The Assessment and Regionalization of Flood/waterlogging Disaster Risk in Middle and Lower Reaches of Liao River of Northeast China

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Abstract

Although many studies have made assessment on flood/waterlogging disaster risk now, it hasn't developed an integrated index. This study presents a methodology for risk assessment and regionalization of flood/waterlogging in the middle and lower reaches of Liao River of Northeast China based on Geographical Information Systems (GIS), technology of natural disaster risk assessment, and the four main factors forming flood/waterlogging disaster risk: hazard, exposure, vulnerability and emergency response and recovery capability from the viewpoints of climatology, geography, disaster science, environmental science and so on, and an Flood/waterlogging Disaster Risk Index(FDRI) is developed. This study is specifically intended to support local and national government agencies as they (1) make resource allocation decisions; (2) make high-level planning decisions; and (3) raise public awareness of flood/waterlogging risk, its causes, and ways to manage it.

Key words: flood/waterlogging disaster risk; middle and lower reaches of Liao River; GIS; technology of natural disaster risk assessment; FDRI

1. Instruction

Flood disaster is the total means of water disaster and waterlogging disaster. Water disaster usually indicates disasters caused by rivers deluging and overwhelming farmland, building, and so on, while waterlogging disaster indicates disasters causing damage to population, building and so on, or causing reduction of production yields because of large area of accumulated water on the ground or because the soil is too wet when downfalls or rainstorms last for a long time. Water disaster and waterlogging disaster often happen at the same time, and sometimes it's hard to distinguish them, so we usually call them flood/waterlogging disaster[1~2].

Flood/waterlogging disaster profoundly influences the advancement of our society and sustainable social-economic development with the characteristics of: 1) causing tremendous losses and damage; 2) happening with quite high frequency; 3) extensive areas influenced. Besides, flood/waterlogging disaster happens with obvious spatial distribution pattern. Although many academic authors have made assessment on its risk[1~7], an integrated index has not yet been developed.

During recent decades, flood/waterlogging disaster caused by constant rainstorms happens frequently in Northeast China, which causes many negative influences to local economy, especially to agriculture production and environment. This study presents a methodology for risk assessment and regionalization of flood/waterlogging in middle and lower reaches of Liao River of Northeast, China, based on Geographical Information System (GIS), technology of natural disaster risk assessment and the four main factors forming flood/waterlogging disaster risk: hazard, exposure, vulnerability and emergency response and recovery capability from the viewpoints of climatology, geography, disaster science, environmental science and so on.

2. General Situation and Analysis on Typical Historical Flood/waterlogging Disaster

2.1 General Situation

Drainage area of middle and lower reaches of Liao River mainly means the area between Fudedian and debouchment of Liao River (Fig1), and it is located between 122°12′E～125°32′E and 40°30′N～43°N, including the following 16 cities and counties: Shenyang City , Liaoyang City, Yingkou City, Panjin City, Faku County, Tieling County, Xinmin City, Dengta City, Liaoyang County, Haicheng City, Dashiqiao City, Laobian County, Dawa County, Panshan County, Taian County, Liaozhong County.

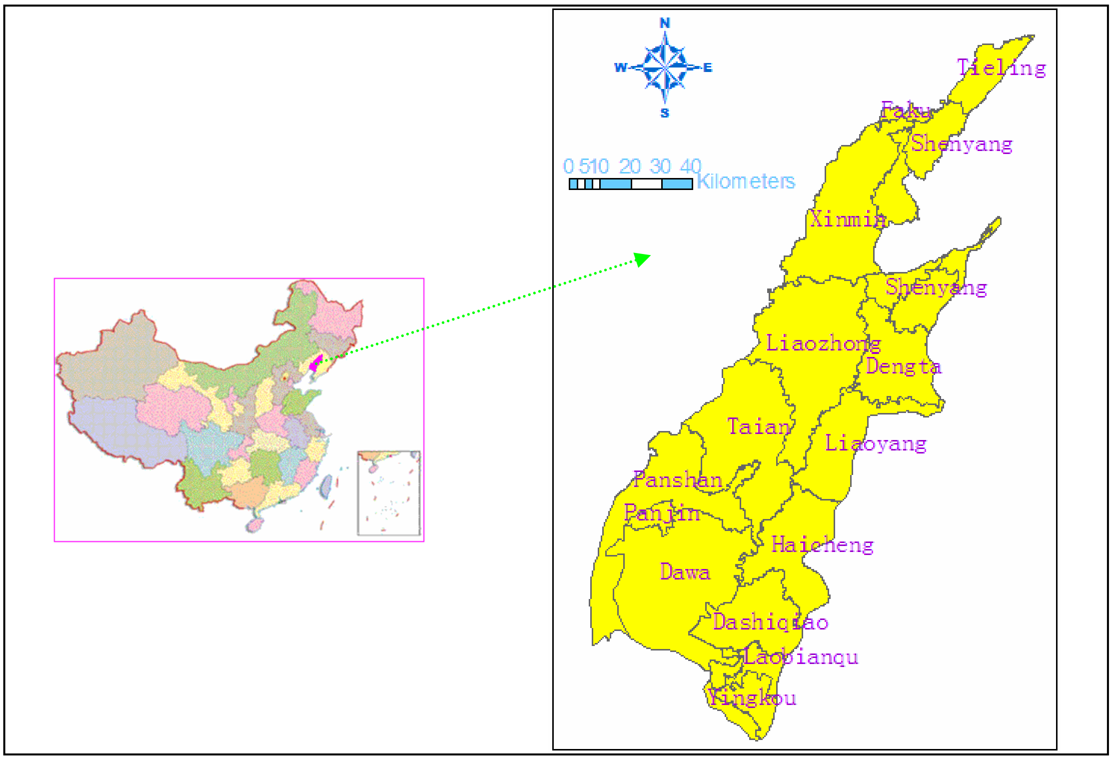

Fig.1 Administration map of counties in the middle and lower reaches of Liao River

This area of which landform is foothill and plain and rivers are dense on the plain(Fig2), is situated in the middle part of Liaoning Province, south of Northeast China, and is about 4.5×10^4km^2.

