

Article

Trend Analysis and Spatial Distribution of Meteorological Disaster Losses in China, 2004–2015

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Abstract: Meteorological disasters caused a lot of losses. We involved six categories (all disasters, floods, hail, typhoon, snow and heatwave) to observe their death and economic losses' spatial-time distribution. The time trend of mortality was analyzed using a chi-square test for linear trends. Economic loss was described by direct economic loss and loss rate of GDP, whose trends were described by a trend line. Using annual percent change (APC) estimated by fitting weighted linear regression model, the change degree of mortality was assessed. On a national level, there was a statistically significant decreasing trend in mortality of all disasters ($Z = -39.82, p < 0.05$), floods ($Z = -18.79, p < 0.05$), hail ($Z = -20.43, p < 0.05$), typhoon ($Z = -37.47, p < 0.05$), snow ($Z = -9.02, p < 0.05$) and heatwave ($Z = -8.76, p < 0.05$) from 2004 to 2015 in China. The time trend of the loss rate of GDP was decreasing while the trend of direct economic losses was increasing. Western China was the most seriously hit area. APCs remained in downward trends (APCs < 0) in most of the provinces, while central provinces were with upward trends (APCs > 0). Areas with increasing mortality (APCs > 0) for different disasters included the southwest areas and Zhejiang (for floods), the northwest and south areas (for hail), Sichuan, Guangxi and Hainan (for typhoon), the west and northeast areas (for snow) and Hebei, Henan and Shanghai (for heatwave). As for economic losses, eastern areas were hit with a high amount of economic losses, but central areas were hit with a high GDP loss rate. Generally, nationwide death and economic losses caused by meteorological disasters have decreased. However, there were some relatively serious effects in the central and western areas for which urgent attention from policymakers is required.

Keywords: meteorological disasters; mortality; direct economic losses; time trend



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1. Introduction

Meteorological disasters are some of the most fatal and costly natural disasters in the world [1]. According to the World Meteorological Organization (WMO), about 7870 meteorological disasters (storm accounted for 36%, drought accounted for 6%, flood accounted for 43%, extreme temperature accounted for 5%, mass movement wet accounted for 6%, and wild fires accounted for 4%) occurred around the world from 1970 to 2009, and they brought about a total of about 186 million deaths and direct economic losses of 1954\$ billion [2]. Of these recorded deaths and economic losses, 85% and 56% were caused by flood disasters and typhoons, respectively [2]. In Africa, 1137 reported disasters caused the loss of 695,163 lives and economic damages of US\$22.2 billion. In Asia, some 2425 disasters were reported, causing the loss of 898,726 lives and economic damages of US\$641 billion. In North America, Central America and the Caribbean, there were 1458 reported disasters that caused the loss of 68,708 lives and economic damages of US\$803.7 billion [2]. The

direct economic losses to gross domestic product (GDP) ratio of middle-income countries was 1%, 0.3% for low-income countries, and less than 0.1% for high-income countries [3,4].

In recent years, most Asian countries are experiencing more frequent meteorological disasters (e.g., floods, hurricanes, extreme temperatures, snowstorms, etc.) as consequences of climate change and intensified human activities [5–7]. Being situated in the southeastern Eurasian Continent, the greatest continent in the world, and on the west coast of the Pacific Ocean, China is impacted by a typical monsoon climate. Furthermore, in the wake of the dense population and mushrooming economic development, China is one of the most severely affected countries by meteorological disasters in the world [8]. Even so, the recorded annual average deaths amounted to more than ten thousand people in the 1950s and the 1960s and then dropped gradually to about one thousand people since the 21st century. The economic losses on gross domestic product (GDP) ratio also decreased from over 15% in the 1950s and to around 1% since the 21st century in spite of the mean annual direct loss increasing from less than CNY 100 billion in the 1950s to more than CNY 300 billion since the 21st century [9]. Otherwise, disaster situations appeared diversely between different species of meteorological disasters. For example, the floods (heavy rains) disasters characterized by high frequency, long duration, wide influencing range, and high intensity increased quickly, particularly in the Yangtze river and the Pearl river [10]. Furthermore, the deaths and economic losses caused by flood disasters have accounted for 66% and 63% since the 1990s and the frequency was almost three times than before [9]. China is one of the countries seriously affected by typhoons especially along the east coast; Typhoons caused 8990 deaths in the Chinese mainland during 1990–2010 and over 1000 deaths in the year 2006 alone. The economic losses caused by typhoons from 1991–2000 and 2001–2010 increased from CNY 29.14 billion to CNY 34.43 billion [11]. Beyond that, the number of high-temperature days ($>35\text{ }^{\circ}\text{C}$) increased after the mid-1990s. In the summer of 2000, many places in the north and south were hit continuously by long-lasting heatwaves, which led to increased mortality [12].

Since the 1990s, the relatively poor planning, management and rapid development of urbanization have increased the climate change and ecological damage caused by all disasters. Using information on natural and social properties and the background of global warming and urbanization, the intergovernmental panel on climate change (IPCC) pointed out that typhoons, droughts, extreme rainfall and other extreme weather might increase, and the economic losses caused by meteorological disasters would increase in the future due to economic developments [3]. Therefore, it is highly imperative to research the life and economic loss changing feature of the meteorological disasters in China, especially for the regional disaster losses distribution characteristic.

At present, research about the geographical characteristics, causes, types and distribution of meteorological disasters in China have been relatively mature. There are also a lot of studies on the impact of certain meteorological disasters on the provinces or the impact of meteorological disasters on the whole country. However, there is still a lack of research on the quantity and variation of losses caused by various meteorological disasters in the whole country, and there is also no research on the amplitude of variation of losses caused by various meteorological disasters at the provincial level.

In this study, the two dimensions of time and space were employed to analyze the trend of meteorological disasters related deaths and economic losses, while providing important references for disaster particular prevention, mitigation planning, meteorological disasters risk management and climate change adaptation.

