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Characteristics of Disaster Losses Distribution and Disaster Reduction Risk Investment in China from 2010 to 2020

Wenping Li 1,2, Yuming Wu 1,* , Xing Gao 1 and Wei Wang 1

1 State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
2 Collage of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: wuym@lreis.ac.cn

Abstract: China is one of an increasing number of countries in the world that is suffering from frequent and severe natural disasters, which cause serious loss of life. The Chinese government has set up a special financial fund for natural disaster mitigation and reduction. Therefore, based on the financial expenditure data and disaster losses data obtained from ministries of emergency management and the China Statistical Yearbook, we analyzed the spatio-temporal distribution of natural disaster losses at the economic zonal scale during 2010–2020, and then evaluated the efficiency of disaster mitigation and reduction using a DEA model. The results showed that the natural disaster losses decreased significantly in most provinces from 2010 to 2020. The distribution of precipitation is extremely uneven (more in the southeast and less in the northwest). Moreover, the Central and Western Economic Zones are the most earthquake-prone regions in China, especially Xinjiang, Tibet, Sichuan, Yunnan and Gansu. Among all natural disasters, floods were the leading natural disasters, causing the most severe losses in China on the national scale. Furthermore, the cities with higher comprehensive efficiency, mean the ratio between the effects and funding on disaster mitigation and reduction, were either economically developed or geographically large and sparsely populated. Finally, we used an exponential regression equation model to explore the relationship between financial input and direct economic losses caused by natural disasters in 2019 and 2020; we found that there is a negative correlation between the financial investment and the direct economic losses. In conclusion, it is necessary to improve the technology of natural disaster mitigation and reduction, and to adjust the scale of investment according to the actual situation of each region and the different disasters in China. This paper aims to provide relevant experience and basis for China’s comprehensive disaster mitigation and reduction work.

Keywords: natural disasters; efficiency evaluation; economic losses; disaster mitigation and reduction; China

1. Introduction

Natural disaster is one of the major problems faced by human beings [1]. In China, one of the countries with the most severe disasters in the world [2,3], 138 million people have been affected by natural disasters. In fact, 591 people died in 2020, and the direct economic losses exceeded 53.03 billion USD in 2020 according to the China Statistical Yearbook. In recent years, the scale of various natural disasters has become catastrophic, showing a trend of increasing frequency and spreading to traditional areas, which has aroused great concern in all regions of China. Thus, natural disasters have become an important factor affecting people’s lives and property safety, and hindering national economic development [4–6]. Some related domestic and foreign studies showed that global climate change will further aggravate disasters in terms of magnitude, severity, and frequency of occurrence [7–10]. Meanwhile, the Chinese economy is also developing rapidly, and the scope of human activities continues to expand. The disaster-prone areas are also becoming more complex.
and changeable as a consequence of this. Thus, the situation of comprehensive disaster mitigation and reduction in China is becoming more intense and severe [11,12].

Disaster mitigation and reduction has always been a huge challenge facing mankind [13,14]. China’s National Disaster Reduction Commission (NDRC) released the outline of the 14th Five-Year Plan for National Disaster Prevention and Mitigation on June 19 in 2022, guiding national disaster mitigation and reduction. The Chinese government paid attention to disaster emergency management gradually. After the Severe acute respiratory syndrome coronavirus (SARS) outbreak in 2003, the construction of the national emergency response system was significantly accelerated [15]. In 2009, the government of China officially invested funds for geological disaster mitigation and reduction [16,17]. In April 2018, the regional emergency management departments were successively established in administrative regions of China [18,19] in order to coordinate the construction of emergency response forces, guide the national emergency mitigation and reduction of natural disasters, and promote the improvement of the national comprehensive disaster mitigation and reduction capacity. Since then, China has officially established a special financial fund for natural disaster mitigation and reduction and emergency management to support mitigation, resistance and relief work. As the country attaches great importance to the mitigation and reduction of natural disasters, the investment in disaster mitigation and reduction is also increasing year by year, but the direct economic losses caused by disasters do not appear to be substantially decreasing. Therefore, exploring the relationships between the investment in natural disaster mitigation and reduction and the direct economic losses of disasters can provide a scientific basis for carrying out effective disaster mitigation and reduction.

At present, there are some studies focusing on the investment and effectiveness of disaster mitigation and reduction at home and abroad [20–23]. Wei S L J et al. analyzed and compared the data of geological disaster status, geological disaster mitigation and reduction investment and social-economic development in Qinghai province from 2009 to 2018 using various methods, and finally concluded that the investment in geological disaster mitigation and reduction in Qinghai province was low and did not reach the optimal relation with income on the whole [24]. Based on the data of geological disasters in 31 provinces in 2013, Han et al. used a DEA model to evaluate the effectiveness of the mitigation and reduction of geological disasters. The results showed that the mitigation and reduction investment achieved a good effect in the high incidence regions of geological disasters, such as Tibet and Sichuan; for other administrative regions, it is necessary to further improve the scale of input or the efficiency of input resources [20].

It is a key breakthrough to study the distribution patterns of disaster losses and the disaster mitigation and reduction effectiveness in order to effectively improve China’s disaster mitigation and reduction; enhance its ability to resist natural disasters effectively, and reduce the losses caused by natural disasters to the people of all countries. Therefore, our study aimed at exploring spatiotemporal characteristics and trends of natural disaster losses, analyzing the efficiency of disaster mitigation and reduction, and discussing the relationships between disaster funds and losses. For this purpose, we compiled the data of Chinese disaster losses in 2010–2020 and disaster mitigation and reduction investment. This study can determine the influencing factors on disaster mitigation and reduction and provide a certain reference to disaster mitigation and reduction in China.

2. Materials and Methods

2.1. Data Materials

The data included financial expenditure data for disaster mitigation and reduction and emergency management, disaster losses data (affected population, fatalities, affected crop area, crop failure area and direct economic losses (given in USD based on exchange rates announced by BOC (value as of 19 September 2022: 1 US$ = 6.98 RMB) (BOC 2022))) [25–28], earthquake data, socio-economic data, the SRTM DEM dataset for China and a precipitation dataset for China (Table 1).
Financial expenditure data for disaster mitigation and reduction and emergency management were collected from provincial ministries of emergency management in China. Provincial ministries of emergency management of China were established to guide natural disaster mitigation and reduction and emergency management of the corresponding provinces in March 2018. The information obtained mainly included fiscal expenditures on disaster mitigation and reduction and emergency management for each province in 2019 and 2020.