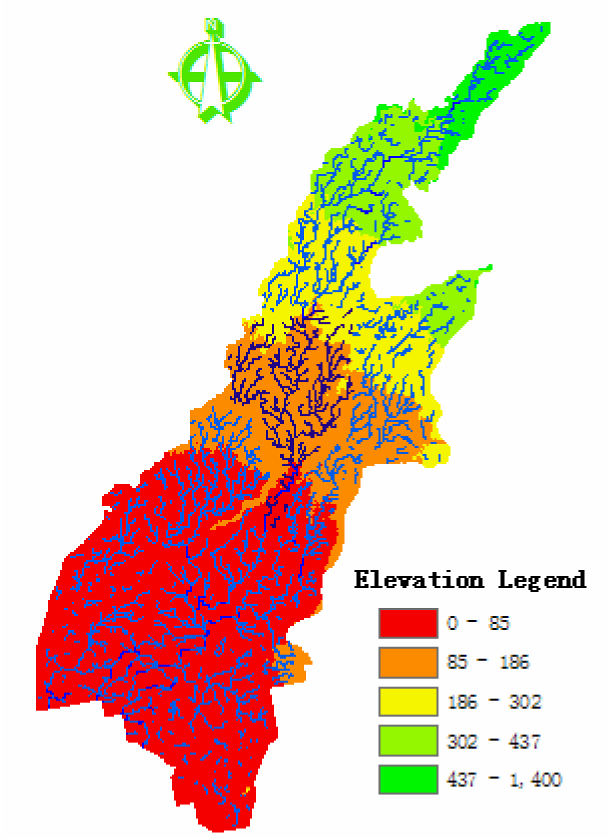

Fig.2 Landform and riverway map of middle and lower reaches of Liao River

Drainage area of middle and lower reaches of Liao River is on the temperate zone, continental monsoon-controlled climatic district, with hot summer and cold winter, and in spring, it is dry with much sand and wind. Its annual temperature difference is large, mean-years annual temperature is 4~9℃, and absolute lowest temperature is -41.1℃. Its mean-years annual precipitation is 300~950mm. The spatial and temporal distribution of precipitation is not regular, more on the east and less on the west, and mostly on July and August which is about 50% of annual precipitation in the way of rainstorm. The annual fluctuation of precipitation is also obvious, and the maximum is more than 3 times to the minimum. Besides, it also has the alternative phenomena of being rainy or rainless for continuous years.

There is extensive farmland and many cities on the drainage area of middle and lower reaches of Liao River, with dense population, and the industry and agriculture of this area are developed. Railways of Jingha, Shenda, Shendan, Shenji and thruways of Shenda, Shenchang, Hafu, Shenben run through from south to north. The mineral resource in this area is abundant, and Liaohe oil field, an important base of oil industry, is seated in Panjin City which is on the debouchment of Liao River. In china, this study area is an important base of industry, agriculture, resources and commercial food production, and is also an important traffic hinge.

Flood/waterlogging disaster happens frequently in Liaoning Province, especially in the drainage area of middle and lower reaches of Liao River which has experienced many times of flooding ,and caused tremendous losses to this area, so it is the most important flood control region of Liao River drainage area.

2.1 Typical Historical Flood/waterlogging Disaster

Since the liberation of China, flooding/waterlogging disaster has happened eight times that severe economic losses were caused in middle and lower reaches of Liao River, and in 1951 and 1985, the losses were even great:

On August, 1951, super rainstorm caused super flood in the middle and lower reaches of Liao River, 33 cities and counties are affected, and about 5,264 km^2 area is flooded, which caused tremendous losses to the industrial and agricultural production, people's lives and properties in the plain region. In this disaster, about 18,400ha of farmland and 876,000 people were stricken, 3123 people died, 138,000 houses collapsed, and yields loss is 430,000 tons. The flood washed away the railways of Shenshan and Changda, which caused the railway communication broken for 40 days, and lost about 600 million RMB at the price of 1951.

In 1985, it constantly rained in middle and lower reaches of Liao River from July to September, the area affected were expansive, and the total precipitation was more than 3.63m^3 billion , which caused four times of continuous flooding on the drainage area of Liao River. Although the flood peak was not high, frequent occurrence because of long duration and great total precipitation caused severe flood/waterlogging disaster. Based on the statistical data of Liaoning Province, about 70 cities and counties which were about 162.4×10^4 km^2, and 12.79 million people were stricken, 2.4 million people died, and the direct economic loss was about 4.7 billion RMB at the price of 1985.

3. Methods and Materials

3.1 Methods

3.1.1 Natural Disaster Risk Index Method

Natural disaster risk is defined as both the possibility of natural disaster occurrence and the degree of damage caused by natural disasters during the following several years. Generally speaking, natural disaster risk is the result that hazard, exposure and vulnerability work integratedly[8~9]. Because emergency response and recovery capability also plays an important part in the formation of natural disaster risk, so it is also considered. The natural disaster risk is formed by hazard(H), exposure(E), vulnerability(V) and emergency response and recovery capability(R), and can be expressed in mathematic formula as follows[10]:

Natural Disaster Risk = Hazard •Exposure •Vulnerability •Emergency response and recovery capability

3.1.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process[11~12] (AHP) is a decision analysis method, which combines both quantitative and qualitative criteria in decision problems. Briefly, there are following five basic steps in applying the AHP in practice: (1) structure the decision hierarchy; (2) collect data by pairwise comparisons; (3) check consistency of material judgments; (4) apply the eigenvector method to compute weights; and (5) aggregate the weights to determine a ranking of decision alternatives.

3.1.3 Weighted Comprehensive Analysis (WCA)

This method assumes that the degree of the influence of each factor i on a particular object j to be assessed is discriminated as the quantification value of the indicator i is different, the total of the influences on this object can be expressed by Eq. (1)[4, 13~14].

$$CV_j = \sum_{i=1}^{m} QV_{ij}\ WC_i \qquad (1)$$

where CV_j is the comprehensive value of the assessment object j, QV_{ij} is the quantification value of the indicator i with respect to the assessment object j ($QV_{ij} \geq 0$), WC_i is a weight on the indicator i ($0 \leq WC_i \leq 1$) and is computed by using AHP, and m is the number of assessment indicators.