2. Materials and Methods

2.1. Meteorological Disaster Type and Data Collections

Currently, there has not been an agreed classification and definition for meteorological disasters. In this paper, consideration of the causes, properties and damage characteristics, and categories have been developed and abbreviated for different types of meteorological disasters as observed in the study. Categorization was performed as follows: (1) all the

meteorological disasters are termed as “all”. There are more than 20 kinds of meteorological disasters including weather, climatic disasters and meteorological secondary and derived disasters; (2) heavy rain, flood disaster, landslide and debris flow are grouped under “floods”; (3) gale, hail and thunder-and-lighting were collectively termed as “hail”; (4) tropical cyclone was termed as “typhoon”; (5) snow disaster, low temperature and freezing were categorized as “snow”; (6) high temperature and heatwave were uniformly termed “heatwave”. Since drought emphasized harm does not involve life losses, just the above-listed six categories were analyzed. The data from the above-mentioned disasters, deaths (including the missing persons) and direct economic losses were obtained from *China Meteorological Disasters Yearbook, 2005–2016* [13]. Information was also obtained on total population and GDP from *China Statistical Yearbook, 2016* [14]. It should be noted that the economic losses from heatwave in the Taiwan province, Hong Kong, and Macao (with no record data) were not included in the analysis due to incomplete data.

2.2. Statistical Analysis

This study adopted mortality rate (/10,000,000), the percent of the cumulative death (%), the absolute value of direct economic losses and the loss rate of GDP (annual direct economic losses/annual GDP) [9] to characterize the losses degree. The chi-square test for linear trend [15] and the annual percent change (APC) were used to reflect the trend changing degree. SAS 9.4 was used to calculate the estimated APC by fitting a weighted linear regression model [16,17] to test the time trend of the mortality at a provincial level. Trends of nationwide direct economic loss and loss rate of GDP were described by a trend line of WPS Excel 2010, which were tested by linear regression of SPSS 22.0. The result of the trend line was shown in Supplementary Files.

APC is calculated as follows [16,17]:

Y represents the natural logarithm of the rate: $Y = \ln(R)$

Fitting weighted linear regression model: $Y = \alpha + \beta x + \varepsilon$

Y is the dependent variable and x is the independent variable (the year), α is the constant term, β is the regression coefficient, and ε is the random error term. The weight is taken as the number of deaths in each year or period.

$$APC = 100 \times (e^{\beta} - 1)$$

If the trend is unchanged, that is $APC = 0$ (null hypothesis). Then the statistical test of APC can be achieved by testing whether the regression coefficient β is equal to 0. The standard error of β can be obtained from the model, using the T test: $t = \frac{\beta}{\sqrt{Var(\beta)}}$. It follows a T-distribution with n-2 degrees of freedom. And the significance of the linear regression model was validated by an F test, while the residual was validated by a normality test.

Furthermore, the mean mortality (/10,000,000), direct economic losses, the mean loss rate of GDP and APC (%) combined with ArcGIS 10.2 (Environmental Systems Research Institute, Redlands, CA, USA. Available at: <http://www.esri.com/software/arcgis/arcgis-for-desktop>, accessed on 1 September 2016) drew the spatial distribution of disasters losses at a provincial level. Fundamental digital maps of China were obtained from the National Earth System Science Data Sharing Infrastructure which are available at: <http://www.geodata.cn> (accessed on 1 September 2016).

3. Results

3.1. Time Trends of Meteorological Disasters in China, 2004–2015

3.1.1. Mortality Caused by Meteorological Disasters, 2004–2015

A total of 27,223 persons died in the nationwide meteorological disasters with a mean mortality of 14.82/10,000,000 from 2004 to 2015. Noticeably, the mortality in 2010 was the highest; with a 2.54 times higher increase than the mean mortality. Among these,

floods were the most serious meteorological disasters with associated cumulative deaths accounting for 51.12% of the total deaths. This was also 1.40 times higher than the sum of the other four disasters and was followed by hail-associated disasters (22.97%). In addition to these five disasters, the death toll rates of the other types of meteorological disasters which contain continuous rain, smoke flog, low altitude wind shear, acid rain, forest fire, air pollution and soon on were 11.27%, 11.92%, 3.62%, 5.97%, 9.56%, 13.85%, 23.46%, 19.85%, 21.95%, 1.02%, 11.28% and 9.91% from 2004 to 2015, showing an increasing trend (Figure S1). Moreover, the cumulative death rate of the other meteorological disasters was 12.31%. (Figure 1, Table 1)

