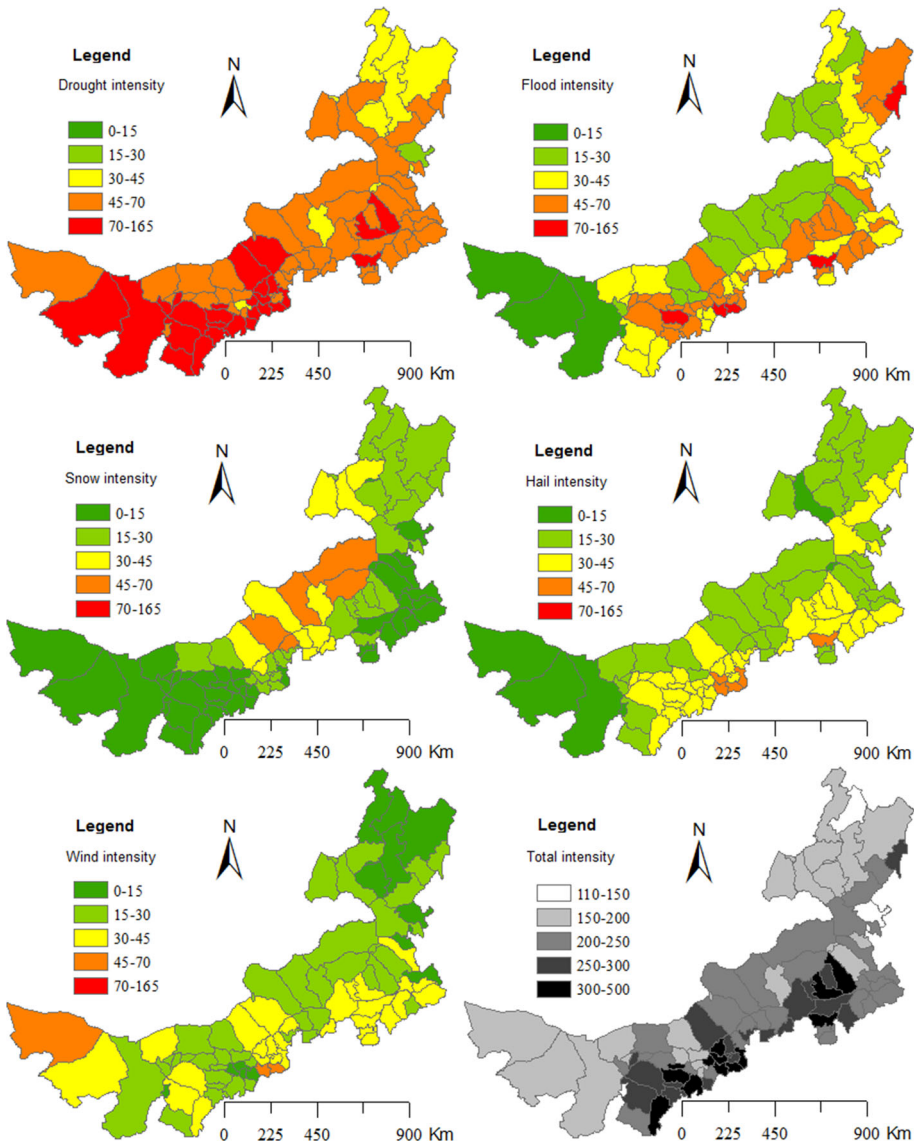


Fig. 4 Maps indicated the spatial distribution of total atmospheric and hydrological natural disasters intensity in Inner Mongolia, China, during 1516–2015

Table 1 Moran’s I of different atmospheric and hydrological natural disasters in recent 500 years

Items	Drought	Flood	Snow	Hail	Wind
Frequency	0.322	0.154	0.332	0.256	0.256
Intensity	0.340	0.186	0.476	0.303	0.233

All values have the significance at 0.05 level

Table 2 Moran's I of different atmospheric and hydrological natural disasters at each period during 1516–2015