Weighted Comprehensive Analysis (WCA) considers the degree of the inference of each factor to the object integratedly, and it integrates every indicator's advantages and disadvantages in the way of an quantitative index to indicate the object to be assessed. So this method is especially applicable to analyze, evaluate and chose the best technology, decision or plan. It is on of the most common used methods now.

Geographical Information System (GIS) has great advantage on analyzing and managing spatial data. The characteristics of precipitation, landform, physiognomy and geomorphologic and geologic factors that are closely connected to the formation of flood/waterlogging disaster can be represented in spatial distribution data, so GIS surely can be used to support the risk analysis on flood/waterlogging disaster. In this paper, with the help of GIS, factor analysis method is chosen to analyze the risk of flood/waterlogging disaster in middle and lower reaches of Liao River.

3.2 Materials

Data needed in this study were mainly obtained from "Annual Statistic in Liaoning Province [15](2004)", and part of them were obtained from Chinese natural resources (http://www.naturalresources.csdb.cn/). Data on precipitation were obtained from "Summarization of Ground Climatic Data in Liaoning Province[16](1971-1980)".

4. Development Procedure of Flood/waterlogging Disaster Index (FDRI)

From the viewpoints of disaster science, and based on the formation mechanism of flood/waterlogging disaster, the conditions on formation of flood/waterlogging disaster must contain:1) factors causing flood(hazard); 2) environment for the formation of flood/waterlogging disaster (disaster-pregnant environment); and 3) there are human or social properties in areas influenced by flood(vulnerability). With the interaction of these three factors, flood/waterlogging disaster is formed.

From the viewpoints of geography, and based on the formation mechanism of flood/waterlogging disaster and area characteristics of the disaster-pregnant environment, we can find out that the main hazard factor of flood/waterlogging disaster in middle and lower reaches of Liao River is flood caused by rainstorms. Besides, geomorphologic and geologic factors such as landform, physiognomy, conditions of vegetation, and so on also play important roles in the formation of flooding.

4.1 Background in Flood/waterlogging Disaster Risk Index (FDRI)

Natural disaster risk indices summarize a great deal of information on natural disaster risk in a way that is easy for non-experts to understand and use in making risk management. Now, natural disaster risk indices have reflect the interest among academic researchers, development banks, government and the insurance industry, and are mostly used to make systematic comparisons of natural disaster risk in different regions.

Based on the formation mechanism of natural disaster[8~9] (Fig.3), formation principle of flood/water-

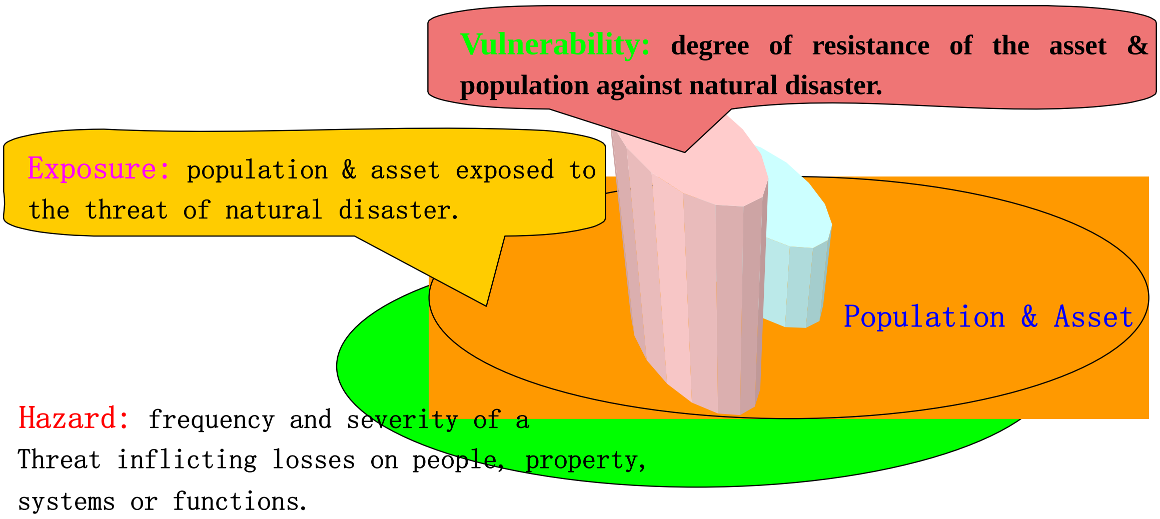

Fig.3 Formation mechanism of natural disaster risk

logging disaster risk[1,3](Fig.4) and evaluation principle of hurricane disaster risk[10], a Flood/waterlogging Disaster Risk Index(FDRI) is developed.

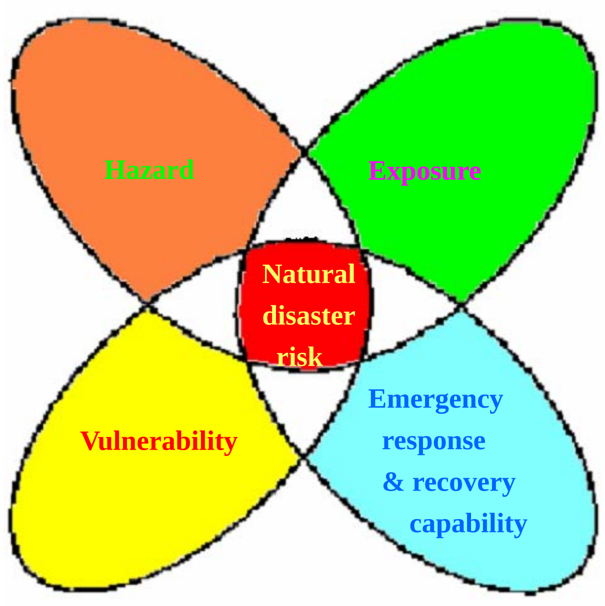

Fig.4 Formation principle of flood/waterlogging disaster risk

The academic authors in and abroad point out that, during the formation of regional natural disaster risk, hazard, exposure and vulnerability should all be included. Natural disaster is the production of variation on the earth surface, and is the result that hazard, exposure and vulnerability interact integratedly. The function of natural disaster risk is as follows:

Natural Disaster Risk = f (Hazard, Exposure, Vulnerability)

During the formation of flood/waterlogging disaster risk, not only these factors: hazard, exposure, vulnerability that form natural disaster risk are included, but also emergency response and recovery capability is playing an important part to the risk of flood/waterlogging disaster. So when analyzing flood/waterlogging disaster risk, it should be considered. The function of flood/waterlogging disaster risk is as follows:

Flood/waterlogging Disaster Risk=f (Hazard, Exposure, Vulnerability, Emergency response and recovery capability)

Evaluation on hurricane disaster risk was to integrate and summarize a great deal of information on how hurricanes occur, and how they effect the environment, building and infrastructure, the economy, and social activities in an easily understandable way, and a hurricane disaster risk index was developed, so as to help government agencies (and others who are not necessarily hurricane experts) make resource allocation and high-level planning decisions

4.2 Conceptual Framework of FDRI

From the viewpoints of systematic theory, and based on the formation mechanism of natural disaster (Fig.3), formation mechanism of flood/waterlogging disaster risk (Fig.4), the conceptual framework of FDRI(Fig.5) is developed, in which four main factors : hazard, exposure, vulnerability, and emergency res-

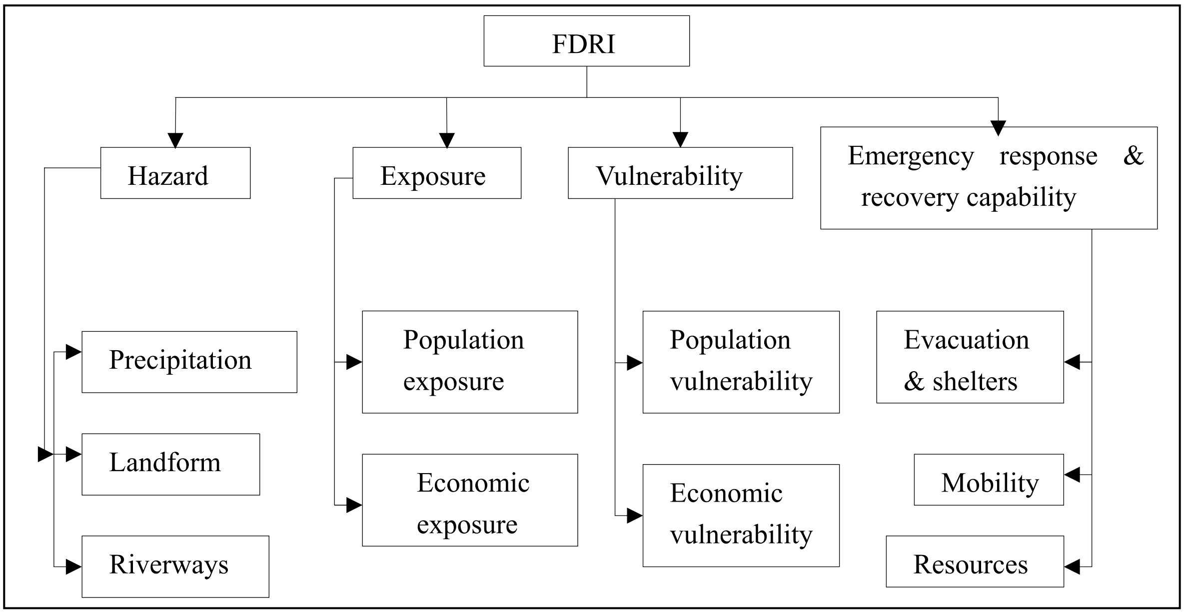

Fig.5 Conceptual framework of flood/waterlogging disaster risk

-ponse and recovery capability contribute to flood/waterlogging disaster risk , and each of them is disaggregated into more specific subfactors. Hazard represents the meteorological phenomena and landform and physiognomy characteristics (such as precipitation, density of riverways, slopes and so on); exposure describes the population and conditions of economy when flood/waterlogging disaster happens in a county; vulnerability represents how easily and severely a county's exposed entities can be effected by a flood; emergency response and recovery capability describes how effectively and efficiently a county can recover from the impact in the short or long term.

4.3 Indicator Selection and Scaling of FDRI

The 15 indicators selected (Table.1) based on the conceptual framework of FDRI to assess the degree of flood/waterlogging disaster risk have a variety of units, so they should be scaled and defined in terms of new scales from 0~10 so as to be combined together, using the following linear scaling function:

$$X'_{ij} = \frac{X_{ij} \times 10}{X_{imaxj}} \quad (2)$$

where $\mathbf{X'}_{ij}$与$\mathbf{X}_{ij}$ refer to the scaled and unscaled values of indicator i for city or county j, respectively, $\mathbf{X}_{imaxj}$ is the maximum value of indicator i among all the cities and counties.

Table.1 Indicators in FDRI

Factor	Subfactor	Indicator
Hazard	Precipitation	X_{H2} Frequency of precipitation＞50mm
	Landform	X_{H2} Slope
		X_{H3} Height
	Riverways	X_{H4} Density
Exposure	Population Exposure	X_{E1}Resident population
		X_{E2}Total Tourists
	Economic Exposure	X_{E3}Yields from agriculture, stockbreeding and fishery
		X_{E4}Economic production
Vulnerab-ility	Population Vulnerability	X_{V1}%population aged from 0~15 and 65+
		X_{V2}Public education indicator
	Economic Vulnerability	X_{V3}%Small businesses
		X_{V4}%Farmland vulnerable to flood
Emergency Resp. & Recovery Capability	Evacuation & Shelters	X_{R1}Number of shelters
	Mobility	X_{R2}Population density
	Resources	X_{R3} per capita GDP