For the disaster losses data, earthquake data and socio-economic data, we acquired them from the China Statistical Yearbook [29], USGS Earthquake Hazards Program and the Global Emergency Disaster Database EM-DAT (EM-DAT) [30]. Disaster losses data included the affected population, fatalities, affected crop areas and crop failure areas caused by natural disasters, and the economic losses directly caused by natural disasters. We analyzed the disaster losses in China during the period of 2010 to 2020. Socio-economic data were the gross domestic product and year-end population of each province in China (2010–2020).

The Precipitation dataset for China was sourced from a 1 km monthly precipitation dataset for China (1901–2020) [31] provided by the National Tibetan Plateau/Third Pole Environment Data Center. The dataset was spatially downscaled from CRUTS v4.02 with WorldClim datasets based on the delta downsampling method; it was evaluated by 496 national weather stations across China, and the evaluation indicated that the down-scaled dataset is reliable for the investigations related to climate change across China. We selected precipitation data from 2010 to 2020 and processed monthly precipitation data into annual monthly average precipitation data.

The Chinese SRTM (Shuttle Radar Topography Mission) DEM were also obtained from the National Tibetan Plateau/Third Pole Environment Data Center [32]. This dataset is the fourth iteration of SRTM terrain data obtained by CIAT (International Center for Tropical Agriculture) using a new interpolation algorithm, and the spatial resolution of the data is 90 m.

Moreover, the vector data of administrative divisions for this paper were obtained from the National Geomatics Center of China.

2.2. Methods

We used several methods to explore the characteristics of the disaster losses in China from 2010 to 2020, analyze the efficiency of natural disaster mitigation and reduction, and discuss the relationships between disaster investment and losses. In this section, we will describe the principles and functions of each method.

2.2.1. Mann–Kendall Trend Test

The Mann–Kendall Trend Test was used to analyze the changes in various losses caused by natural disasters in China. The Mann–Kendall trend test can analyze the trends of order variables and type variables, and is not disturbed by a few outliers [33].
procedure of the Mann–Kendall trend test is as follows: Hypothesis $H_0$ (assuming that the data in the series have no significant trend) and $H_1$ (assuming that there is a monotonic upward or downward trend in the series) are assumed. Under $H_0$, the test statistical variable $S$ is defined, and the calculation formula is as follows:

$$S = \sum_{k=1}^n \sum_{j=k+1}^n Sgn(x_j - x_k)$$  \hspace{1cm} (1)

Where $Sgn$ is the sign function, which can be expressed as:

$$Sgn(x_j - x_k) = \begin{cases} +1 & (x_j - x_k) > 0 \\ 0 & (x_j - x_k) = 0 \\ -1 & (x_j - x_k) < 0 \end{cases}$$  \hspace{1cm} (2)

While $n \geq 10$ in the Formula (1), $S$ follows a standard normal distribution approximately. $Z$ is obtained by standardizing $S$, and a significance test is conducted by using test statistic $Z$, whose formula is as follows:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S + 1}{\sqrt{Var(S)}} & S < 0 \end{cases}$$  \hspace{1cm} (3)

$$Var(S) = \left( n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5) \right) / 18$$  \hspace{1cm} (4)

where $n$ is the number of data in the sequence, $m$ is the number of nodes (repeated data groups) in the sequence and $t_i$ is the width of nodes (the number of repeated data in $i$ groups of repeated data groups). Finally, we used the test statistic $Z$ for a significance test, under a given significance level alpha. When $|Z| \leq Z_{1-a/2}$, we accepted $H_0$, namely, the trend was not significant; otherwise, $H_1$ was accepted—that is, $Z > Z_{1-a/2}$ indicates a significant upward trend of the sequence, and $Z < Z_{1-a/2}$ indicates a significant downward trend of the sequence. In our study, the significance levels were $a = 0.05$, $Z_{1-a/2} = 1.96$.

2.2.2. Correlation Analysis

Pearson’s correlation coefficient is a measure of the degree of linear correlation [34], based on which the correlations between various variables that were measured. The formula is as follows:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}, \quad |r| \leq 1$$  \hspace{1cm} (5)

where $x_i$ and $y_i$ are the values of two variables, and $\bar{x}$ and $\bar{y}$ are the averages of two variables. When $r > 0$, $x$ and $y$ are positively correlated; when $r < 0$, $x$ and $y$ are negatively correlated; when $r$ is equal to 0, $x$ and $y$ are independent. Moreover, the closer $|r|$ is to 1, the higher the degree of $x$ and $y$’s linear correlation.

2.2.3. DEA Model

In order to evaluate the efficiency of natural disaster mitigation and reduction investment, we used the DEA model, an efficiency evaluation method which was proposed by Charnes, Cooper and Rhodes, the famous operation research experts and professors of the University of Texas, in 1978 [35]. This method improves the limitations of having a single input and single output in traditional methods, and uses a complex index system that is multi-input and multi-output to evaluate the relative efficiency of decision-making units (DMUs). In addition, the method is not limited to the unit of measurement. Based on the data we obtained, we selected disaster investment and the ratio of disaster investment to GDP as input variables; and affected population, fatalities, affected crop area, crop failure
area and direct economic losses as output variables. We took the inverse of the output variables, because the output variables were the disaster losses. The larger the value, the lower the mitigation and reduction efficiency, so we took the inverse of its value. We then chose the DEA-BC\(^2\) model with variable scale return. The model is expressed as follows:

\[
\begin{align*}
\text{s.t. } & \sum_{j=1}^{n} x_j \lambda_j \leq \theta x_0 \\
& \sum_{j=0}^{n} y_j \lambda_j \geq y_0 \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0 \quad (j = 1, 2, \ldots, n)
\end{align*}
\]