Period	Drought	Flood	Snow	Hail	Wind
1916–2015	0.148821**	0.161549**	0.492318**	0.215905**	0.249128**
1816–1915	0.368221**	0.107989**	−0.00652	0.311435**	0.076593*
1716–1815	0.350199**	0.069218	0.013823	0.138473**	0.018059*
1616–1715	0.224576**	0.407642**	0.507694*	0.270777**	0.022242*
1516–1615	0.199396**	0.109695**	−0.01952	0.130819**	0.131913

* Indicates the significance at 0.05 level; ** indicates the significance at 0.01 level

Table 3 Trends of different atmospheric and hydrological natural disasters at 10-, 50- and 100-year cycle during 1516–2015, respectively

Cycle (yr)	Items	Drought	Flood	Snow	Hail	Wind
10	Frequency	1.875	1.432	0.614	1.682	0.773
	Intensity	2.454*	1.193	0.659	1.625	1.227
50	Frequency	1.216	2.170*	1.420	2.022*	1.739
	Intensity	1.284	2.000*	1.375	1.818	1.761
100	Frequency	0.432	1.318	1.125	1.011	0.943
	Intensity	0.580	1.330	1.080	1.011	0.955

* Indicated the significant at 0.05 level based on M–K test

3.4 The change trends

All disasters showed an increasing trend at all time scales (Table 3). It is obvious that the intensity of drought at 10-year cycle, the frequency of hail and flood, as well as the intensity of flood at 50-year cycle, have a significant increasing trend by M–K test.

The spatial distributions of trends in different disasters are shown in Fig. 5. It is indicated that except drought intensity which has a declining trend in most parts of Inner Mongolia, other disasters showed an increasing trend in study area at a 50-year cycle. For drought density, west, north and east parts of the region showed a declining trend and reached significant level in one county. The drought intensity also showed an increasing trend which is scatterly distributed in middle and east parts of the region and even reached significant level at several counties. The intensity of flood and hail has almost same trend in spatial distribution. The middle, north and northeast parts have a significant increasing trend. The wind intensity has a significant increasing trend in most counties. The trend of snow intensity showed a different pattern that the significant trends scattered among the entire study region. For overall intensity of all disasters, it demonstrated an increasing trend through all counties, where the significant increasing trend scattered in several counties in northwest, southeast and northeast parts of the region.

3.5 The zoning of atmospheric and hydrological natural disasters

Based on the intensity of five disasters, the zoning tree was produced, and the map was created by merging the counties with similar characteristics and is displayed in Fig. 6. It shows that the most counties have the similar characteristics as indicated in deep blue and light blue, respectively. The counties in light blue indicated a region influenced by multiple