4.4 FDRI Mathematical Model

Once scaled, the indicators and their weights for each county are employed in the following FDRI mathematical model based on the standard natural disaster risk mathematical formulation and conceptual framework of flood/waterlogging disaster risk and using the methods of Weighted Comprehensive Analysis (WCA) and Analytic Hierarchy Process (AHP):

$$FDRI=(H^{WH})(E^{WE})(V^{WV})[0.1(1-a)R+a] \quad (3a)$$

$$H=W_{H1}X_{H1}+W_{H2}X_{H2}+W_{H3}X_{H3}+W_{H4}X_{H4} \quad (3b)$$

$$E=W_{E1}X_{E1}+W_{E2}X_{E2}+W_{E3}X_{E3}+W_{E4}X_{E4} \quad (3c)$$

$$V=W_{V1}X_{V1}+W_{V2}X_{V2}+W_{V3}X_{V3}+W_{V4}X_{V4} \quad (3d)$$

$$R=W_{R1}X_{R1}+W_{R2}X_{R2}+W_{R3}X_{R3} \quad (3e)$$

where FDRI indicates the degree of flood/waterlogging disaster risk , and generally, the higher the value is, the grater the flood/waterlogging disaster risk is; variables H, E, V, and R represent the hazard, exposure, vulnerability, and emergency response and recovery capability factor indices, respectively; and W_H、W_E、W_V represent the weights of the hazard, exposure, and vulnerability factors, respectively. In (3c)-(3e), X_i refers to the scaled value of indicator *i*, and W_i used to represent the relative importance of the indicators to each factor refers to the weight associated with indicator *i*. Variable *a* is constant($0 \le a \le 1$), and is used to describe the part that emergency response and recovery capability factor plays to reduce the overall FDRI.

The weight values were determined using the Analytic Hierarchy Process(AHP)(Fig6). In this paper, there are many indicators chosen for each factor. When analyzing the relative importance of a set of many indicators, the AHP is a useful tool because it requires only pairwise comparisons of indicators, rather than a direct comparison of all indicators simultaneously, and pairwise comparisons are easier to make and improve consistency. Weight values are assessed by the authors, and are used for the analysis of flood/waterlogging disaster risk of the cities and counties in middle and lower reaches of Liao River.

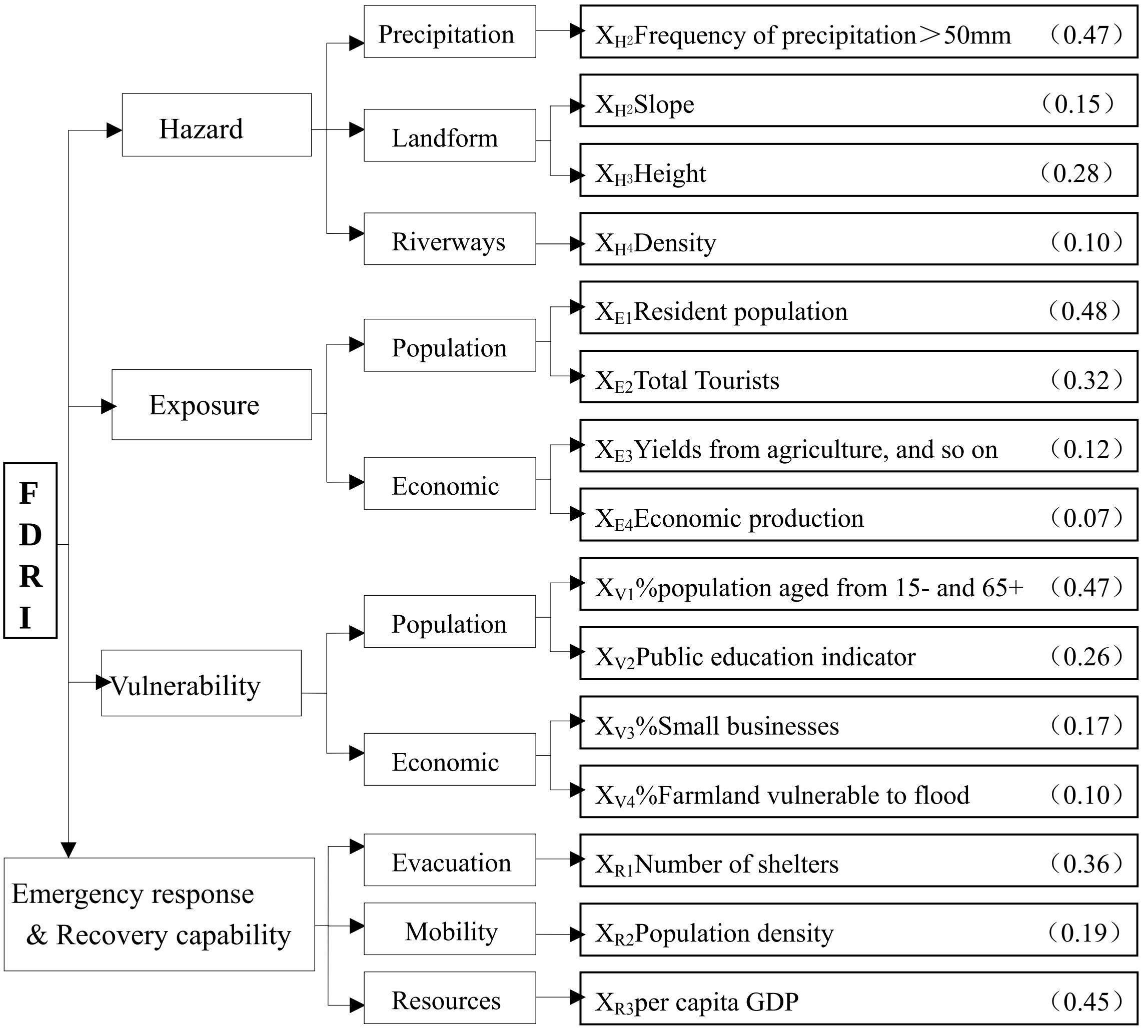

Fig.6 Weight values of indicators in FDRI

Although these values are considered to be reasonable for this FDRI, the values of the weights can be further explored and, if necessary, adjusted. In the FDRI, the factor weights(W_H，W_E，W_V) are assessed to be 0.45,0.36,0.19, respectively. Because emergency response and recovery capability factor is included as a possible reduction factor, the weight of it is not given.

