Preliminary prediction of economic loss of crops due to flood disaster in Northeast China and disaster mitigation measures

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Abstract: To study the economic losses of crops and related disaster mitigation measures affected by floods in Northeast China, we used the data of the affected area of crops, the area of crops, and the total agricultural output value of as many as 35 flood events from 2004 to 2019. With the total probability formula, Bayesian basic formula, and the flood return period, the data's probability density function is obtained to analyze the crop disaster risk and economic loss estimation of three provinces in Northeast China. At the same time, by combining the above content with the distribution characteristics of crops in Northeast China and the spatial distribution of flood disaster events, disaster mitigation measures are proposed. With Bayesian and total probability formulas, it is easy to find that the probabilities of crop damage under each level of flood in each province are 0.0041, 0.0272, 0.0555, and 0.0952, respectively. The economic loss can be obtained by using the data of the gross annual value of agricultural output. The probability of failure of crops in Northeast China is 0.0197422. It can be predicted that the economic loss of crops in the three northeastern provinces in 2023 will be 16.57468 billion yuan.

1. Introduction

Northeast China is a geographical region of China. It usually corresponds to the three provinces east of Daxinganling, namely Liaoning, Heilongjiang, and Jilin. The region's center is China's largest plain - Northeast China Plain, covering more than 350000 square kilometers. It is separated from Amur River, Argonne River, and Ussuri River; from South Korea to Yalu River and Tumen River; from Inner Mongolia to the west, it passes through Daxinganling and some areas of Xiliaohe River. The main crops of these provinces are rice, corn, soybeans, potatoes, sugar beets, sorghum, and temperate fruits and vegetables [1]. Crops are mainly planted in the vast plain areas of Heilongjiang, Jilin, and Liaoning provinces. They are produced in the highly fertile black land, which has absorbed enough nitrogen, phosphorus, potassium, and other mineral elements. There are sufficient sunshine, rain and dew, and clean and pollution-free irrigation water.

Northeast China is the primary grain-producing area in China, so we must pay attention to the food security in Northeast China. Flood disaster is one of the most harmful disasters to human beings worldwide, which often occurs on the densely populated riverside and in the plains with large agricultural reclamation areas. It has caused significant damage to human life and agricultural production. According to the international disasters database [2], a bar chart shows the total estimated damages from flood disasters during the past two decades. Among them, China suffered the most severe loss from flood disasters. At the same time, due to its unique geographical position and climatic conditions, northeast China has become one of the most severely affected areas in China by flood disasters. From the southeast to the northwest, the annual precipitation in the Northeast decreases from 1000 mm to less than 300mm, and transitions from the humid area, semi-humid area to semi-arid area.

Northeast China has high forest coverage, which can prolong the melting time of ice and snow, and forest snow storage is conducive to the development of agriculture and forestry. Due to the climate, landform, and other factors in Northeast China, it is often attacked by floods. Severe flooding is caused by atmospheric conditions that lead to heavy rain or the rapid melting of snow and ice. Geography can also make an area more likely to flood. For example, areas near rivers and cities are often at risk for flash floods. These factors contributed to more than 80 floods in Northeast China in 18 years, from 2001 to 2018. Floods usually occur from June to August, with the affected crop area ranging from less than 10,000 hectares to 600,000 hectares. The affected population can even reach 2.4 million, and the direct economic losses can reach 4.1 billion.