The dual model of the above model is planned as:

\[
\begin{align*}
\min & \quad \theta \\
\text{s.t. } & \sum_{j=1}^{n} x_j \lambda_j \leq \theta x_0 \\
& \sum_{j=0}^{n} y_j \lambda_j \geq y_0 \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0 \quad (j = 1, 2, \ldots, n)
\end{align*}
\]

where \(x_j\) represents the input indicators of all decision-making units (DMUs), \(x_0\) represents the input to the target DMU, \(y_j\) represents the output indicators of all decision-making units, \(y_0\) represents the output to the target DMU, \(l_j\) is the actual value of disaster losses of all decision-making units and \(k > \max \left( \frac{1}{l_j} \right)\), \(\omega\) is a non-Archimedean infinitesimal quantity, \(\mu^T\) is the weight coefficient of output \(y_j\), \(\lambda_j\) is the variable coefficient and \(\theta\) is the efficiency evaluation value—while \(\theta = 1\), it indicates that the input–output level of the DMU is optimal. Figure 1 shows how the model works:

**Figure 1.** DEA model implementation process.

### 2.2.4. Exponential Regression Model

Based on this mathematical model, we explored the relationships between financial investments in natural disaster mitigation and reduction and emergency management and direct economic losses caused by natural disasters in China in 2019 and 2020. The formula can be expressed as follows:

\[
L_n = K \times e^{-\beta \cdot I_n}
\]

where \(L_n\) refers to the direct economic losses caused by natural disasters in all provinces (and autonomous regions or municipalities directly under the Central Government) of China, \(K\) is the regression constant, \(-\beta\) is the regression coefficient, and \(I_n\) refers to comprehensive investment in disaster mitigation and reduction, represents by fiscal expenditure on natural disaster mitigation and reduction and emergency management/the corresponding regional GDP.
3. Result
3.1. Disaster Losses in China
3.1.1. Spatio-Temporal Characteristics in China

According to the differences in natural conditions, economic resources, economic development, transportation conditions and economic benefits in the different regions in China, we divided the area of China into three economic zones: the Eastern Economic Zone (including Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan), the Central Economic Zone (containing Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan) and the Western Economic Zone (including Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang). Based on the three economic zones of China, we further analyzed the spatial and temporal distribution characteristics of disaster losses caused by natural disasters in China from 2010 to 2020 based on the economic zones and provincial divisions.

During 2010–2020, China experienced huge disaster losses: a total of 2.7 billion people were affected by natural disasters, 18,880 fatalities were recorded and the direct economic losses totaled 593.95 billion USD. Meanwhile, other countries also suffered from similar situations, such as the United States (88.7 million affected, 3310 fatalities and 706.24 billion USD in losses) and Japan (3.7 million affected, 22,058 fatalities and 360.54 billion USD in losses). Figure 2 shows the average annual direct economic losses caused by natural disasters in each administrative region of China during our study period. We found that the average direct economic losses caused by natural disasters in China are very large. Since 2010, direct economic losses in most administrative regions have reached 0.29 billion USD or more annually on average, especially in the Central Economic Zone and Eastern Economic Zone. Sichuan is the province that has suffered the largest direct economic losses annually, reaching 5.41 billion USD. One reason is that Sichuan is close to the Tibetan Plateau and lies on the Mediterranean and Himalayan seismic zone between the Indian Ocean plate and the Asia–Europe plate; the other is that the main climates of Sichuan are those of plateaus and mountains and a subtropical monsoon climate. Therefore, Sichuan is prone to geological and meteorological disasters.

Figure 2. Spatial distribution of different magnitudes of earthquakes in China from 2010 to 2020. (The colored areas represent the annual averages of direct economic losses in administrative regions from 2010 to 2020).
Figure 3a shows that there were significant differences in the affected populations among the three economic zones. The Central Economic Zone had the largest affected population, at 100.58 million people on average annually, accounting for 40.74% of the total. Next came the Western Economic Zone, accounting for 32.63% of the total; but even more to the point, Sichuan had the largest affected population in the whole of China, with 21.31 million people. Overall, there are fewer people affected by natural disasters in the Eastern Economic Zone than those in Central and Western Economic Zones. The fatalities were concentrated in the southeast of the Western Economic Zone and the south of the Central Economic Zone; there were higher values in the southwest and lower values in the northeast (Figure 3b). The affected crop area was mainly distributed in the Central Economic Zone (Figure 3c). There were 10 provinces (including Hebei, Shanxi, Inner Mongolia, and etc.) with more than 1 million ha of crops affected. Among them, the maximum was in Heilongjiang, at 2.43 million ha. Regarding the crop failure area, in the Central Economic Zone, it was concentrated in the northeast of China (Figure 3d). The annual average crop failure area in Inner Mongolia reached 0.36 million ha, exceeding the 0.26 million ha in Heilongjiang.

Moreover, natural disasters are always categorized as hydrological and geological disasters. Here, we focused on seven typical disasters (drought, earthquake, extreme temperature, flood, landslide, mass movement and storms) included in the above categories, and analyzed the losses during the study period. According to our mean statistics in the last decade, major disasters in China have affected 563.57 million people, caused 15,286 deaths, and cost 291.03 billion USD in direct economic losses. Different degrees of damage to

![Spatial distributions of averages and rates of affected population, fatalities, affected crop area, crop failure area caused by natural disasters, from 2010 to 2020, in China.](image-url)
diverse disaster-bearing bodies have been caused by various natural disasters. Droughts, floods and storms were the main natural disasters causing damage to the population, accounting for 14.15, 70.21 and 12.66% of the total population affected by major disasters in China, respectively. In contrast, the total proportions of the affected population caused by earthquakes, extreme temperatures, landslides and mass movement were less than 3% (Figure 4). Fatalities were mainly induced by floods (accounting for 43.18%), followed by earthquakes (27.62%) and landslides (18%). Floods were the leading natural disasters causing direct economic losses, accounting for approximately 58.93% of the total, followed by storms and earthquakes at 27.8% and 7.23%, respectively. In short, floods were the leading natural disasters, causing the most severe losses in China.