When certain conditions are satisfied, the model is useful for FDRI and every factor. First, if there is no hazard, exposure or vulnerability, then there is no risk of a disaster [if H=0, or E=0, or V=0, then FDRI=0]. Second, if a county or city has virtually no emergency response and recovery capability, then the risk equals the usual product of hazard, exposure and vulnerability [if R=0, then FDRI= $a(H^{WH}E^{WE}V^{WV})$]. In the analysis of flood/waterlogging disaster risk to the cities and counties in middle and lower reaches of Liao River, it is assumed that a=0.75.

5. Analysis and Regionalization of Flood/waterlogging Disaster Risk in Middle and Lower Reaches of Liao River

When analyzing flood/waterlogging disaster risk, the formation mechanism of flood/waterlogging must be followed, and with the help of GIS, the four main factors that form flood/waterlogging disaster risk should be analyzed separately. Hazard analysis is to study on what kind of flood/waterlogging disaster the study area will experience at certain time, and to analyze the distribution probability of this flood/waterlogging disaster's intensity. The main content of it is risk identification and assessment. Vulnerability analysis is a general designation of exposure analysis and vulnerability analysis. It is to study on the vulnerability degree that the flood disaster causes and the endurance ability every vulnerability has to the flood/waterlogging disaster. Then the function between flood grade and flood/waterlogging losses are built up. Emergency response and recovery capability analysis is to study on a series of project and non-project measures used to reduce the losses that flood/waterlogging disasters cause.

5.1 Hazard Regionalization

Hazard of flood/waterlogging disaster is to show threats and harms to human, properties, systems and function caused by flooding. When analyzing the hazard, climatic factors and geomorphologic and geologic factors must be considered, and to the area in middle and lower reaches of Liao River, the main climatic factor affecting the formation of disaster is rainstorm, and the main geomorphologic and geologic factors are landform, physiognomy, vegetation, soil and so on, in which the landform, physiognomy and riverways greatly influence the hazard. So precipitation, landform, physiognomy and riverways are mainly considered when doing hazard analysis on the area of middle and lower reaches of Liao River, and the hazard regionalization map is as follows(Fig7):

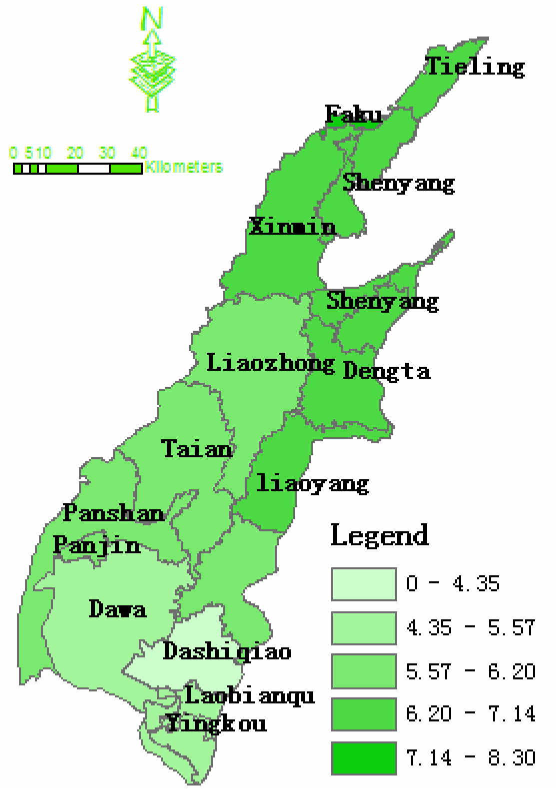

Fig.7 Regionalization map of hazard in middle and lower reaches of Liao River

From Fig.7, we can find that hazard of flood/waterlogging in the area of middle and lower reaches of Liao River is reducing from north to south. This is because that, variations of landform is not great in this region from north to south, and densities of riverways are similar, but the precipitation of the northern low mountains and hills area is higher than the precipitation of the southern plains, and the branches of Liao River join to the Liao River in Tieling County, Shengyang City, Xinmin City, Dengta County and Liaoyang County, so the flood/waterlogging disaster hazard is relatively higher than other cities and counties.

5.2 Exposure Regionalization

Exposure describes the number of people and economic values that will experience flood/waterlogging disaster hazards, and may be adversely impacted by them. Not only local residents but also tourists are included in the number of people, because on July and August it is the midseason of travelling which causes the number of people exposed increases; the income of industry, agriculture, forestry, stockbreeding, and fishery are mainly considered to describe economic values. The exposure regionalization map is as follows (Fig8):

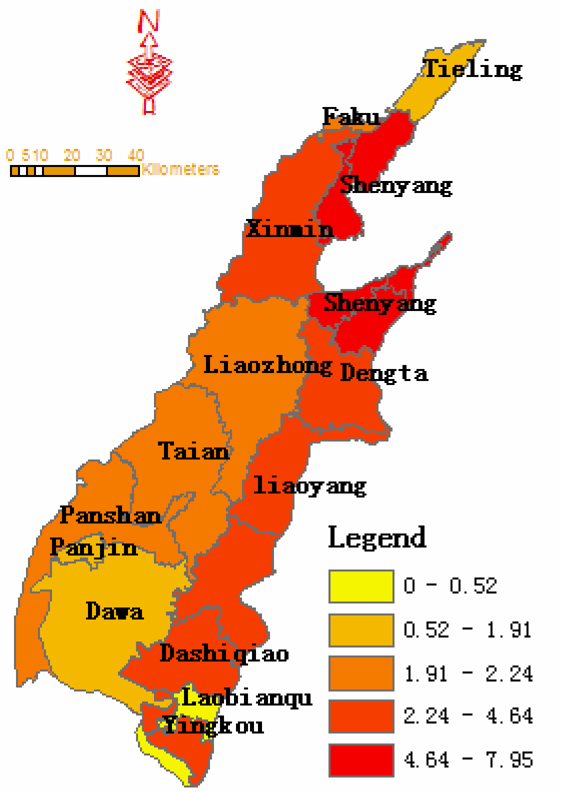

Fig.8 Regionalization map of exposure in middle and lower reaches of Liao River

In Fig.8, exposure in north and east of the area in middle and lower reaches of Liao River is relatively high. From the statisticcal data, we can find that, in these regions the economy is developed, number of residents and tourists is great, and especially in Shenyang City which is the center of economy and culture activities in Liaoning Province, the economy is more developed, and number of residents and tourist is greater, so the exposure is relatively great.