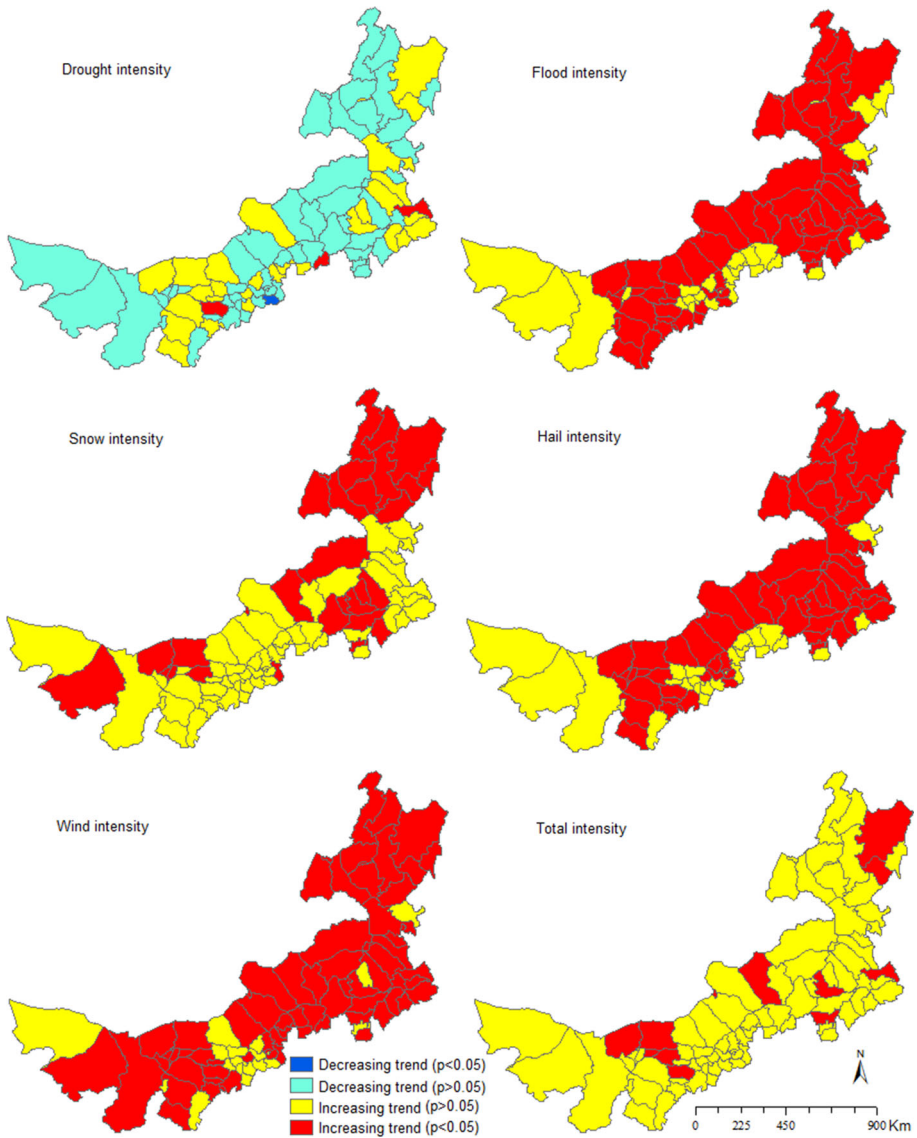


Fig. 5 M–K tests of the trends in the intensity of atmospheric and hydrological natural disasters at 50-year cycle during 1516–2015

disasters with relatively moderate intensity; the deep blue one indicated relatively low intensity. These two categories of zones occupied almost two-third of the study region. Snow and wind prevailed on two zones, respectively. The highest and higher disasters only scattered in several small counties.