![Figure 4. Annual average percentage losses (affected population, fatalities and direct economic losses) caused by drought, earthquake, extreme temperature, flood, landslide, mass movement and storm, as proportions of the total losses during 2010–2020.](image)

Of the above typical disasters, earthquakes always cause many secondary disasters and often happen in China. With the occurrence of catastrophic earthquake events, a variety of induced geological disasters, such as landslides, debris flow, ground cracks and land subsidence often cause serious secondary disaster losses [36,37]. Therefore, there is a high spatial overlap between regions with frequent earthquakes and regions with frequent geological disasters such as landslides. In our study, we divided the earthquakes into 4 magnitudes (including magnitudes 5.0–5.5, 5.5–6.0, 6.0–6.5 and 6.5 and above). As we can see from Figure 2, the entire Central and Western Economic Zones are the most earthquake-prone regions in China, especially Xinjiang, Tibet, Sichuan, Yunnan and Gansu. From 2020 to 2020, a total of 226 earthquakes happened in China, and among all, magnitudes 5.0–5.5 accounted for 84.51%, magnitudes 5.5–6.0 accounted for 9.74%, magnitudes 6.0–6.5 accounted for 4.42%, and magnitudes 6.5 and above accounted for 1.33%. In addition, the most earthquakes occurred in 2013 exceeded 35, following by 2010 and 2018 (both exceeded 25).

Table 2 shows the trends of disaster losses from 2010 to 2020 caused by natural disasters. If |Z| ≥ 1.96, it indicates that the change trends of natural disaster losses have significant upward or downward trends with significance levels exceeding 0.05. Given Figure 5e, we found that the natural disaster losses decreased significantly in each economic zone from 2010 to 2020. Among them, the affected population had a clear downward trend in each economic zone and the whole of China; fatalities displayed a significant downward trend except in the Eastern Economic Zone; and the affected crop area decreased significantly except in the Central Economic Zone. As for crop failure area and direct economic losses, most regions showed no obvious trend, except the crop failure area in the Western Economic...
Zone, which presented a significant downward trend. Similarly, the Central Economic Zone suffered the most serious losses, followed by the Eastern and Western Economic Zones, which both showed a trend of decreasing fluctuations without any special inflection point or regularity.

Table 2. Trends in various losses caused by natural disasters in China during 2010–2020.

| Zone                     | Affected Population (Million People) | Fatalities | Affected Crop Area (Million ha) | Crop Failure Area (Million ha) | Direct Economic Losses (Billion USD) |
|--------------------------|--------------------------------------|------------|---------------------------------|-------------------------------|-------------------------------------|
| The Whole of China       | −3.27 \( p \)                        | −2.49 \( p \) | −2.96 \( p \)                  | −1.09                         | −0.93                               |
| Eastern Economic Zone    | −3.74 \( p \)                        | −1.40 \( p \) | −3.27 \( p \)                  | −0.47                         | −0.93                               |
| Central Economic Zone    | −2.49 \( p \)                        | −2.18 \( p \) | −0.93                           | 0.77                          | 0                                   |
| Western Economic Zone    | −3.43 \( p \)                        | −2.34 \( p \) | −2.80 \( p \)                  | −3.11 \( p \)                 | −1.71                               |

Note: \( p \) denotes a significance level of 0.05.

Figure 5. Trends in (a) affected population, (b) fatalities, (c) affected crop area, (d) crop failure area, (e) direct economic losses caused by natural disasters, from 2010 to 2020, in China.

Regarding the affected population, except for Tianjin and Shanghai (Figure 3a), the provinces all presented a decreasing trend. However, there were three cutoff points during the study period. In 2010, approximately 425.18 billion people were affected by natural disasters. The main reason is that a 7.1 magnitude earthquake struck in Yushu of Qinghai province; this event caused significant losses to China, and 2220 people died. Another big
disaster was the mudslide which hit the Zhouqu County of Gansu on August 8, which killed 1434 people. Then, in 2013, due to the 7.0 magnitude earthquake in Ya’an of Sichuan, a total of 196 people were killed, 21 people went missing and 11,470 people were injured. In 2016, a huge flood happened in Beijing, Tianjin, Shanxi, Shandong and Henan because of the heavy rainfall between the 18th and the 23rd of July. That event caused 325 fatalities. It can be seen that the people affected by natural disasters in each of the three economic zones and the whole of China showed a decreasing trend. In most situations, the Central Economic Zone had the largest number of disaster-affected people in each year, followed by the Western Economic Zone, and the Eastern Economic Zone had the least number of disaster-affected people (Figure 5a). Only the fatalities in Shanxi increased over time; the fatalities in the remaining districts all decreased (Figure 3b). Most deaths were in 2010 because of the two catastrophic disasters mentioned above. The decreasing trend was greater in the Western Economic Zone than the Eastern Economic Zone and Central Economic Zone (Figure 5b). The affected crop area generally decreased, but it increased in Ningxia, Inner Mongolia, Heilongjiang, Jilin, Liaoning and Shanghai during the period 2010–2020 (Figure 3c), among which the affected crop area in Heilongjiang increased the most, by 1.7 million ha per year. Meanwhile, the affected crop areas in Shandong and Hunan decreased by 2 million ha per year, and even decreased most at more than 6 million ha per year in the Eastern Economic Zone (Figure 5c). In Yunnan, the crop failure area decreased by an amount exceeding 0.8 million ha (Figure 3d). Only the Western Economic Zone presented a fluctuating decreasing trend; there were no obvious trends in the Central Economic Zone or Eastern Economic Zone (Figure 5d). As for the direct economic losses, several provinces, including Heilongjiang, Tianjin, Ningxia, Chongqing, Hubei, Anhui, Zhejiang, Shanghai and Guangxi, all presented an increasing trend, especially the direct economic losses in Anhui exceeding 0.57 billion USD per year; the others all had decreasing trends. The direct economic losses caused by natural disasters showed a fluctuating decreasing trend; there were no obvious trends (Figure 5e).

3.1.2. Precipitation

Some previous studies have pointed out that due to natural and human factors, such as climate change and population movement, natural disaster events will continue to increase in scale and severity [8–10], especially geological disasters. The occurrence of geological disasters is determined by both internal factors and external factors, and climate change is a very important external cause [38,39]. Of all the climatic conditions, precipitation is the main cause of geological disasters [40]; it affects the stability of rock and soil masses by changing the stability of the surfaces of slopes, and some geological disasters may occur when the bearing capacity of a slope exceeds its critical value.