Such huge economic losses have attracted our attention. Although there have been studies on flood disasters in many other areas in China, few people pay attention to the flood disasters in Northeast China. Research about "flood disaster" began to appear in 1952 and reached the hottest in 1998. So far, there are 9538 relevant papers. The commonly used flood disaster analysis model in China is the quantitative evaluation model of economic loss of flood disaster. The model considers many influencing factors such as urban-rural difference, inundation object type, water depth, inundation duration, and early warning time, and can be used for loss estimation before and during flood disasters [3]. A new simple approach for modeling urban flooding in the urban environment is coupling SWMM and LISFLOOD-FP, two widely used freeware with relatively simple components. The coupled model was first applied to the Shiqiao Creek District in Dongguan City, South China, verified against four major historical floods. The testing results demonstrate the capability of the coupled model in predicting urban flooding [4]. Other flood disaster research models have been proposed abroad. In steep river basins and catchments, the potential flood inundation range can be estimated using a flood inundation model, which may vary in the level of physical and numerical modeling complexity involved in the solution process [5]. And flood risk management and vulnerability assessment of buildings in rainstorm flood - a three-dimensional numerical model of flood and its interaction with buildings. This study helps develop a physical-based comprehensive vulnerability assessment framework [6]. Our research is based on the results of these flood disaster research models, and the evaluation method of flood disaster is improved and simplified.

In order to analyze the economic loss of floods better, this paper studied the Disasters Memorabilia from 2001 to 2003 in China and China Meteorological Disasters Yearbook [7, 8], combined with the agricultural output value, agricultural reclamation area released by the National Bureau of Statistics. The flood return period adopted by the hydrological information forecast specification [9], using the Bayesian formula, complete probability formula, is concluded that the flood classification and the probability of occurrence. The probability that floods will occur is often expressed as a return period. For example, the return period of a flood might be 100 years; otherwise described as its probability of occurring being 1/100, or 1% in any one year [10]. We focused on 35 representative floods in Northeast China in the recent 20 years, aiming to better meet the needs of flood monitoring and provide a scientific basis and suggestions for crop disaster reduction. This paper introduces the original flood classification method, combining flood hazard severity with the return period.

2. Materials and methods

2.1 Research steps

To accomplish this study and observe sample data in detail, five steps are required in this study. First, collect crop-related data. Second, make a histogram and determine the type of distribution. Third, choose the parameters of the function. Fourth, show the descriptive statistics for later utilization. Fifth, analyze floods in combination with the Bayesian rule.

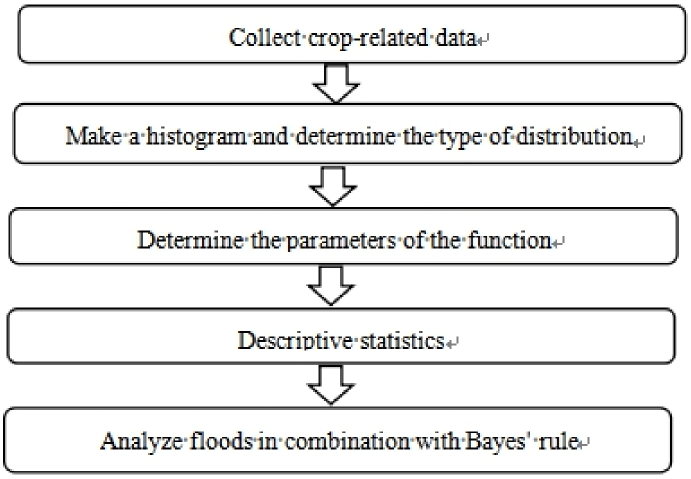

Figure 1. Research procedures.

2.2 Source of data

2.2.1 Data on affected crops from Disaster Chronicles in China

Part of the raw data on the area of crops affected by floods used in this paper is disaster data provided by Disaster Chronicles in China from 2001 to 2006. There are six floods related data from this book. This includes a relatively severe flood that occurred in Jilin province in 2003. The flood caused by the heavy rainfall engendered a total of 2.438 million people to be affected, and the affected area of crops reached approximately 590,000 hectares.

2.2.2 Data on affected crops from China Meteorological Disaster Yearbook

Most of the raw data on the area of crops affected by floods used in this paper comes from the fourth chapter called Overview of meteorological disasters by the province in China Meteorological Disaster Yearbook from 2004 to 2019. There are 29 floods related data from these yearbooks.