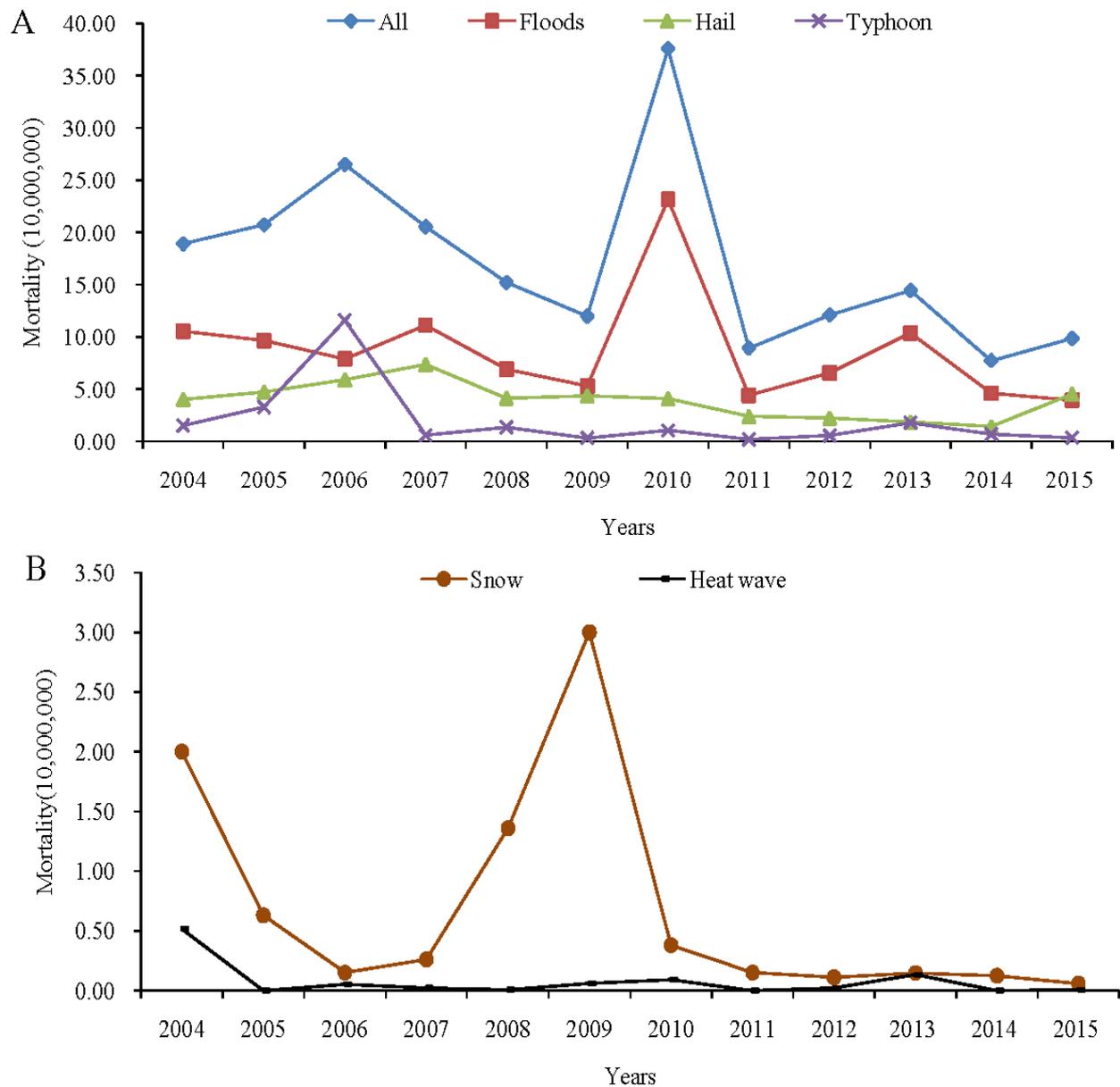


Figure 1. Trend chart for meteorological disasters related mortality, 2004–2015. (A). All, floods, hail and typhoon (B). Snow and heatwave.

Table 1. Meteorological disasters related deaths from 2004 to 2015 and result of time trend analysis.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Z ^a
All	2457	2710	3485	2713	2018	1596	5038	1199	1637	1963	1055	1352	−39.82
Floods	1370	1260	1036	1467	915	704	3104	591	887	1411	631	540	−18.79
Hail	521	616	774	971	549	580	549	323	302	252	194	621	−20.43
Typhoon	196	429	1522	76	179	43	140	27	74	242	94	48	−37.47
Snow	26	82	20	34	181	40	51	20	15	20	17	8	−9.02
Heatwave	67	0	7	3	1	8	12	0	3	18	0	1	−8.76

^a: $p < 0.001$.

Obviously, there was a statistically significant decreasing trend in mortality of all disasters ($Z = -39.82, p < 0.05$), floods ($Z = -18.79, p < 0.05$), hail ($Z = -20.43, p < 0.05$), typhoon ($Z = -37.47, p < 0.05$), snow ($Z = -9.02, p < 0.05$) and heatwave ($Z = -8.76, p < 0.05$) from 2004 to 2015 in China, but with relatively large inter-annual variability. (Table 1)

3.1.2. Time Trend of Direct Economic Losses Caused by Meteorological Disasters, 2004–2015

The direct economic losses caused by the nationwide meteorological disasters were accumulatively CNY 3602.22 billion with mean direct economic losses of about CNY 274.08 billion. Similar to mortality, the number of losses in 2010 was the largest (Figure 2). In general, the absolute value of the direct economic losses showed an increasing trend (Figure S2). In contrast, the loss rate of GDP caused by all the meteorological disasters showed a decreasing trend over the years (Figure S3).

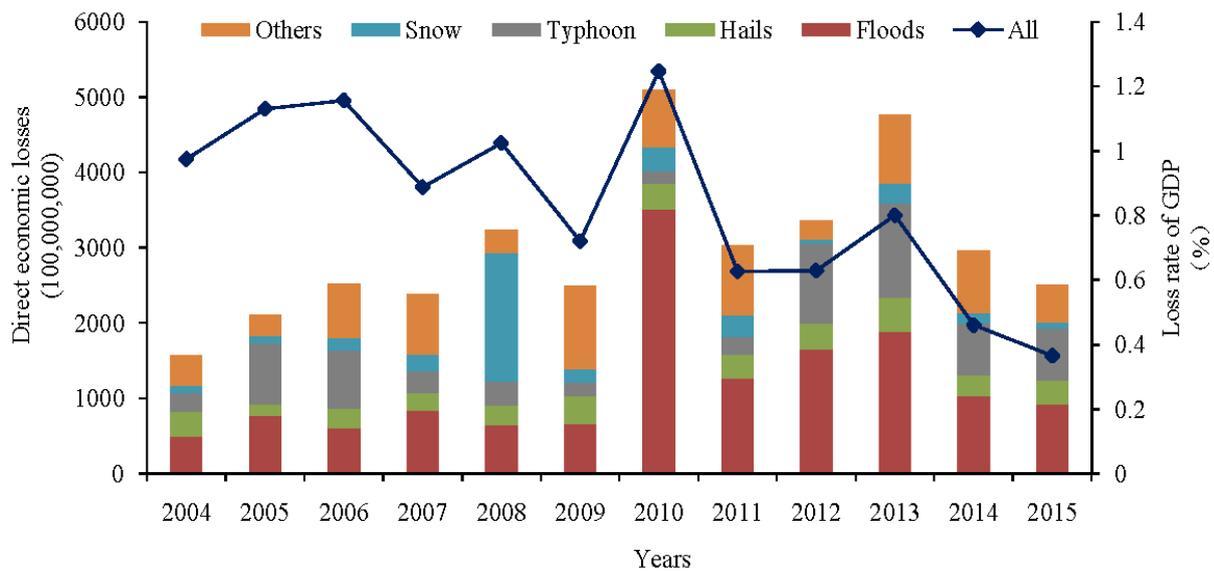


Figure 2. Direct economic losses caused by floods, hail, typhoon, snow and others and loss rates of GDP caused by all the meteorological disasters, 2004–2015. Others: rain, smoke flog, low altitude wind shear, acid rain, forest fire, air pollution and soon on.