China is mainly affected by the southeast monsoon and southwest monsoon. The southeast region is rainy and wet, while the northwest region has scarce rain and is dry, and the spatiotemporal distribution of atmospheric precipitation is extremely uneven. We analyzed the spatial and temporal distribution characteristics of annual mean monthly precipitation and the annual economic losses directly caused by natural disasters in the whole of China and the three economic zones from 2010 to 2020 and then explored the influence of climatic conditions on disaster mitigation and reduction. From Figure 6 and Table 3 (where p-values are all lower than 0.05), we can see that there are significant regional differences in the relationship between annual mean monthly precipitation and annual direct economic losses by natural disasters. For the whole of China, the Eastern Economic Zone and the Central Economic Zone, the annual mean monthly precipitation is higher than that of the Western Economic Zone, and the trend of the annual mean monthly precipitation vs. the annual losses directly caused by natural disasters is basically consistent in most years, showing a positive correlation. However, the monthly precipitation in the Western Economic Zone is rarer, and there is a negative correlation between precipitation and economic losses directly caused by natural disasters there (correlation coefficient −0.35). Therefore, while implementing related disaster mitigation and reduction policies in each
region, it is necessary to understand the direction of local climate change, in combination with the characteristics of local climatic conditions, judge the possible impacts of climatic conditions on relevant disasters qualitatively, and then finally formulate corresponding disaster reduction measures.

Figure 6. The distributions of monthly average precipitation (red bar) and natural disaster losses (blue line) each year in the period 2010–2020.

Table 3. The correlation coefficient between monthly average precipitation and natural disaster losses in each region.

| Region                  | Whole China | Eastern Economic Zone | Central Economic Zone | Western Economic Zone |
|-------------------------|-------------|-----------------------|-----------------------|-----------------------|
| correlation coefficient | 0.38        | 0.59                  | 0.42                  | −0.35                 |
| p-value                 | 4 × 10^{-10} | 3.65 × 10^{-8}       | 2.68 × 10^{-7}        | 1.02 × 10^{-8}        |

3.1.3. Earthquake

Precipitation and earthquake are two of the major factors for triggering disasters in China [41–47]. Here, we also selected the frequency of earthquakes (including of magnitudes 5.0–5.5, 5.5–6.0, 6.0–6.5 and 6.5 and above) and direct economic losses as indicators to discuss the seismic effects on disaster mitigation and reduction in China.

Figure 7 shows the temporal distribution characteristics of earthquake frequency in China from 2010 to 2020. The total occurrence of earthquakes also existed in three cutoff points during the study period, which were 28 in 2010, 36 in 2013, and 27 in 2018 in the whole of China. Table 4 (where p-values are all lower than 0.05) shows the correlation coefficient between earthquake occurrence and natural disaster losses in each region. In the whole of China, there is a positive correlation between the losses of natural disasters and earthquakes of magnitudes 5.0–5.5, 5.5–6.0, and 6.5 and above. For the Central Economic Zone, there is even a negative correlation between magnitude 5.0–5.5 and disaster losses, and a positive correlation between magnitude 5.5–6.0 and disaster losses. In addition, there is almost no correlation between natural disasters and earthquakes of magnitudes 6.0–6.5 and 6.5 and above in the Central Economic Zone. As for the Western Economic Zone, there is a relative strong positive correlation between the occurrence of earthquakes of magnitude 6.5 and above and the losses of natural disasters. We think the regional difference in seismic effects on natural disasters is that the Western Economic Zone is the most earthquake-prone region.
addition, there is almost no correlation between natural disasters and earthquakes of magnitudes 6.0–6.5 and 6.5 and above in the Central Economic Zone. As for the Western Economic Zone, there is a relative strong positive correlation between the occurrence of earthquakes of magnitude 6.5 and above and the losses of natural disasters. We think the regional difference in seismic effects on natural disasters is that the Western Economic Zone is the most earthquake-prone region.

Figure 7. The distributions of earthquake frequency (bar chart) and natural disasters losses (blue line) each year in the period 2010–2020.

Table 4. The correlation coefficient between earthquake occurrence and natural disasters losses in each region.

| Magnitude | Whole China | Central Economic Zone | Western Economic Zone |
|-----------|-------------|-----------------------|-----------------------|
| 5.0–5.5   | 0.55        | –0.22                 | 0.77                  |
| 5.5–6.0   | 0.48        | 0.60                  | 0.38                  |
| 6.0–6.5   | –0.23       | –                     | –0.13                 |
| >6.5      | 0.62        | –                     | 0.83                  |

| p-value   | 5.0–5.5     | 7.35 × 10^{-10}       | 4.37 × 10^{-7}        | 8.53 × 10^{-7}     |
|           | 5.5–6.0     | 7.21 × 10^{-10}       | 3.59 × 10^{-7}        | 7.95 × 10^{-8}     |
|           | 6.0–6.5     | 4.68 × 10^{-10}       | 1.47 × 10^{-7}        | 4.58 × 10^{-8}     |
|           | >6.5        | 3.71 × 10^{-10}       | 1.47 × 10^{-7}        | 1.6 × 10^{-6}      |

3.2. Disaster Reduction Risk Investment in China

We evaluated the efficiency of natural disaster mitigation and reduction investment using the DEA model. In this study, we selected disaster investment and the ratio of disaster investment to GDP as input variables, and affected population, fatalities, affected crop area, crop failure area and direct economic losses as output variables. Then, we implemented the DEA model in Python to evaluate the efficiency of natural disaster mitigation and reduction in China in 2019 and 2020.