2.2.3 Data from China National Bureau of Statistics

Raw data on total crop area and the gross annual value of agricultural output in Heilongjiang, Jilin, and Liaoning provinces can be found in the China National Bureau of Statistics database. These data are used to calculate the expected economic loss in a province. The pivotal formula is listed as follow:

$$\text{Expected loss} = \text{Gross annual value of agricultural output} \times P(F_i) \tag{1}$$

In the formula, P(Fi) is the probability of failure of crops in one of the three provinces in Northeast China (Heilongjiang, Jilin, or Liaoning province) if the impending flood occurs.

2.3 Descriptive statistics for 35 groups of floods events in Northeast China

After gleaning the required data from books, websites, and yearbooks and plotting the area data of the affected crops into a histogram, we can distinguish the type of distribution for this data set. The data of 'affected area of crops' of 35 groups of flood events in Northeast China does not conform to the normal distribution but is exponential. The Probability density function (PDF) of the exponential distribution is shown below:

$$f(x) = \begin{cases} \lambda e^{-\lambda x} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{2}$$

The parameter lambda can be worked out by utilizing the maximum likelihood estimation. The simple derivation steps are shown as follows:

$$L(\lambda) \propto \prod_{i=1}^{n} \lambda e^{-\lambda x} \propto \lambda^{n} e^{-\lambda \sum_{i=1}^{n} x_i} \tag{3}$$

2.4 Methods

As for how to define the flood level, we introduced the flood return period. Briefly, the flood return period is an indicator used to measure the probability of floods will occur. For example, the return period of a flood might be 100 years; otherwise expressed as its probability of occurrence being 1/100, or 1% in any one year. This does not mean that if a flood with such a return period occurs, then the next will occur in about one hundred years -- instead, it means that, in any given year, there is a 1% chance that it will happen, regardless of when the last similar event was. In China, floods are divided into four levels according to their return periods: less than 5 years, 5-20 years, 20-50 years, and over 50 years. We classified the floods into different levels according to the return period and the area affected. The details will be presented in the next part.

At the same time, we also use the total probability formula and Bayes' formula. It is mainly used to calculate and process the data of different provinces and different years.

Total probability formula:

$$P(B) = \sum_{i=1}^{n} P(A_i) \cdot P(B|A_i) \tag{4}$$

$$\text{Bayes' rule: } P(A|B) = \frac{P(B|A)P(A)}{P(B)} \tag{5}$$

3. Results and discussion

3.1 Flood probability of crops in Northeast China combined with Bayesian method

Under the flood disaster, combined with the return period, Bayesian formula, total probability formula, and the descriptive statistics of 35 flood events, the disaster probability of crops in Northeast China is calculated. The frequency histogram for the area of affected crops is shown below:

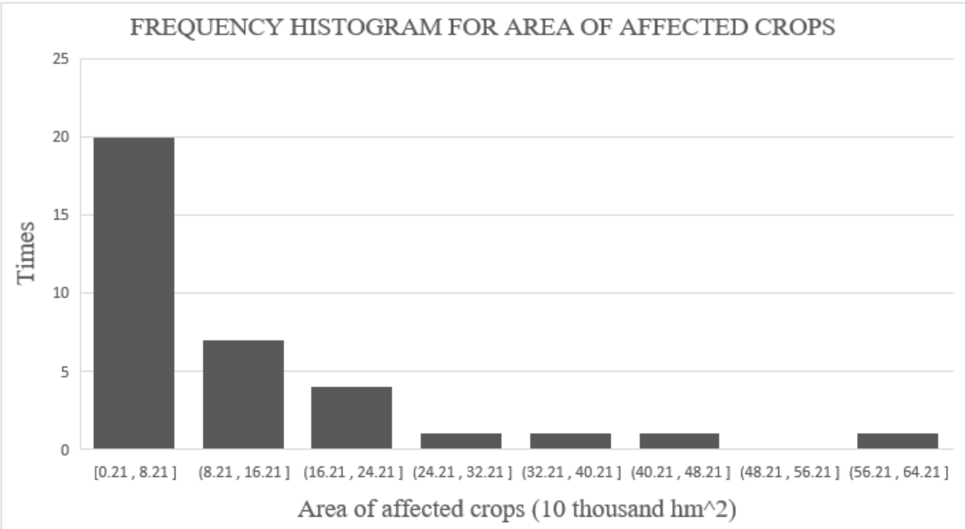

Figure 2. Frequency histogram for the area of affected crops.