3.2. Spatial Pattern of Mortality Caused by Meteorological Disasters at Provincial Level, 2004–2015

3.2.1. Spatial Distribution of Mean Mortality Caused by Meteorological Disasters at Provincial Level, 2004–2015

The distribution and clusters of different meteorological disasters were presented in the maps (exact positions for province names refer to Figure 3). It apparently indicated that different types of disasters had distinct spatial characteristics. The southwestern areas were most seriously influenced by the meteorological disasters shown in Figure 4A. Floods and hail were the most widely distributed disasters in China among the five types (Figure 4B,C). In contrast, typhoons occurred intensively in the southeast coastal areas, with Hainan,

Zhejiang, Guangdong, Fujian affected the most (Figure 4D). Snow and heatwave were the least occurring disasters with a low frequency per year (no more than three) and recorded the least related death counts (less than five) in most regions of mainland China from 2004 to 2015 (Figure 4E,F). Snow disasters mainly influenced the western areas, with the highest related mean mortality in Tibet (Figure 4E). As for heatwave, it occurred sporadically in eastern (Hebei, Jiangsu, Shanghai and Guangdong), central (Henan, Hubei and Shaanxi), and northwest (Xinjiang) China and did not cause serious effects in death (Figure 4F).



Figure 3. Map of China labeled with provinces names.

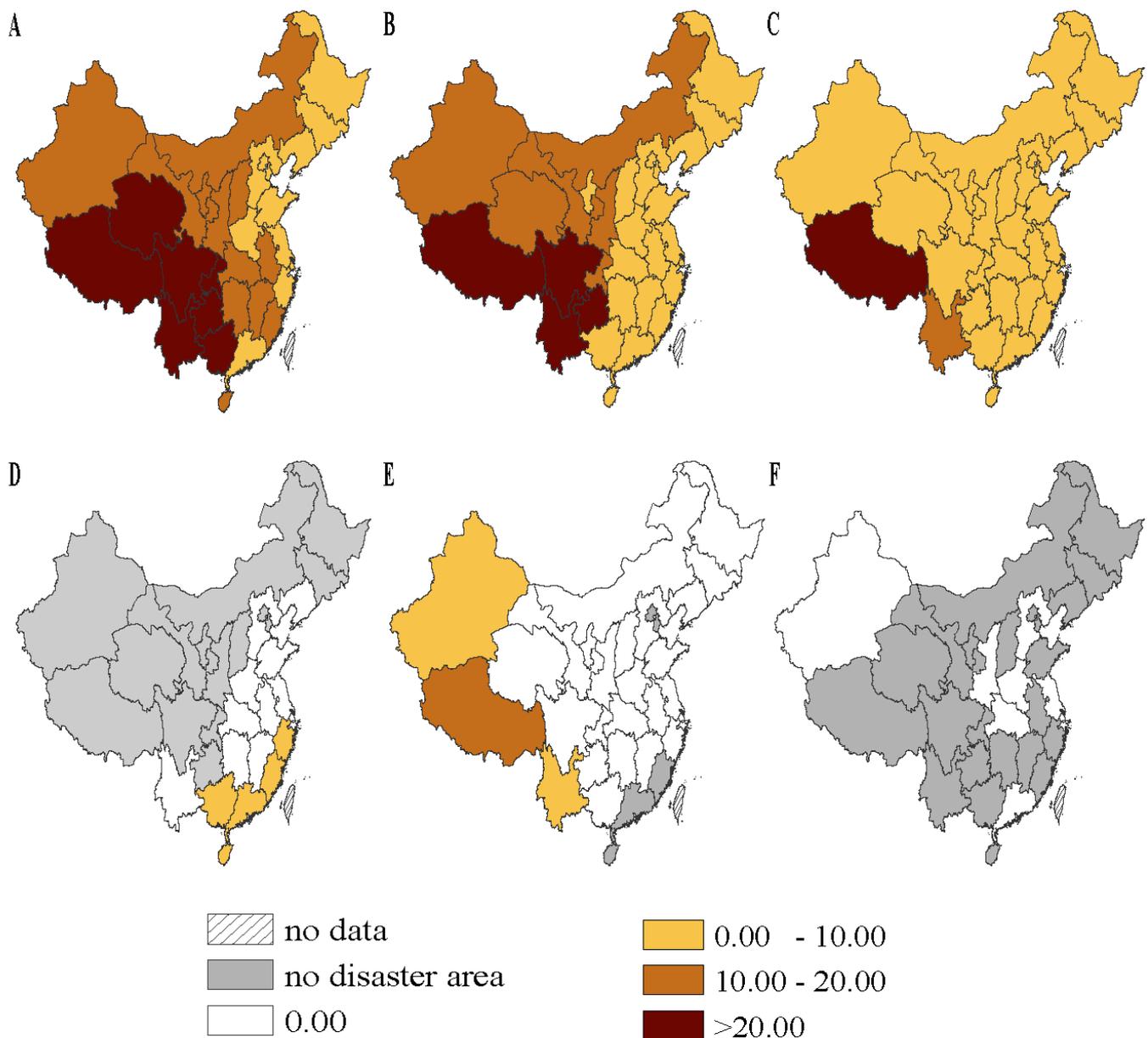


Figure 4. Mean mortality (/10,000,000) caused by meteorological disasters at provincial level, 2004–2015: (A). All. (B). Floods. (C). Hail. (D). Typhoon. (E). Snow. (F). Heatwave. Note. ArcGIS 10.2 (<http://www.arcgis.com>, accessed on 15 October 2018) was used to create this map. Please refer to the full map in Figure 3.

3.2.2. Time Trend of Mortality Caused by Meteorological Disasters at Provincial Level, 2004–2015

We obtained APC results based on linear regression models of mortality (Table 2). We can see that the changing degree of time trends for different disasters vary from region to region. Generally decreasing trends were recorded for most parts of China with an increase in years while notably increasing trends were observed for five provinces (Beijing, Ningxia, Shaanxi, Hubei and Hainan) in northeast, eastern, central and southwest China (Figure 5A). Provinces in the eastern, central, southern and southwest areas of the country (Zhejiang, Shaanxi, Hainan, Qinghai and Tibet) observed increasing trends for flood (Figure 5B). Areas highly affected by hail (Tibet and Yunnan) showed a downward trend while sporadically provinces (Jilin, Beijing, Tianjin, Ningxia, Hubei, Guangxi, Guangdong, and Xinjiang) in northeast, central, southern and northwest areas were with an upward trend (Figure 5C).