As listed in Table 5, Tianjin, Shanghai, Hainan and Tibet are decision-making units (DMUs) with a comprehensive efficiency value of 1 in 2019, which indicates that the effect of natural disaster mitigation and reduction has reached the maximum under the current investment amount. Meanwhile, the scaled returns of these provinces remained unchanged, which means that output has reached the maximum level under the same input intensity; that is, the optimal ratio has been reached between the input to natural disaster mitigation and reduction and the effect. If the input continues to increase, the control effect can only increase in the same proportion, and the output cannot increase more. It is worth mentioning that all provinces’ scaled returns increased, which means it is necessary to increase the input of disaster mitigation and reduction so that the increase in the mitigation and reduction effect is greater than the input, and then the optimal
ratio between input and output can be reached. On the contrary, except for Beijing, Jilin, Heilongjiang, Jiangsu, Ningxia and Xinjiang, the comprehensive efficiency values of the provinces are less than 0.2, showing a poor input-output structure. Most of these provinces (including Hunan, Yunnan, Shanxi, Guangxi, Guizhou, Sichuan, etc.) are disaster-prone (especially Yunnan and Sichuan with frequent earthquakes we mentioned above), and their GDPs are relatively low. We found that the cities with higher comprehensive efficiency were either economically developed or geographically large and sparsely populated. The technical effectiveness of the 14 provinces were more than 0.5, which indicates that the use efficiency of the input resources is relatively large. As for the other provinces, there may be excess input or insufficient output. There were only six provinces with scaled effectiveness values more than 0.5; overall, the scaled effectiveness is relatively low, and the scale of disaster mitigation and reduction should be further increased. Generally, the mean values of comprehensive efficiency, technical effectiveness and scaled effectiveness of disaster mitigation and reduction investment in China were 0.247, 0.583 and 0.318, respectively, indicating that the existing mitigation and reduction technology and mitigation and reduction investment in China did not reach optimal levels in 2019, and the overall effect of natural disaster mitigation and reduction has some room for improvement.

Table 5. DEA efficiency values of natural disaster mitigation and reduction in China in 2019.

| DMUs        | Comprehensive Efficiency Value ($\theta^*$) | Technical Effectiveness ($\delta^*$) | Scaled Effectiveness ($S^*$) | Scaled Return |
|-------------|--------------------------------------------|-------------------------------------|-----------------------------|---------------|
| Beijing     | 0.358                                      | 0.358                               | 1                           | -             |
| Tianjin     | 1                                          | 1                                   | 1                           | -             |
| Hebei       | 0.09                                       | 0.274                               | 0.329                       | irs           |
| Shanxi      | 0.013                                      | 0.420                               | 0.03                        | irs           |
| Inner Mongolia | 0.037                                     | 0.265                               | 0.139                       | irs           |
| Liaoning    | 0.101                                      | 0.550                               | 0.183                       | irs           |
| Jilin       | 0.212                                      | 0.467                               | 0.454                       | irs           |
| Heilongjiang| 0.244                                      | 0.538                               | 0.453                       | irs           |
| Shanghai    | 1                                          | 1                                   | 1                           | -             |
| Jiangsu     | 0.256                                      | 0.999                               | 0.256                       | irs           |
| Zhejiang    | 0.026                                      | 0.808                               | 0.033                       | irs           |
| Anhui       | 0.034                                      | 0.455                               | 0.074                       | irs           |
| Fujian      | 0.188                                      | 1                                   | 0.188                       | irs           |
| Jiangxi     | 0.009                                      | 0.473                               | 0.02                        | irs           |
| Shandong    | 0.026                                      | 0.448                               | 0.059                       | irs           |
| Henan       | 0.11                                       | 0.556                               | 0.197                       | irs           |
| Hubei       | 0.009                                      | 0.203                               | 0.046                       | irs           |
| Hunan       | 0.011                                      | 0.294                               | 0.038                       | irs           |
| Guangdong   | 0.156                                      | 0.616                               | 0.254                       | irs           |
| Guangxi     | 0.013                                      | 0.301                               | 0.044                       | irs           |
| Hainan      | 1                                          | 1                                   | 1                           | -             |
| Chongqing   | 0.039                                      | 0.305                               | 0.128                       | irs           |
| Sichuan     | 0.018                                      | 0.422                               | 0.042                       | irs           |
| Guizhou     | 0.018                                      | 0.344                               | 0.051                       | irs           |
| Yunnan      | 0.011                                      | 0.455                               | 0.025                       | irs           |
| Tibet       | 1                                          | 1                                   | 1                           | -             |
| Shaanxi     | 0.019                                      | 0.407                               | 0.048                       | irs           |
| Gansu       | 0.042                                      | 0.348                               | 0.12                        | irs           |
| Qinghai     | 0.137                                      | 0.791                               | 0.173                       | irs           |
| Ningxia     | 0.49                                       | 1                                   | 0.49                        | irs           |
| Xinjiang    | 0.976                                      | 0.976                               | 1                           | -             |
Compared with 2019, the mean values of comprehensive efficiency, technical effectiveness and scaled effectiveness of disaster mitigation and reduction investment in China all decreased in 2020 (Table 6); they were 0.141, 0.507 and 0.185, respectively. The overall level of natural disaster mitigation and reduction actually fell. Among all, the effect of natural disaster mitigation and reduction in Shanghai and Tibet was great; the scaled returns of these provinces remain unchanged. Except for Beijing, the others should increase their input to disaster mitigation and reduction.