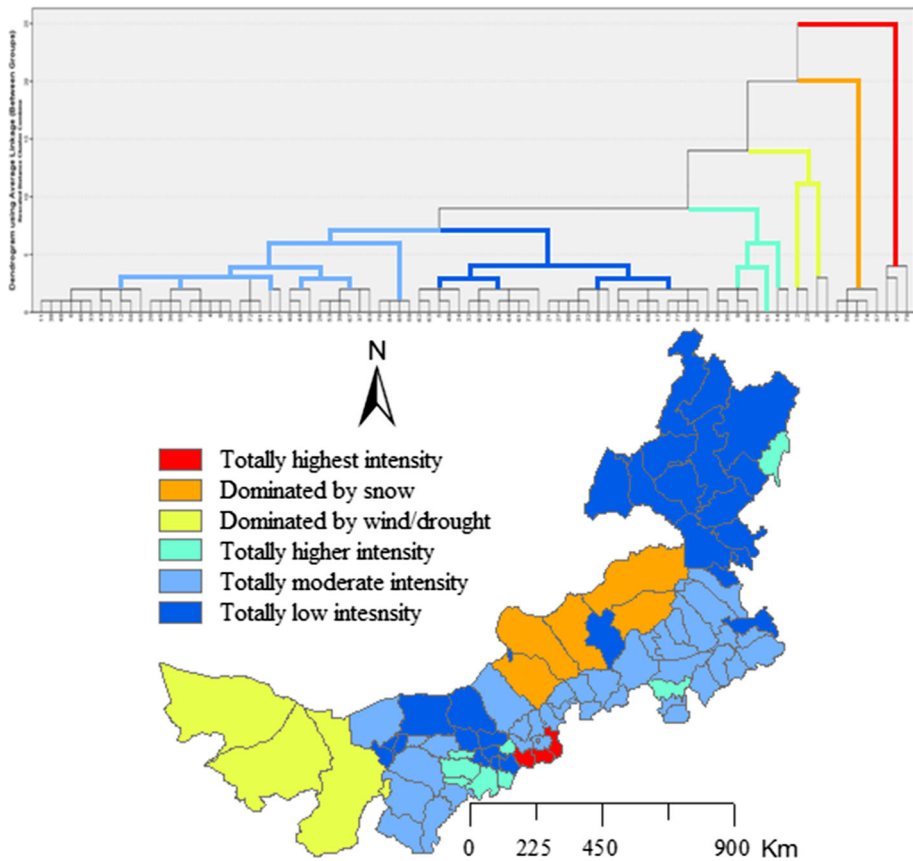


Fig. 6 Classification tree and zoning map of atmospheric and hydrological natural disasters in Inner Mongolia, China, based on intensity data during 1615–2015. The counties with same color indicated the same zone for both above graph of clustered tree and below zoning map

3.6 The correlation among atmospheric and hydrological natural disasters

In order to identify the scale dependence of natural disaster, the correlation was analyzed at 10-, 50- and 100-year cycle, respectively (Table 4). The correlation coefficients demonstrated a variability pattern in frequency and intensity at various temporal scales, i.e., the scale dependence effect. For frequency, drought showed a positive relation to wind at 10-, 50- and 100-year cycle, to flood at 100-year cycle with significant level, to hail at 10- and 100-year cycle with significant level while it showed a significant negative relation to hail at 50-year cycle and a nonsignificant negative relation with flood and snow at 10- and 50-year cycle. It is notable that hail, an instantaneous disaster, is positively related to flood and snow at all cycles, with drought at 10- and 100-year cycle, and wind at 10- and 50-year cycle.

For intensity, the correlations of hail with other disasters were enhanced at all cycles, indicating robust positive relations. Snow showed significant positive relation with hail and wind at 10- and 50-year cycles, with drought at 100-year cycle, significant negative relation with drought at 50-year cycle.

Table 4 Correlation coefficients among the frequency and intensity of five atmospheric and hydrological natural disasters at 10-, 50- and 100-year cycle in Inner Mongolia during recent 500 years

Disaster	Cycle (yr)	Drought	Wind	Flood	Snow	Hail
Drought	10	1	0.065	-0.047	-0.134	0.259*
	50	1	-0.028	-0.104	-0.274**	0.077
	100	1	0.089	0.145	0.223*	0.425**
Wind	10	0.065	1	0.037	0.295**	0.250*
	50	0.051	1	0.044	0.436**	0.484**
	100	0.102	1	0.049	-0.157	0.233*
Flood	10	-0.047	0.037	1	0.209	0.122
	50	-0.076	0.042	1	0.096	0.347**
	100	0.214*	-0.085	1	-0.088	0.402**
Snow	10	-0.134	0.295**	0.209	1	0.219*
	50	-0.086	0.438**	-0.050	1	0.470**
	100	0.035	-0.021	0.061	1	0.055
Hail	10	0.259*	0.250*	0.122	0.219*	1
	50	-0.306**	0.067	0.358**	0.185	1
	100	0.248*	-0.110	0.317**	0.188	1

Bold signal means the correlation analysis results for intensity, and the no mark values describe the results for frequency