The impacts of typhoons showed a universal decreasing trend in the high-frequency areas (except Hainan province), while an increase was observed for the other low-frequency provinces in the north of eastern China and Yunnan and Guangxi (Figure 5D). For snow disasters, Tibet Autonomous Region Heilongjiang recorded the highest APC and the rest with increasing trends observed in the eastern, central and southwest China (Shandong, Gansu, Sichuan and Tibet) (Figure 5E). Hebei and Henan showed an increasing trend influenced by heatwave. Meanwhile, Guangdong, Jiangsu and other influenced provinces showed a decreasing trend (Figure 5F).

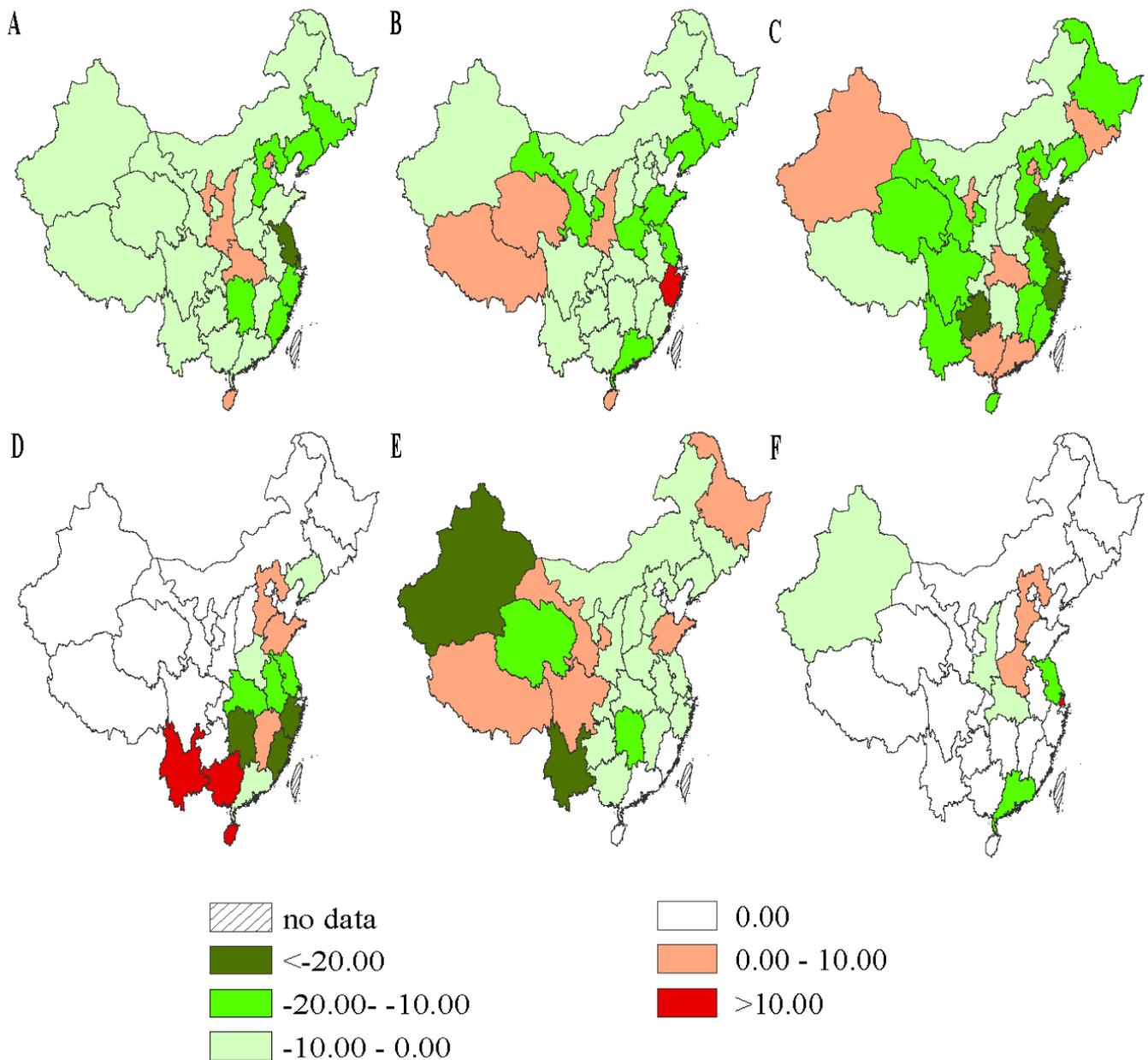


Figure 5. APC (%) of mortality caused by meteorological disasters at provincial level, 2004–2015: (A). All. (B). Floods. (C). Hail. (D). Typhoon. (E). Snow. (F). Heatwave. Note. ArcGIS 10.2 (<http://www.arcgis.com>, accessed on 15 October 2018) was used to create this map. Please refer to the full map in Figure 3.

Table 2. APC (%) of mortality caused by meteorological disasters at provincial level, 2004–2015.