### Table 6. DEA efficiency values of natural disaster mitigation and reduction in China in 2020.

| DMUs       | Comprehensive Efficiency Value (θ*) | Technical Effectiveness (δ*) | Scaled Effectiveness (S*) | Scaled Return |
|------------|------------------------------------|-------------------------------|---------------------------|---------------|
| Beijing    | 0.565                              | 1                             | 0.565                     | drs           |
| Tianjin    | 0.216                              | 0.428                         | 0.504                     | irs           |
| Hebei      | 0.014                              | 0.319                         | 0.045                     | irs           |
| Shanxi     | 0.009                              | 0.468                         | 0.019                     | irs           |
| Inner Mongolia | 0.004                      | 0.243                         | 0.016                     | irs           |
| Liaoning   | 0.016                              | 0.868                         | 0.018                     | irs           |
| Jilin      | 0.004                              | 0.169                         | 0.022                     | irs           |
| Heilongjiang | 0.006                     | 0.49                          | 0.012                     | irs           |
| Shanghai   | 1                                  | 1                             | 1                         | -             |
| Jiangsu    | 0.076                              | 0.738                         | 0.103                     | irs           |
| Zhejiang   | 0.054                              | 0.522                         | 0.103                     | irs           |
| Anhui      | 0.004                              | 0.457                         | 0.008                     | irs           |
| Fujian     | 0.301                              | 1                             | 0.301                     | irs           |
| Jiangxi    | 0.004                              | 0.389                         | 0.011                     | irs           |
| Shandong   | 0.008                              | 0.233                         | 0.033                     | irs           |
| Henan      | 0.026                              | 0.468                         | 0.056                     | irs           |
| Hubei      | 0.002                              | 0.235                         | 0.007                     | irs           |
| Hunan      | 0.002                              | 0.16                          | 0.014                     | irs           |
| Guangdong  | 0.043                              | 0.313                         | 0.138                     | irs           |
| Guangxi    | 0.01                               | 0.203                         | 0.05                      | irs           |
| Hainan     | 0.49                               | 0.814                         | 0.602                     | irs           |
| Chongqing  | 0.017                              | 0.264                         | 0.065                     | irs           |
| Sichuan    | 0.006                              | 0.304                         | 0.018                     | irs           |
| Guizhou    | 0.016                              | 0.366                         | 0.044                     | irs           |
| Yunnan     | 0.008                              | 0.62                          | 0.013                     | irs           |
| Tibet      | 1                                  | 1                             | 1                         | -             |
| Shaanxi    | 0.007                              | 0.578                         | 0.02                      | irs           |
| Gansu      | 0.006                              | 0.195                         | 0.03                      | irs           |
| Qinghai    | 0.35                               | 0.461                         | 0.759                     | irs           |
| Ningxia    | 0.092                              | 0.859                         | 0.107                     | irs           |
| Xinjiang   | 0.028                              | 0.758                         | 0.037                     | irs           |

### 4. Discussion

In this section, we discussed the relationships between investment in disaster reduction and disaster losses in order to further explore the effect of disaster reduction input, and then focused on the impacts of different types of disasters, regional economy and other factors on national disaster mitigation and reduction efforts.

#### 4.1. Relationships between Financial Investment and Direct Economic Losses

We used the exponential regression equation model to explore the nonlinear relationships between financial investment in natural disaster mitigation and reduction and emergency management and direct economic losses in China. We selected the ratio of finan-
cial investment in natural disaster mitigation and reduction and emergency management to GDP as a variable to explore the nonlinear relationship between investment in natural disaster mitigation and reduction and direct economic losses. Since the data of financial investment in natural disaster mitigation and reduction and emergency management were only available for after March 2018, we only analyzed the relationships between financial investment in natural disaster mitigation and reduction and emergency management and direct economic losses in 2019 and 2020 in China.

In Figure 8, the direct economic losses are shown on a logarithm scale. It can be seen in the figure that the direct economic losses caused by natural disasters gradually decreased with the increase in the proportion of investment in disaster mitigation and reduction, which indicates that the efficiency of disaster mitigation and reduction is relatively good in economically developed cities. In fact, this is also closely related to the locations of developed cities, where disasters are generally less frequent. From the perspective of the three economic zones, whether in 2019 or 2020, the absolute slope of the regression trend line in the Eastern Economic Zone region is greater than that in the Central and Western Economic Zones; the Eastern Economic Zone had the most obvious increase in disaster reduction investment, followed by the Western Economic Zone, and the Central Economic Zone had the least increase in disaster reduction investment. The national investment in disaster mitigation and reduction in 2020 is slightly higher than that in 2019. The Eastern and Central Economic Zones invested slightly more in disaster reduction than the Western Economic Zone in actual funds; and the Eastern and Western Economic Zones invested slightly more in disaster reduction than the Central Economic Zone proportionally, especially the Western Economic Zone.

![Figure 8](image-url)

**Figure 8.** Relationships between direct economic losses from natural disasters and disaster funds in 2019 and 2020. (a) Relationships between direct economic losses from natural disasters and disaster funds obtained in 2019 (Eastern Economic Zone: $R^2 = 0.1833$, Central Economic Zone: $R^2 = 0.0465$, Western Economic Zone: $R^2 = 0.4783$); (b) Relationships between direct economic losses from natural disasters and disaster funds obtained in 2020 (Eastern Economic Zone: $R^2 = 0.0524$, Central Economic Zone: $R^2 = 0.1834$, Western Economic Zone: $R^2 = 0.2099$).

For all natural disasters, whether in 2019 or 2020, the Eastern Economic Zone had the most obvious increase in disaster reduction investment, and there is a negative correlation between the financial investment and the direct economic losses; that is, the efficiency of disaster mitigation and reduction is relatively better in economically developed cities (most cities in Eastern Economic Zone). However, a reasonable proportion should also be set according to the actual situation of each region.

### 4.2. Reason for Investment Efficiency

The efficiency of disaster mitigation and reduction does not just depend on the amount or proportion of investment, which is the result of various factors such as disaster types, regional economic conditions, etc. Here, we discussed the effects of disaster types, regional economic conditions and other factors on disaster mitigation and reduction investment efficiency.
4.2.1. Different Types of Disasters

In fact, the disaster reduction measures on different types of disasters are also different, and different funds are required based on different disaster reduction strategies, so the efficiency of disaster reductions are certainly different. For the earthquake, which is a sudden strong geological disaster with huge destruction, people cannot react immediately and escape; in addition, the earthquake will cause a series of secondary disasters, such as floods, landslides, and debris flow. The occurrence of the series of disasters may bring large losses and lower the efficiency of disaster reduction (such as with Yunnan and Sichuan). For the rainfall disasters, which belong to a continuous and seasonal hydrological disaster with long duration, people may have a certain amount of time to take shelter, but the damage to transportation, communications, and building facilities are hard to predict, and the normal operation to the city will be affected; it may also induce collapse, landslide, debris flow and other geological and hydrological disasters. The efficiency of disaster reduction is also poor in regions accompanied by rainfall disasters (such as Shanxi, Anhui, Hunan, Guangxi and etc.). Therefore, it is necessary to improve the technology of natural disaster reduction and adjust the scale of investment depending on different disasters in China.

4.2.2. Economy

With the rapid development of the social economy, China’s ability to respond to natural disasters has improved remarkably. Meanwhile, natural disasters are increasing in severity due to the expanding of the population day by day. Disaster mitigation and reduction is related to people’s lives, property safety and socio-economic development. Therefore, the relationships between economic development and natural disasters has attracted the attention of relevant scholars and the whole of society [48–56].