* Indicated significance at 0.05 level; ** indicated significance at 0.01 level

4 Discussion and conclusion

We took 500 years as the study period and 10-, 50-, 100-year as the temporal cycle for analyzing the spatial and temporal pattern of five main disasters in Inner Mongolia based on the disaster frequency and intensity. This study demonstrated a robust trend that disaster has accelerated its frequency and intensity during recent 500 years. There were case studies reported that the changing rate became more quickly in recent decades (Ge et al. 2016; Wu et al. 2015). As a longer time series, we found that climate extreme sharply increased in recent 100 years than any period before. When there is increase in frequency and intensity at inter periods, the fluctuation degree within period becomes narrower. These results were same as reported before (Huang et al. 2015; Quan 2014). Totally, drought and flood have more frequency and higher intensity than other disasters in this temperate region. As some case studies indicated, although drought is a main disaster limiting the vegetation growth in semiarid and arid areas (Hu et al. 2016), there also existed flood in short time (Wang et al. 2013). Either drought or instant flood can bring severe harm to grassland ecosystem (Hoover et al. 2014), which is widely distributed in Inner Mongolia region.

The atmospheric and hydrological natural disaster also displayed uneven pattern in spatial distribution, varied in frequency and intensity. The high intensity for all disasters mainly appeared in southwest, middle and northeast parts of Inner Mongolia. For spatial pattern indicated by Moran’s I, the frequency and intensity of five disasters showed a clustered distribution in this region during recent 500 years. This clustered pattern indicated that multiple atmospheric and hydrological natural disasters are tend to outbreak

together, or following each other, at same locations (Yang et al. 2011). That is, it must exist somewhat associations among the disasters. The Pearson's correlation analysis surely found such close association among multiple disasters in the present study. A clustered pattern in environmental conditions may also attribute to the spatial distribution of disasters (Martins et al. 2012; Busuioc et al. 2015). The trends of frequency and intensity also demonstrated spatial variability. The middle, north and northeast parts of the region have a significant increasing trend in the frequency and intensity of flood and hail. The wind intensity has a significant increasing trend in most counties. Increasing trends of snow intensity have a scattered distribution. A high variability existing in spatial distribution was also found for climate extremes in northwestern China (Wang et al. 2013), the Tarim River Basin (Yang et al. 2011) and alpine grassland (Hu et al. 2016) in Central Asia.

Except for spatial variability, the occurrences and change trend of disasters also demonstrated a temporal variability and scale dependence. The frequency and intensity of drought, flood, hail and wind had a clustered pattern during 500 years, while snow had a dispersed pattern during 1516–1615 and 1816–1915. All disasters showed an increasing trend at all cycles: 10-, 50- and 100-year cycle, indicating a significant level by M–K test for the intensity of drought at 10-year cycle and flood at 50-year cycle, and the frequency of hail and flood at 50-year cycle. These results can be validated by related previous studies. For drought, increasing trend in this study was found located in high and very high drought risk zones classified by He et al. (2013). The change trend map of annual precipitation in northeast China during 1957–2012 (Wang et al. 2015) also helps to validate the drought trend in this study. High variability existing in change trend of disasters was also confirmed by the study (Liu et al. 2016) in same region during 1960–2013. The complicated spatial–temporal variability in change trend demonstrates the importance of scale effects analysis in prediction of atmospheric and hydrological natural disaster. Based on the total intensity of five disasters, by the hierarchical cluster analysis, the counties in this region were clustered into six groups. Most counties have the similar characteristics and hence were clustered into one group, the highest and higher extreme weather only scattered in several small groups.

The investigation on the coexisted correlations among different natural disasters can also help to improve the accurate of trend forecast (Martins et al. 2012; Pfahl and Wernli 2012). The emergence of one natural disaster could closely associate with other disaster (Yang et al. 2011). As for this study, snow, hail and wind have significant chance to simultaneously happen at 10- and 50-year cycles. Hail has more chances to occur with flood, snow at all cycles, with drought at 10- and 100-year cycle, and wind at 10- and 50-year cycle. It is reported that the extreme precipitation and temperature over arid region were tend to show high variations in temporal–spatial patterns which results in more frequent droughts combined with higher intensity floods (Yang et al. 2011). Our study confirmed this correlation effect at 100-year cycle and further found its temporal dependence at various period cycles.