5.3 Vulnerability regionalization

Vulnerability describes the extent of damage and losses all the population and property in the area of middle and lower reaches of Liao River experiencing because of the potential threats of flood. Population vulnerability describes the characteristics of individuals and groups that make them more or less likely to be injured, killed, displaced, and to have their daily lives disrupted as the result of a flood, or to be able to recover from any impact they do experienced. A person’s vulnerability can depend on, for example, age, flood awareness, and so on. Because when flooded small businesses have relatively low levels of disaster preparedness and relatively little capacity to recover from and the production of farmlands are particularly vulnerable to the flood/waterlogging disaster impacts, so the percentage of them are chosen to represent the vulnerability of economic activities. The regionalization of vulnerability on the area of middle and lower reaches of Liao River are show on the following map (Fig9):

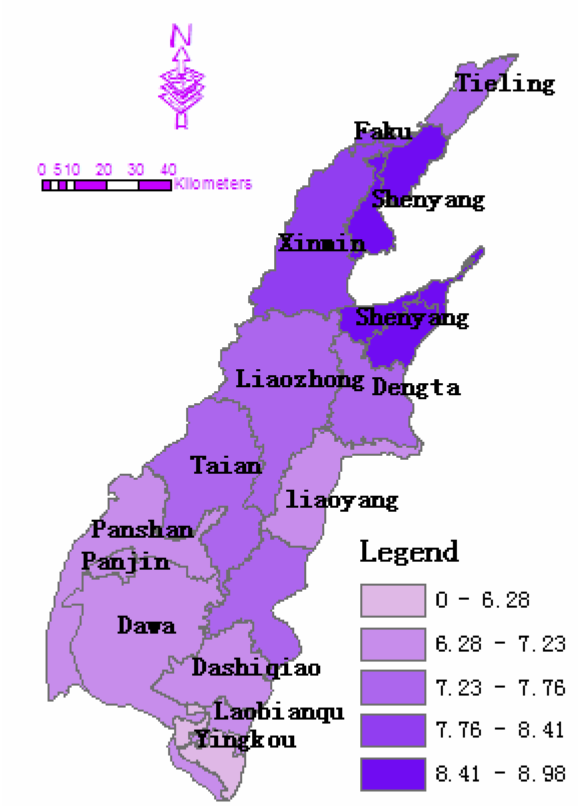

Fig.9 Regionalization map of vulnerability in middle and lower reaches of Liao River

Form Fig.9, we can find that, Shenyang City has the greatest vulnerability, and then Faku County, Xinmin City, but their discrepancy is not great. Yingkou City has the lowest one. That's because in Yingkou City, the percentage of population that may be particularly vulnerable due to age is relatively low, and in other cities and counties, the discrepancy is not great.

5.4 Emergency Response and Recovery Capability

Emergency response and recovery capability describes a series of project and non-project measures used to reduce the losses that flood/waterlogging disasters cause. In this paper, measures of evacuation and shelters, mobility of emergent evacuation when disaster happens, and resources available for emergency response and recovery capacity are considered. Because it was assumed that project measures are equally available in every city and county of middle and lower reaches of Liao River, so they were not included, and the regionalization of emergency response and recovery capability map is as follows (Fig10):

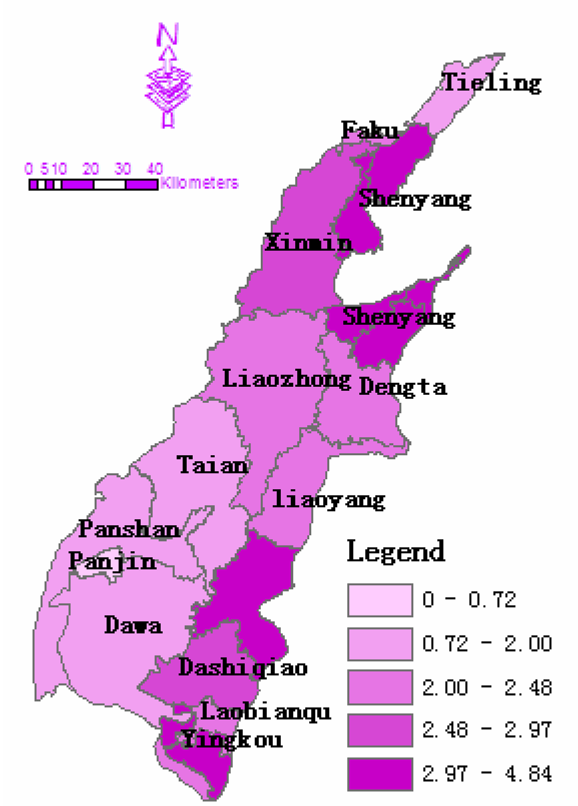

Fig.10 Regionalization map of emergency response and recovery capability in middle and lower reaches of Liao River

From Fig.10, it is easy to find that, Shenyang City, Faku County, Xinmin City, Haicheng City and Yingkou City have high emergency response and recovery capability, that's because in these cities and counties, the economy is developed, the per capita GDP is high, and they have many shelters, so when disaster happens, these areas can save themselves.

5.5 Risk Analysis and Regionalization

In the risk analysis on flood/waterlogging disaster of area in middle and lower reaches of Liao River, the four main factors forming risk are considered together. In Fig.11, focusing on one factor at a time allo-