Province Name	APC of All Dis-aster	<i>p</i> Value ^a	<i>p</i> Value ^b	APC of Floods	<i>p</i> Value ^a	<i>p</i> Value ^b	APC of Hail	<i>p</i> Value ^a	<i>p</i> Value ^b	APC of Typhoon	<i>p</i> Value ^a	<i>p</i> Value ^b	APC of Snow	<i>p</i> Value ^a	<i>p</i> Value ^b	APC of Heat-wave	<i>p</i> Value ^a	<i>p</i> Value ^b
Beijing	8.93	0.63	0.20	−0.51	0.98	0.00	1.29	0.91	0.10									
Shanxi	−6.07	0.49	0.20	−6.04	0.50	0.20	−8.93	0.41	0.04				−0.76	0.89	0.00			
Liaoning	−13.12	0.17	0.05	−11.46	0.47	0.20	−17.80	0.05	0.20	−6.15	0.55	0.00	−9.40	0.29	0.01			
Jilin	−10.03	0.47	0.20	−10.60	0.55	0.02	3.97	0.76	0.20				−4.10	0.50	0.00			
Shanghai	−22.55	0.01	0.20	−6.21	0.11	0.79	−8.47	0.39	0.09	−3.88	0.72	0.00	−2.32	0.68	0.00	10.25	0.33	0.00
Tianjin	−7.04	0.60	0.20	−6.59	0.44	0.00	1.38	0.87	0.00									
Hebei	−13.37	0.12	0.01	−7.59	0.43	0.20	−10.91	0.01	0.20	2.50	0.50	0.00	−0.85	0.89	0.00	0.60	0.89	0.00
Heilongjiang	−4.45	0.78	0.08	−4.00	0.80	0.03	−13.95	0.11	0.20				6.26	0.33	0.00			
Jiangsu	−21.19	0.00	0.03	−16.13	0.04	0.20	−20.13	0.00	0.17	−16.22	0.01	0.20	−4.01	0.55	0.00	−14.13	0.13	0.05
Guizhou	−5.50	0.15	0.20	−4.59	0.17	0.20	−24.02	0.00	0.20				−3.47	0.76	0.00			
Hunan	−10.82	0.09	0.03	−7.96	0.09	0.20	−6.67	0.22	0.20	−30.55	0.08	0.20	−13.70	0.14	0.05			
Ningxia	4.41	0.68	0.06	−2.73	0.81	0.20	3.96	0.50	0.08				−1.64	0.68	0.00			
Hainan	7.35	0.54	0.54	3.91	0.45	0.00	−11.94	0.15	0.20	28.17	0.11	0.20						
Shanxi	7.78	0.32	0.20	0.34	0.95	0.05	−9.47	0.29	0.20				−0.97	0.89	0.00	−2.40	0.33	0.00
Guangdong	−1.99	0.82	0.05	−10.24	0.20	0.20	6.49	0.38	0.09	−5.00	0.84	0.20				−18.84	0.22	0.03
Guangxi	−6.32	0.14	0.20	−5.80	0.30	0.20	1.27	0.89	0.16	23.54	0.29	0.20	−1.48	0.68	0.00			
Gansu	−8.75	0.55	0.20	−17.10	0.29	0.20	−19.58	0.01	0.20				0.66	0.95	0.00			
Neimenggu	−0.93	0.87	0.03	−1.94	0.76	0.20	−2.22	0.57	0.20				−4.85	0.62	0.00			
Qinghai	−1.82	0.74	0.20	5.30	0.44	0.20	−11.25	0.04	0.20				−14.84	0.06	0.17			
Jiangxi	−8.08	0.08	0.07	−2.34	0.67	0.20	−11.45	0.05	0.20	7.06	0.78	0.11	−9.43	0.19	0.01			
Anhui	−8.55	0.20	0.20	−0.26	0.98	0.17	−14.87	0.00	0.20	−18.64	0.12	0.20	−3.15	0.68	0.00			
Zhejiang	−11.95	0.23	0.20	11.69	0.28	0.20	−20.48	0.00	0.20	−33.60	0.03	0.20	−8.72	0.41	0.01			
Henan	−9.20	0.21	0.20	−13.71	0.27	0.20	−5.30	0.47	0.20	−2.35	0.21	0.01	−0.88	0.89	0.00	2.16	0.53	0.00
Shandong	−9.38	0.25	0.20	−17.63	0.06	0.20	−21.11	0.01	0.20	2.10	0.68	0.00	0.93	0.84	0.00			
Xizang	−0.20	0.97	0.20	0.13	0.99	0.20	−6.36	0.08	0.20				4.42	0.52	0.20			
Hubei	1.17	0.86	0.02	−9.73	0.06	0.13	2.71	0.79	0.20	−12.45	0.30	0.00	−8.71	0.28	0.00	−0.30	0.97	0.00
Yunnan	−7.97	0.05	0.20	−8.60	0.08	0.20	−19.78	0.00	0.20	31.03	0.27	0.00	−22.29	0.05	0.20			
Xinjiang	−4.96	0.37	0.20	−8.76	0.08	0.20	5.12	0.50	0.20				−26.52	0.03	0.15	−4.69	0.30	0.01
Chongqing	−5.29	0.43	0.20	−6.04	0.45	0.20	−8.06	0.38	0.20				−2.74	0.68	0.00			
Sichuan	−6.08	0.33	0.20	−8.56	0.08	0.20	−18.52	0.01	0.16				1.61	0.81	0.00			
Fujian	−11.24	0.27	0.20	−3.75	0.79	0.20	−13.83	0.25	0.01	−26.17	0.09	0.20						

^a: The *p* value of F test for the significance of linear regression model and t-test for the significance of the coefficients; ^b: The *p* value of normality test for the residual of linear regression model. Relevant data are blank because individual provinces were not affected by some kind of disaster.

3.3. Spatial Pattern of Direct Economic Losses Caused by Meteorological Disasters at Provincial Level, 2004–2015

As indicated from Figure 6, it can be found that most of the provinces in China experienced relatively high economic losses (>CNY 7.14 billion). Except for Jilin, Gansu, Hainan and Jiangxi, the loss rates of other provinces were all under 3.00%. Provinces such as Tibet, Yunnan, Guizhou and Qinghai in western China were most seriously affected by death, ranked in the lowest economic losses level and also in the lower mean loss rate of GDP level. On the contrary, Yunnan and Guizhou suffered more economic loss and higher loss rates. The provinces showing the second and third highest loss rates were intensively distributed in the middle and western parts as observed from the east to the west on the map. Among these provinces, Yunnan province was not only in the highest loss rate level but also in the most serious death situation level. The least serious provinces influenced by death in the east suffered nearly the most losses but showed the lowest loss rate. The same as nationwide direct economic losses, the direct economic losses in most provinces of China varied while showing degrees of increasing trends. (Figure 6)