The horizontal axis shows the area of affected crops, while the vertical axis shows the number of occurrences in each section. We can obtain statistical data such as the probability density function to obtain the disaster probability of crops in Northeast China combined with the concept of the return period.

Through the definition of the return period, we determine a unique method of flood classification. It is the crop hazard severity ranking method combined with the return period. According to the classification standard of the return period (T) described by the Standardization Administration of China in the "Standard for Hydrological Information and Hydrological forecasting" (GB/T22482-2008) [9].

A flood with a return period of fewer than 5 years is a small flood (S), between 5 to 20 years is a moderate flood (M), between 20 to 50 years is an enormous flood (B), and greater than 50 years is a catastrophic flood (C). Then we assume events S, M, B, and C are mutually exclusive and collectively exhaustive, namely (P(S)+P(M)+P(B)+P(C)=1). Therefore, the probability of different floods can be calculated according to the definition of the return period.

$$P(S) = \frac{1}{T_S} \tag{6}$$

$$P(M) = \frac{1}{T_M} \tag{7}$$

$$P(B) = \frac{1}{T_B} \tag{8}$$

$$P(C) = \frac{1}{T_C} \tag{9}$$

P is the probability in the formula, and T is the return period in each flood level. In our case, the probability of flooding is 1, so the probability of each level is 0.609, 0.243, 0.087, and 0.061, respectively.

$$P(S) = \frac{P(S)}{P(S)+P(M)+P(B)+P(C)} \tag{10}$$

Using the basic rules of total probability and Bayesian formula, it is not hard to determine the hazard of crops failure in a certain province under a certain intensity of flood disaster (small, moderate, big, catastrophic floods).

The statistical descriptions for our data set of 'affected area of crops' of 35 groups of flood events in Northeast China are shown as follows:

Probability density function:

$$f(x) = \begin{cases} 0.0854e^{-0.0854x} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{11}$$

Cumulative density function:

$$F(x) = \begin{cases} 1 - e^{-0.0854x} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{12}$$

The probability density function and cumulative density function these two formulas are the basis for obtaining other statistical data. From these two functions, one could work out the mean, mode, standard deviation, coefficient of variation, zeroth to the fourth moment of the probability density function with ease.

In our case, the probability of flooding is 1, so the probability of each level is 0.609, 0.243, 0.087, and 0.061, respectively. Take Heilongjiang province as our region of interest, the probability of failure of crops in Heilongjiang Province if the impending flood occurs is:

$$P(F_{Heilongjiang}) = P(F_{Heilongjiang}|S)P(S) + P(F_{Heilongjiang}|M)P(M) + P(F_{Heilongjiang}|B)P(B) + P(F_{Heilongjiang}|C)P(C) \tag{13}$$

In addition, if it is necessary to know the probability that an upcoming flood in Jilin Province is a catastrophic flood, the calculation shall be as follows:

$$P(C|F_{Jilin}) = \frac{P(F_{Jilin}|C)P(C)}{P(F_{Jilin})} = \frac{P(F_{Jilin}|C)P(C)}{P(F_{Jilin}|S)P(S) + P(F_{Jilin}|M)P(M) + P(F_{Jilin}|B)P(B) + P(F_{Jilin}|C)P(C)} \tag{14}$$

P(F|S), P(F|M), P(F|B), P(F|C) can be determined with ease by calculating the arithmetic mean of flood events of each magnitude. They are equal to 0.0041, 0.0272, 0.0555, and 0.0952 respectively.