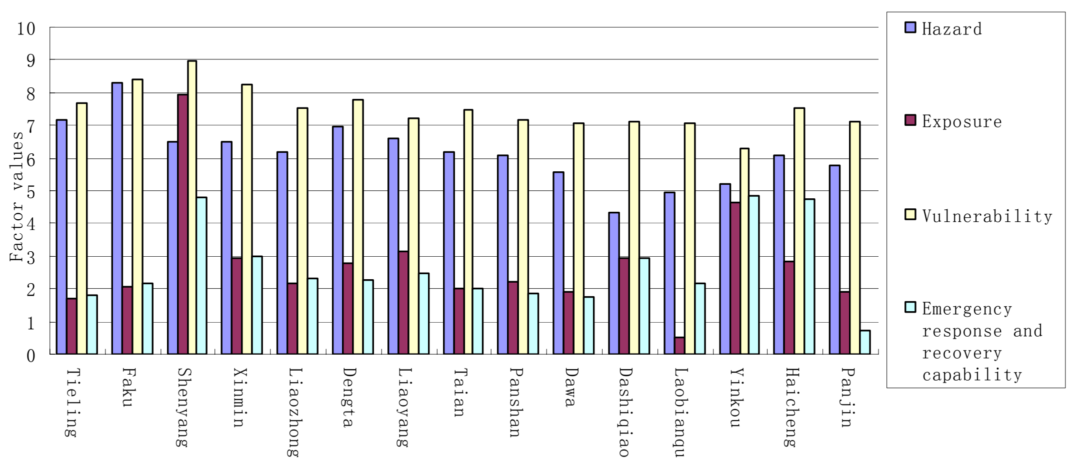

Fig.11 Analysis results map of factors in middle and lower reaches of Liao River

-ws users to determine, for example, that Faku County has the highest hazard value, while Dashiqiao City has the lowest; Shenyang City has the highest exposure value, while Laobianqu County has the lowest; Shenyang City has the highest vulnerability value, while Yingkou City has the lowest; Shenyang City, Yingkou City and Haicheng City have the highest emergency response and recovery capability, and Yinkou City has the most highest, while Panjin City has the lowest. When analyzing these factors integratedly, in Fig.12, we can easily find out that, when flood/waterlogging disaster happens, FDRI value of Shenyang City is the highest, more than 6.5; FDRI values of other cities and counties fall on the lower half of the scale, and only Fuku County has the value of a little bigger than 5, and Laobianqu are even less than 3. From the regionalization map of risk in the middle and lower reaches of Liao River(Fig13), it is much easier to compare risk of every city and county.

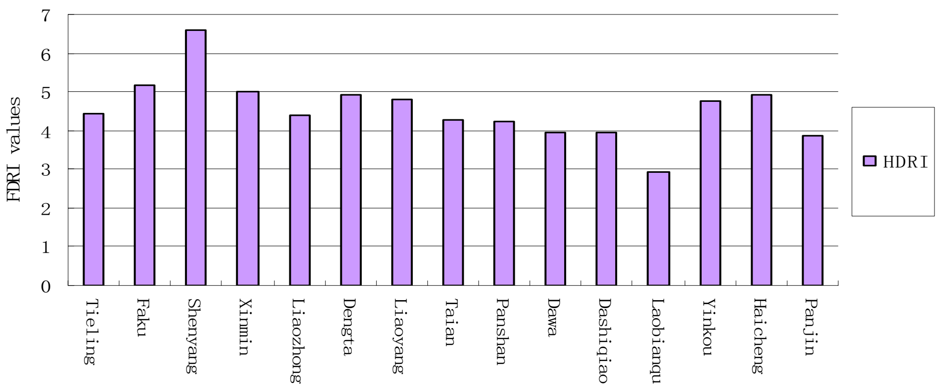

Fig.12 Analysis results map of risk in the middle and lower reaches of Liao River

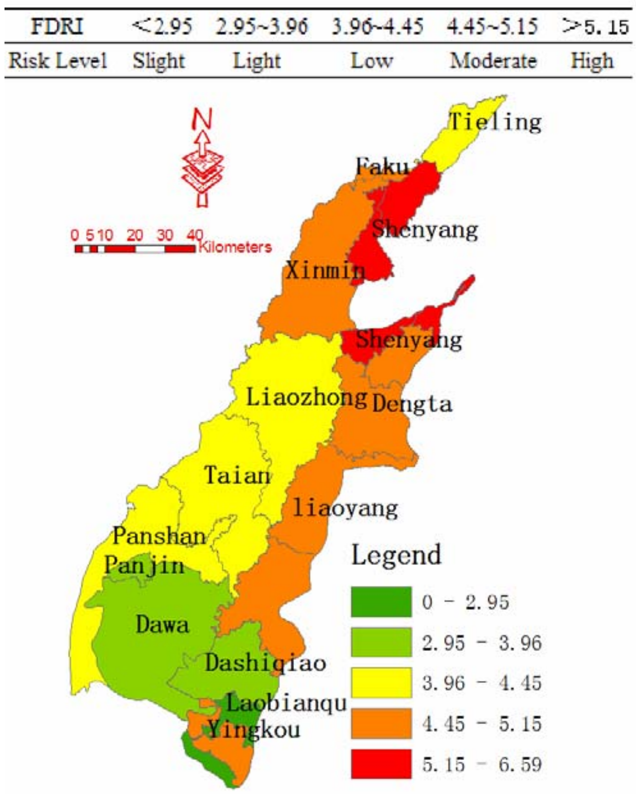

Fig.13 Regionalization map of risk in middle and lower reaches of Liao River

Relatively to say, only the flood/waterlogging disaster risk of Shenyang City is great among these cities and counties in the middle and lower reaches of Liao River, but it doesn't mean that none of these cities and counties having lower risk values has a high flood/ waterlogging disaster risk. Rather, it indicates that the maximum annual loss in the middle and lower reaches of Liao River reasonably expected in the next few years is significantly higher than the risk in any city or county in the sample analysis today.

This study considers all the factors of nature, social-economic aspect and emergency response and recovery capability, and so on. Compared to the information of historic flood/waterlogging disasters[17] and the zonation map[5] of flood disaster risk in Liao River basin made before, it can be find out that, the regionalization map of flood/waterlogging disaster risk in middle and lower reaches of Liao River is objective. The result with high precision accords with the actual condition.

6 Conclusions

The FDRI is specifically intended to support local and national government agencies as they (1) make resource allocation decisions; (2) make high-level planning decisions; and (3) raise public awareness of flood/waterlogging disaster risk, its causes, and ways to manage it. The FDRI synthesizes and summarizes a great deal of disparate information to facilitate comparison of the magnitude and nature of flood/waterlogging disaster risk in the area of middle and lower reaches of Liao River in a way that is easily accessible to potential users. Because of limited data, the FDRI may not be perfect, and may be further explored in the future and, if necessary, adjusted.

Acknowledgement

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