The atmospheric and hydrological natural disasters study, especially the temporal–spatial variability and its scale dependence, could provide important information for the adaptation and alleviation management of society and natural systems. There are more characteristics that should be extracted from natural disaster data during the period of 500 years. More research work in the future, particularly the cycle and its possible occurrences under the conditions of climatic changes, as well as the spatial pattern related to environmental heterogeneity, is needed for a more profound understanding of the rules in natural disasters over the arid and semiarid regions.

Acknowledgments The authors thank two anonymous reviewers for their grammar corrections and valuable suggestions. The study was financially supported by the 111 Program of the Bureau of China Foreign Experts and the Ministry of Education (2008-B08044); the Top Discipline and First-class University Constriction Project (ydzxxk201618) of Minzu University of China; the 2011 project from the Collaborative Innovation Centre for Ethnic Minority Development in China; the Undergraduate Research and Training Program (URTP2016110048) of Minzu University of China.

References

- Afshar MH, Sorman AU, Yilmaz MT (2016) Conditional copula-based spatial–temporal drought characteristics analysis—a case study over Turkey. *Water* 426:1–16
- Bernard E, Naveau P, Vrac M, Mestre O (2013) Clustering of maxima: spatial dependencies among heavy rainfall in France. *J Clim* 26(20):7929–7937
- Busuioac A, Dobrinescu A, Birsan M, Dumitrescu A, Orzan A (2015) Spatial and temporal variability of climate extremes in Romania and associated large-scale mechanisms. *Int J Climatol* 135(7):1278–1300
- Dahal P, Shrestha NS, Shrestha ML, Krakauer NY, Panthi J, Pradhanang SM et al (2016) Drought risk assessment in central Nepal: temporal and spatial analysis. *Nat Hazards* 80(3):1913–1932
- Du XD, Jin XB, Yang XL, Yang XH et al (2015) Spatial-temporal pattern changes of main agriculture natural disasters in China during 1990–2011. *J Geogr Sci* 25:387–398
- Easterling DR (2000) Climate extremes: observations, modeling, and impacts. *Science* 289:2068–2074
- Ge Y, Apurv T, Cai X (2016) Spatial and temporal patterns of drought in the Continental US during the past century. *Geophys Res Lett* 43:6294–6303
- Green D (2016) The spatial distribution of extreme climate events, another climate inequity for the world’s most vulnerable people. *Environ Res Lett* 11:91–102
- Harrington LJ, Frame DJ, Fischer EM, Hawkins E, Joshi M, Jones CD (2016) Poorest countries experience earlier anthropogenic emergence of daily temperature extremes. *Environ Res Lett* 11(5):55–67
- He B, Wu JJ, Lu AF, Liu M, Zhao L, Cui XF, Zhou L (2013) Quantitative assessment and spatial characteristic analysis of agricultural drought risk in China. *Nat Hazards* 66:155–166
- Hoover DL, Knapp AK, Smith MD (2014) Resistance and resilience of a grassland ecosystem to climate extremes. *Ecology* 95:2646–2656
- Hu Z, Li Q, Chen X (2016) Climate changes in temperature and precipitation extremes in an alpine grassland of Central Asia. *Theor Appl Climatol* 126:519–531
- Huang J, Xue Y, Sun S, Zhang J (2015) Spatial and temporal variability of drought during 1960–2012 in Inner Mongolia, north China. *Quat Int* 355:134–144
- Jia H, Pan D, Wang JA, Zhang WX (2016) Risk mapping of integrated natural disasters in China. *Nat Hazards* 80(3):2023–2035
- Li R, Tsunekawa A, Tsubo M (2014) Index-based assessment of agricultural drought in a semi-arid region of Inner Mongolia, China. *J Arid Land* 6:3–15
- Lin ML, Chu CM, Tsai BW (2011) Drought risk assessment in Western Inner-Mongolia. *Int J Environ Res* 5:139–148
- Liu S, Kang W, Wang T (2016) Drought variability in Inner Mongolia of northern China during 1960–2013 based on standardized precipitation evapotranspiration index. *Environ Earth Sci* 75:145
- Lopes AV, Chiang JCH, Thompson SA, Dracup JA (2016) Trend and uncertainty in spatial–temporal patterns of hydrological droughts in the Amazon Basin. *Geophys Res Lett* 43:3307–3316
- Martins DS, Raziei T, Paulo AA, Pereira LS (2012) Spatial and temporal variability of precipitation and drought in Portugal. *Nat Hazards Earth Syst Sci* 12(5):1493–1501
- Meteorological (Bureau 2016) Meteorological yearbook of China (1999–2015). Meteorological Press, Beijing
- Modarres R, da Silva VPR (2007) Rainfall trends in arid and semi-arid regions of Iran. *J Arid Environ* 70:344–355
- Mu JE, Chen Y (2016) Impacts of large natural disasters on regional income. *Nat Hazards* 83:1485–1503
- Pfahl S, Wernli H (2012) Spatial coherency of extreme weather events in Germany and Switzerland. *Int J Climatol* 32:1863–1874
- Quan RS (2014) Risk assessment of flood disaster in Shanghai based on spatial–temporal characteristics analysis from 251 to 2000. *Environ Earth Sci* 72:4627–4638
- Seo SN (2015) Adapting to extreme climates: raising animals in hot and arid ecosystems in Australia. *Int J Biometeorol* 59:541–550
- Tabari H, Abghari H, Talaei PH (2012) Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran. *Hydrol Process* 26:3351–3361