3.2 Impact of typical events on geomorphic characteristics of crops and economic loss evaluation

a) Spatial distribution characteristics of crops were affected by floods in the three northeastern provinces. Looking closely at the data of 'affected area of crops' of 35 groups of flood events in northeast China, 16 of the flood events happened in Heilongjiang, 11 of them happened in Jilin, and 8 of them happened in Liaoning. In addition, surprisingly, the only two catastrophic floods both occurred in Jilin Province. More crop-related flood disaster reduction measures can be taken by combining the crop distribution map and the spatial distribution law of flood frequency.

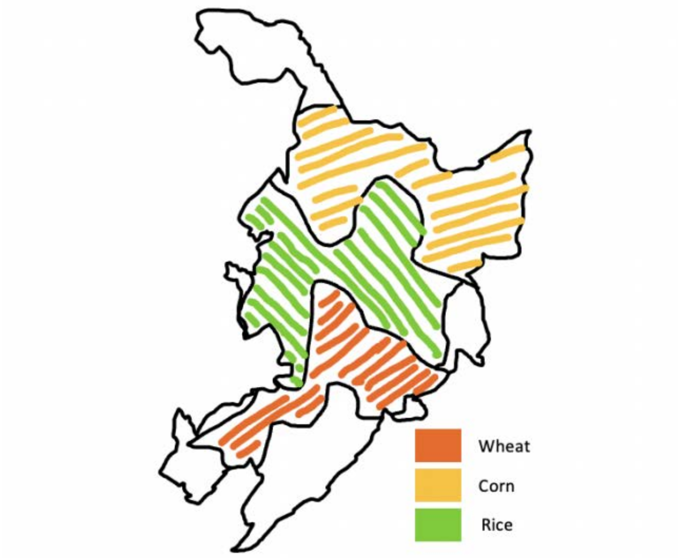

Figure 3. Distribution characteristics of crops in Northeast China.

Figure 4. Distribution of frequency of floods in Northeast China.

b) Economic loss evaluation on the gross annual value of agricultural output or value at risk (VaR) model.

The economic loss evaluation of crops caused by flood disasters in Northeast China was conducted by observing the gross annual value of agricultural output or utilizing the value at risk (VaR) model.

Before articulating the methodology, we need to confirm that the definition of economic loss of crops we study is the RMB that someone loses in a year due to crop damage in a certain area. The 'certain area' in our case is Northeast China, including Heilongjiang Province, Jilin Province, and Liaoning Province. However, the drawback of this method is that it ensures the forecast's accuracy.

We can only use this method to estimate the economic loss of crops in the following very ephemeral period of about one year to two years.

Value at risk is a quantitative risk analysis tool in risk management. It represents the maximum possible economic loss of a financial asset in a certain time in the future under a given confidence level.

According to the transformed formula that Sijian Zhao and Qiao Zhang derivates in their paper [5]:

$$P = (y_e < VaR) = 1 - \frac{1}{T} \quad (15)$$

In this formula, P represents the probability, and ye is the disaster rate. VaR is the value at risk. T is the return period that is often used as a barometer of disaster frequency.

3.3 Discussion on targeted disaster reduction measures

Most of the Northeast lies in plain areas with many rivers and tributaries, a crucial reserve base for agricultural development. It is also a densely populated area with good economic growth. In addition, the monsoon climate in the Northeast leads to heavy seasonal rainfall, which causes the river level to rise rapidly in a short period. Deduced from the occurrence process of disaster chain reaction [11], when many days of heavy rain caused waterlogging in the rainy season, riverbanks collapsed, and houses collapsed. This chain effect of disasters causes far more losses than a single disaster. Due to the unique environment of disaster (weather, terrain, infrastructure), northeast China has become one of the most severely affected regions by the flood disaster in China. Therefore, if we analyze the perspective of the disaster chain, several of the disaster processes can be cut off so that the disaster chain cannot be carried out to damage the crops.