For this section, we selected per capita GDP and direct economic losses as indicators to discuss the impact of regional economies on disaster mitigation and reduction in China. As we can see in Figure 9, the Chinese economy has developed rapidly in the last 10 years, especially the Eastern Economic Zone. The Western Economic Zone has developed relatively slowly. In addition, the direct economic losses caused by natural disasters also show a fluctuating but decreasing trend, and the direct economic losses caused by natural disasters have a significant negative correlation with GDP per capita. It is worth mentioning that we found that disasters actually hinder economic growth, which is also consistent with the conclusions of related research results [57,58]. According to Figure 9, the annual direct economic losses caused by disasters in the Eastern Economic Zone were generally the least; on the contrary, its GDP per capita and GDP per capita growth rate were the highest. However, the Western Economic Zone had the largest direct economic losses caused by disasters every year; its GDP per capita was lower than the whole of China’s level, and its growth rate was the slowest.

Figure 9. The distributions of natural disaster losses (blue line) and GDP per capita (red line) in each region during the period 2010–2020.
Therefore, we believe that economic development is helpful in improving regional disaster mitigation and reduction ability, but the occurrence of disasters also hinders economic development. Therefore, in order to achieve optimal efficiency in disaster mitigation and reduction, we should balance the relationship between the above two, maximizing the benefits as much as possible and reducing disaster losses.

4.2.3. Other Aspects

In addition to the disaster types and regional economies, there are also regional disaster mitigation and reduction knowledge propaganda [59], ethnic culture, geological and hydrological conditions, residents’ education level, etc., all jointly regulating the effectiveness of regional disaster mitigation and reduction. Japan is one of the highest-ranking countries in the world in terms of disaster mitigation and reduction. One of the main reasons is that Japan attaches special importance to disaster mitigation and reduction awareness [60], which makes the awareness of disaster mitigation and reduction deeply rooted in people’s hearts and enables them to calmly and quickly enter a prepared state of disaster response when disasters occur.

In brief, China’s disaster mitigation and reduction capacity is controlled by a variety of factors, so we should weigh various factors to improve the comprehensive disaster mitigation and reduction capacity and reduce the losses caused by disasters. Therefore, in order to improve the effectiveness of China’s disaster mitigation and reduction work in the future, the government should set a reasonable proportion of its investments for disaster mitigation and reduction according to the actual situation of each administrative region and type of disasters. In addition, it is also of great significance to improve the economy and do a good job in the publicizing and education of emergency knowledge in response to disasters. The country’s government and people should do the best they can to mitigate the losses of life and property caused by disasters. In addition, the establishment of the Ministry of Emergency Management of China and the allocation of special funds for disaster mitigation and reduction have played important and positive roles in controlling losses from natural disasters. In order to consolidate and further improve the results of national comprehensive disaster mitigation and reduction, we propose the following recommendations: (1) continue to implement the allocation of special funds for disaster mitigation and reduction; (2) a reasonable amount of special funds should be decided on according to the geographical, climatic and economic conditions of each administrative region; (3) the government also needs to further improve the disaster reduction system in China. We should take into account various factors and further improve the effectiveness of the country’s comprehensive disaster mitigation and reduction work so as to ensure the safety of people’s lives and property.

5. Conclusions

In order to explore the influence of disaster mitigation and reduction investment on natural disaster mitigation and reduction, this study analyzed the disaster losses caused by natural disasters in China from 2010 to 2020. We then evaluated the efficiency of natural disaster mitigation and reduction investment in 2019 and 2020 because of the limited data. Finally, we explored the relationships between financial investment in natural disaster mitigation and reduction and direct economic losses in 2019 and 2020. The conclusions are listed in the following:

1. The natural disaster losses decreased significantly in most provinces from 2010 to 2020, except for the affected people in Tianjin and Shanghai; these included fatalities in Shanxi; affected crop areas in Ningxia, Inner Mongolia, Heilongjiang, Jilin, Liaoning and Shanghai; crop failure areas in Heilongjiang, Liaoning, Tianjin, Shanxi, Henan, Anhui, Jiangsu and Shaanxi; and direct economic losses in Heilongjiang, Tianjin, Ningxia, Chongqing, Hubei, Anhui, Zhejiang, Shanghai and Guangxi. Among all natural disasters, floods were the leading natural disasters, causing the most severe losses in China
on a national scale. Moreover, the Central and Western Economic Zones are the most earthquake-prone regions in China, especially Xinjiang, Tibet, Sichuan, Yunnan and Gansu.

(2) The cities with higher comprehensive efficiencies mean that the ratio between the effects and funding on disaster mitigation and reduction were either economically developed or geographically large and sparsely populated. Most of the provinces (especially Hunan, Yunnan, Shanxi, Guangxi, Guizhou, Sichuan and Chongqing) are disaster-prone areas, and their GDPs are relatively low, so their input is relatively low. It is necessary to improve the technology of natural disaster mitigation and reduction and adjust the scale of investment in China.

(3) For all natural disasters, there is a negative correlation between the financial investment and the direct economic losses, but a reasonable proportion should be allocated according to the actual situation of the region. In fact, the locations of developed cities are often where disasters are generally less frequent, so the efficiency of disaster mitigation and reduction is relatively good in economically developed cities. In conclusion, the financial investment for disaster mitigation and reduction should be reasonably arranged according to the actual situation of each region and different types of disasters so as to achieve the optimal efficiency of disaster mitigation and reduction. In addition, disaster mitigation and reduction need to consider many social factors, such as the economy, publicity, education, and national culture.

Author Contributions: Conceptualization, methodology, data processing, experiment and analysis, writing, W.L.; conceptualization and review, Y.W.; conceptualization and funding acquisition, X.G.; review, W.W. All authors contributed to the editing and reviewing of this manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Strategic Priority Research Program (Class A) of the Chinese Academy of Sciences, grant number XDA23090503; Youth Science Funds of LREIS, CAS, grant number O88RAA0EYA.

Data Availability Statement: Not applicable.

Acknowledgments: The authors wish to thank academic editor and the anonymous reviewers for the revision process, and all the authors contributed to this article.

Conflicts of Interest: The authors declare that they have no conflict of interest.

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