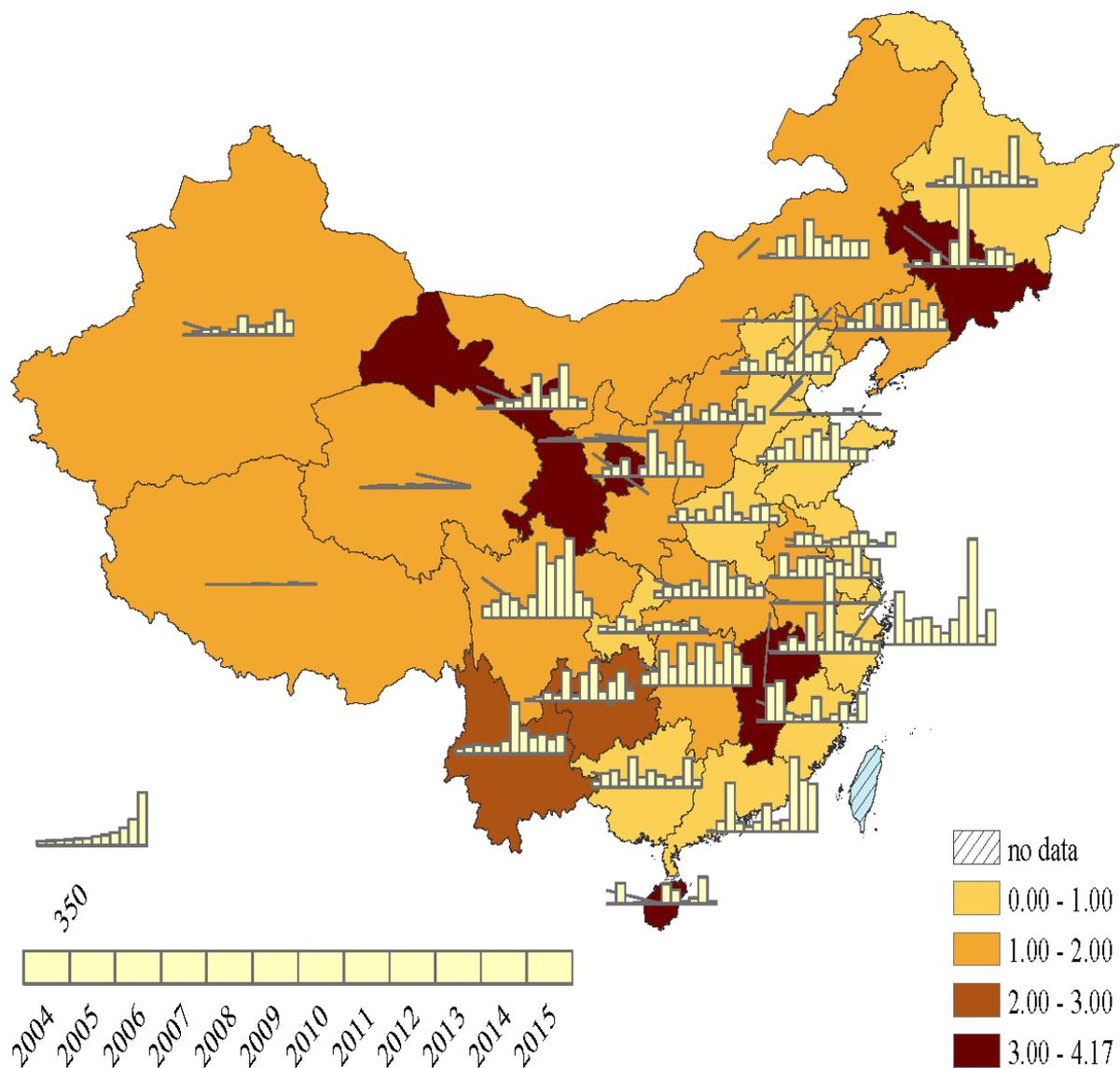


Figure 6. Direct economic losses (100,000,000) and mean loss rate of GDP (%) caused by meteorological disasters at provincial level, 2004–2015. The bar charts correspond to direct economic losses while the color map corresponds to mean loss rate of GDP (%). Note. ArcGIS 10.2 (<http://www.arcgis.com>, accessed on 15 October 2018) was used to create this map. Please refer to the full map in Figure 3.

4. Discussion

We have found a statistically significant decreasing trend in the associated mortality rate for all the meteorological disasters namely: floods, hail, typhoon, snow and heatwave during 2004–2015, which have been shown in Table 1. However, previous similar studies have indicated that some kinds of extreme weather events might occur more frequently in the future due to ongoing global warming [18,19]. Hence the observed decreasing trend in loss phenomenon may be attributed to efficient disaster risk management by policymakers. The Chinese government comprehensively strengthened its capacity to prevent and reduce disasters, and preliminarily formed a comprehensive disaster prevention and reduction system with Chinese characteristics that integrates disaster prevention, reduction and management; the risk management capabilities of government agencies at all levels and the awareness of risk for the public as well as legal system related to disaster prevention and reduction have obviously improved. In addition, Chinese society as a whole has preliminarily formed a healthy atmosphere aimed at mitigating disaster risks [20,21]. Moreover, economic development was a benefit package included in the above-mentioned management development [9]. It was also observed that the cumulative loss rate of GDP nationwide decreased with years while the direct economic losses were increased. This trend can be attributed to the consequence of property exposure increasing and GDP cardinal number augmented due to high-speed economic development [9].

However, the declining trend was with large inter-annual variability, particularly in the year 2010. The mortality and the direct economic losses caused by all the meteorological disasters recorded their highest peaks in 2010, of which floods accounted for the largest proportion. This observation was attributed to the fact that several heavy rainfall and flood disasters occurred in 2010. This included an over-warning flood in the Yangtze, Yellow River, Huaihe River, West River, Songhua River, Liaohe River, Taihu Lake and the Minjiang River. The effects of these floods affected Jilin, Jiangxi, Henan, Fujian, Guangxi, Sichuan, Qinghai and 31 other provinces. Heavy casualty events caused by torrential debris flow occurred more than once in the western areas such as Gansu, Shanxi, Yunnan, Guizhou, Guangxi and Henan in the same year. Above all, 1501 people died while 239 people went missing in Zhouqu due to an off-record flooding in the main stream of the Yangtze in the same year [22,23].

Furthermore, it was observed that the western areas of China were the most seriously affected by these meteorological disasters. This is due to the complex terrain nature of China i.e., height is higher in the west and lowers in the east, thereby forming three steps as one gradually moves from the west to the east. The southwest forms the first step, followed by the Tibetan Plateau, where the average highest plateau of the world is also located [24]. Disaster-related deaths were highest in mountainous regions where the topography is complex and the population is unevenly distributed. The severity of meteorological hazards depends not only on the disaster frequency but also strongly on the region's geographical features, population distribution and socioeconomic development which encompasses the level of the exposure and vulnerability of the area to disasters [25]. In addition, the ability of local people or communities to cope with and recover from the aftermath effects of disasters varies from region to region and the economic status of societies which to a large extent determine their capability to cope and “live” with these disasters [3,26].