Based on the flood disaster data and focus on some of the most damaging floods, we found that most of the occurrence of large flood disasters is caused by an extreme rainstorm characterized by long duration, wide range, heavy rain repeated rainfall areas. Most of the flood triggers were caused by tropical cyclones from the south [12]. Tropical storms from the Pacific bring heavy rain of more than 100 milliliters of rainfall, and the massive floods caused by them have caused severe damage to northeast China. Therefore, it is of particular significance to study the essential characteristics of a northbound tropical cyclone and analyze its law of flood disaster caused by a rainstorm in Northeast China to do an excellent job of flood prevention and control. Meanwhile, some of the extreme weather conditions were caused by the combined action of the Mongolian low weather system and the subtropical high-pressure weather system.[13] This climate produces extreme rainstorms that cause severe flood disasters. Consequently, the study and observation of low and high-pressure weather systems may play an important role in disaster prevention and mitigation.

We all know that prolonged exposure to floods can kill crops. At present, the research and development of genetic engineering of crops are getting better and better. We propose that the impact of floods on crops can be reduced by improving the flood resistance of crops. Based on Angelika Mistruth’s essay, we can obviously get a method to ascend the flood resistance of crops.[14] That's it by increasing the metabolic adaptations of crops. The waterlogging tolerance might be able to improve as well. If we put more effort into this research, the flood resistance of crops will improve. Furthermore, we can do a good job in forecasting and improve agricultural insurance services in combination with 5G service since 5G technology is become mature and has a wide coverage. [15] This paper makes a comprehensive investigation of 5G technology in the agricultural field and discusses the necessity and role of intelligent and precision agriculture. Based on that, we believe that 5G technology can be used for real-time monitoring, predictive maintenance, and data analysis, which can collect detection data in time to implement countermeasures, making flood control of crops more effective and convenient.

4. Conclusion

This paper conducts a risk assessment and prediction for crops in Northeast China under flood disasters. The data used in it comes from Disaster Chronicles in China, China Meteorological Disaster

Yearbook, and the National Data Administration, etc. In this paper, the probability distribution of 35 flood disaster events from 2001 to 2019 and a rough estimate of the economic loss caused by crop damage are obtained, and corresponding plans and suggestions for reducing economic loss are put forward. At the same time, the concept of the return period is briefly introduced, and the probability of each flood level is obtained by combining 35 sets of research data. This probability can be used to predict the probability of a certain level of flood in a province in Northeast China, which is convenient for the government to carry out the transfer and resettlement of the disaster-affected persons and to prepare for disaster mitigation and relief.

In conclusion, we believe that the government should increase the investment in the scientific research of crop flood resistance and enhance the flood resistance of crops through joint cultivation, genetic modification, and other methods. At the same time, it should be in line with the country's policy of developing 5G technology. Such as applying it to agriculture, making data collection and data analysis more efficient.

Innovatively, we classified the collected flood data in combination with the method of the flood return period. This has a very important positive impact on our subsequent data fitting. What's more, by analyzing 35 sets of data, we predict and evaluate the risk of crop damage and give some suggestions, which are of great significance to flood fighting and flood prevention of crops.

Although this paper discusses the preventive measures of crop flood disaster in Northeast China, the measures for different kinds of crops are not detailed enough. Lack of protection measures for wheat, corn, and soybean planted in Northeast China according to the characteristics of their growth environment. The content of economic loss evaluation under flood disaster is relatively single, and there is no discussion on casualties, cultivated land damage, and building damage one by one. Therefore, the economic loss given in this paper can only be used as a rough prediction and cannot be used as a direct basis for further research. The classification model of flood disaster in this paper needs to be based on the flood return period and can only be used when there is much data, which has certain limitations for application, and the accuracy of grade evaluation needs to be verified.

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