- Tan CP, Yang JP, Li M (2015) Temporal–spatial variation of drought indicated by SPI and SPEI in Ningxia Hui Autonomous Region, China. *Atmosphere* 6:1399–1421
- The Counselor Office of Inner Mongolia Government (1988) Continued edition of historical materials of natural disasters in past ages in Inner Mongolia (1949–1986). Inner Mongolia Government Printed Book, Hohhot
- The Edition Group (1982) Historical materials of natural disasters in past ages in Inner Mongolia (B.C. 244–A.D. 1949). Inner Mongolia Government Printed Book, Hohhot
- Wang H, Chen Y, Xun S (2013) Changes in daily climate extremes in the arid area of northwestern China. *Theor Appl Climatol* 112:15–28
- Wang X, Hou X, Li Z, Wang Y (2014) Spatial and temporal characteristics of meteorological drought in Shandong province, China, from 1961 to 2008. *Adv Meteorol* 12:1–11
- Wang X, Shen H, Zhang W, Cao J, Qi Y, Chen G et al (2015) Spatial and temporal characteristics of droughts in the Northeast China Transect. *Nat Hazards* 76(1):601–614
- Weng B, Zhang P, Li S (2015) Drought risk assessment in China with different spatial scales. *Arab J Geosci* 8(12):10193–10202
- Wu CH, Huang GR, Yu HJ, Chen ZQ, Ma JG (2015) Spatial and temporal distributions of trends in climate extremes of the Feilaixia catchment in the upstream area of the Beiji River Basin, South China. *Int J Climatol* 34(11):3161–3178
- Xin Y (2001) Annals of natural disasters in Inner Mongolia (1986–1999). The Inner Mongolia People Press, Hohhot
- Yang T, Wang X, Zhao C, Chen X, Yu Z, Shao Q et al (2011) Changes of climate extremes in a typical arid zone: observations and multimodel ensemble projections. *J Geophys Res* 116(D19):1441–1458
- Yi C, Rustic G, Xu X (2012) Climate extremes and grassland potential productivity. *Environ Res Lett* 7:035703
- Zarei AR, Moghimi MM, Mahmoudi MR (2016) Analysis of changes in spatial pattern of drought using RDI index in south of Iran. *Water Resour Manag* 30(11):3723–3743
- Zhou Y, Li N, Wu WX, Wu JD, Shi PJ (2014) Local spatial and temporal factors influencing population and societal vulnerability to natural disasters. *Risk Anal* 34(4):614–639