According to the analysis of data from 2004 to 2015, it was found that the distribution characteristics were disparate with different disasters. Due to the distinctions in its terrain, the climates, temperatures and rainfall in various regions of China change very much. These changes are the main facilitators that generate meteorological disasters in China. These disasters are of many types and occur under complex circumstances, as well as differ across regions [24]. While floods caused the highest cumulative deaths (51.12%), it was the most widely distributed disaster having its highest effects on southwest areas of China since the middle and lower reaches of the Yellow River and the Yangtze River basin usually suffered more frequent floods. In southwest China, the decreasing annual

number of rain-days coincided with an increase in annual precipitation, which implied a much more extreme flood event. In addition, landslide episodes significantly centered on southwest China and always caused serious life losses in the area [25].

Hail was the second disaster with high serious effects on its impact areas (22.97%) and the southwest region still suffered the worst of all. This stems from the geographical distribution of two big hail zones in China [27]. The southern hail zone passes through the southwest and central areas of China. As for typhoons, China's southeast coastal areas composed the storm-prone zone, influenced by tropical cyclones generated from the Western North Pacific [24]. The economically well-developed areas (e.g., Guangdong, Zhejiang, Jiangsu, Shandong, etc.) are primarily concentrated in the coastal areas on account of the economic development of coastal areas in the mainland and hence the losses caused by tropical storm disasters in these areas grow rapidly. Thus, the economic losses induced by typhoons were non-negligible, ranking the second level (18.66%). Tibet, Xinjiang and Yunnan which were seriously affected by snow disasters were identified with an analysis of spatio-temporal change of snow disaster which showed that there were three heavy snow disaster areas in China: the center of Inner Mongolia, north of Xinjiang and northeast of Qinghai-Tibet plateau [28]. Heatwaves affected provinces located in the northern and western parts of North China, the central-northern part of Northwest China, the central part of South China, the Yangtze River Delta and the southern Sichuan Basin. Nevertheless, it is worth noting that since the 1990s, the frequency, duration and intensity of heatwaves have remarkably increased, and their range of impact has also increased in size [29].

Similar to the analysis of the nationwide effects, there were generally decreasing trends in most provinces of China. However, some individual provinces showed increasing trends in different regions of China for different disasters. It can therefore be argued that the affected area of certain disasters has changed due to the change in climate patterns. That is: the affected areas of meteorological disasters, especially floods and snow disasters have increased largely during the past 60 years [25]; however, it is the integrated effect of multiple factors, like the diversity of the natural environment, unbalanced economic development, political interests, and unbalanced resources that made a difference [30]. From the above argument, it is evident that some less seriously affected areas prior to the impact of environmental change on human health should be an important component of government management strategies; on the side, much more effective management will be further achieved by identifying common targets from the viewpoint of multiple layers of policy, education, the public, propaganda, technology and research [30].

As for economic losses, eastern China suffered most but showed the lowest loss rate for GDP. This finding is consistent with other studies [31] that found that losses caused by disasters largely hinged on the level of economic development in affected populations and areas. Contrary to this statement though, the central regions of China did not suffer the largest losses but ranked higher and even highest in the level of loss rate, which implied more value and management.

In addition to these five disasters, the death toll rate of the other types of meteorological disasters which contain drought, continuous rain, smoke flog, low altitude wind shear, acid rain, forest fire, air pollution and soon on showed an increasing trend and the direct economic losses associated with them showed an average proportion. Although drought was not of focus in our study, its direct or immediate death rate was seldom compared to other natural disasters in China. However, drought in some cases was associated with catastrophic outcomes to the environmental and socio-economic conditions [32]. In addition, another matter of concern has been made on the many types of secondary disasters taking a toll on the country. Examples of such secondary disasters include forest and grassland fires, pests and diseases, sea icing, ice flood, famine, desertification, and so on [24]. What is more, there would be more types of disasters to occur or several disasters synchronizing in the same area in the future [8].

Our study has several strengths. We have covered all the major categories of meteorological disasters. Not only the national data were analyzed, but also the provincial data

were described and analyzed to better discover regional differences. Moreover, by using maps, regional distribution characteristics of losses caused by meteorological disasters could be more intuitively displayed. In order to further identify major prevention and control areas, APC was used to quantify the trend of meteorological disaster mortality in each province and estimate the increasing or decreasing of mortality to a certain extent. However, this study also has several limitations. The major limitation of this study is insufficient data acquired for analysis. First, the upward or downward trend obtained by using the trend line was the visual observational result. Therefore, the analysis of economic losses might be less precise than death. It would be more meaningful to combine the results of economic losses with the death analysis results. Second, the β of fitting weighted linear regression was used in APC calculation. However, we did not get statistically significant results of the p value from the test for the vast majority of β . So, the APCs in our study were some kind of estimations expression of the change range of the trend. Third, information on the frequency of the meteorological disasters at a nationwide and provincial level was not available hence the time trend eliminating the influence of frequency could not be analyzed. Fourth, we only had comprehensive data from 2004 to 2015 at the time when we conducted data analysis.

5. Conclusions

The time trends of mortality and economic losses induced by the meteorological disasters in China and spatial distribution of disaster mortality and losses from 2004 to 2015 were analyzed in this study. The mortality and GDP loss rate of the whole country showed a downward trend while the direct losses showed an increasing trend. The trend change severity of different disasters at a provincial level had unique spatial characteristics. Disaster frequency increased with climate change; however effective government management and rapid economic development prevented some associated losses to some extent. There are a lot of areas suffering increasing mortality and more attention should be given to these areas and integrated preventive methods from the government, publicity systems, education and scientific research institutions should be developed.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/atmos13020208/s1>, Supplementary File S1: Trend line of the death toll rates of the other types of, meteorological disasters, 2004–2015; Supplementary File S2: Trend line of Direct Economic Losses Caused by Meteorological Disasters, 2004–2015; Supplementary File S3: Trend line of loss rates of GDP caused by all the meteorological disasters, 2004–2015; Supplementary File S4: Mean Mortality Caused by Meteorological Disasters at Provincial Level, 2004–2015.

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