Seismic Risk Assessments for Border Area of Shanxi, Hebei and Inner Mongolia, China

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***Abstract*—With a large amount of information, materials of seismic intensity in history include PGA, seismic intensity attenuation and effects of site and buildings etc. By analyzing well-recorded materials of seismic intensity in border areas of Shanxi, Hebei and Inner Mongolia within 500 years, this paper proposes the method of seismic tendency assessment, which is similar to seismic risk analysis. The key to that way is establishing relation curve of seismic intensity and average repetition period, and applying it to the assessment of seismic risk. First, based on ArcGIS, we built a data bank of seismic intensity, and turned administrative map of border areas into longitude and latitude grid line with basic unit of 0.1°×0.1°; second, we got seismic intensity—frequency relation (namely hazard curve) of each unit by using the least squares fitting on seismic intensity materials; last, based on the hypothesis that the earthquake has cycle, we use hazard curve to estimate the repetition period of different intensities, intensity distribution of every 100 year, and exceeding probability of certain intensity (such as *VI*, *VII* and*VIII*) in 50 years in representative cities and counties of Shanxi, Hebei and Inner Mongolia border areas;The calculation indicates that Datong-Huairen-Hunyuan and Huailai-Yanqing have high seismic risk and should be paid attention to.**

***Index Terms*—seismic intensity, hazard curve, repetition period, exceeding probability, seismic risk**

I. INTRODUCTION

The earthquake always causes huge casualties and property loss among all the natural calamities on the planet. There happened many destructive earthquakes [1] in the history of China since the country locates between the two tremendous seismic belts: Circum-Pacific Seismic belts and Mediterranean–Himalayan Seismic belts, such as the Shanxi Guanzhong earthquake with a magnitude of 8.0 in 1556(over 830 thousand people died or disappeared) and the Sichuan Wenchuan earthquake with the same magnitude in 2008(over 80 thousand people died or lost) [2]. The most primary factors causing giant lives loss and property damaging are always surrounding construction and region environment destroying by the earthquake. So far on the fact that the earthquake could not be predicted precisely, seismic fortification step is the best way to reduce economy loss and death [3], which is closely correlated to the technology level and the economy development of the country according to the basic documents in seismic subject. Rich and detailed historical seismic data offers beneficial advantages for researching the seismic hazard. The paper carries on the seismic hazard analyzing and risk predicting with the seismic intensity documents from A.D. 1500 to A.D. 2000 in Shanxi, Hebei and Inner Mongolia bording area so as to obtain time features of the region earthquake activeness [4].

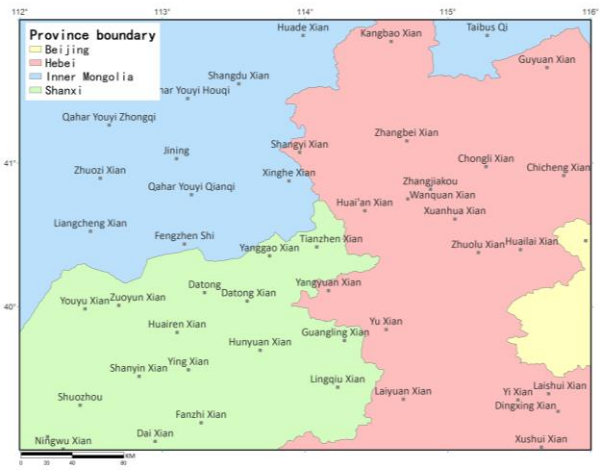

Figure 1. The study area

The Shanxi, Hebei and Inner Mongolia bording area locates roughly in 112° to 116° in longitude and 39° to 42° in latitude (Fig. 1), which includes the central and southern parts of Inner Mongolia (Liangcheng, Fengzhen, Chayouqianqi, Helinger and so on), North Shanxi(Datong, Yanggao, Youyu and so on), Northwest Hebei (Zhangbei, Shangyi, Huaian and so on) [5]. The bording area is the annual key risk region to the above three provinces and even the country. Since the beginning of history there had been a great deal of strong earthquakes happened in this region, such as the Shanxi Lingqiu *M*7.0 earthquake in 1626, the Shanxi Yuanping *M*7.0 earthquake in 1683, the latest medium magnitude earthquake was the Hebei Zhangbei *M*6.2 earthquake on Jan. 10th, 1998. In the paper the seismic hazard is evaluated and the seismic risk is predicted by the historical intensity documents [6], [7] of the bording area to get the exceeding probability for the specific intensity in the next 50 years. Results could be regarded as the references for anti-seismic design of building and project construction facilities.

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II. SOURCE AND DIGITALIZING OF HISTORICAL SEISMIC INTENSITY DATA

Earthquakes after A.D. 1500 were recorded in detail as the intensity degree reaches v [8], hence, the paper chooses all the earthquakes with the magnitude greater or equals to 4.75 after A.D. 1500 from the earthquake catalogues, including 32 ancient earthquakes (A.D. 1500-A.D. 1911) and 15 modern times' earthquakes (A.D. 1912-A.D. 2000), parts of which are listed in Table I. However, there are 26 earthquakes with no complete earthquake examples, which could not lead to assured intensity level. The experiments adopt the mean axis intensity decaying formula [9] suitable to Shanxi and Hebei of North China:

$$I = 2.429 + 1.499M - 1.39\ln(R+11) \quad \sigma{=}0.377 \tag{1}$$

and the earthquake intensity decaying relation suitable to medium and west region of Inner Mongolia [10]:

$$I_a = 2.7517 + 1.2610M - 1.0941\ln(R_a+12) \quad \sigma{=}0.519 \tag{2}$$

$$I_b = 2.5671 + 1.0966M - 0.9338\ln(R_b+6) \quad \sigma{=}0.536 \tag{3}$$

to estimate the intensity in the study area, where I represents the intensity degree, M represents the magnitude level, R represents mean-axis radius (in km), the index a, b respectively equals to the direction of the long axis and the short axis, R_a and R_b represents the long axis radius and the short axis radius of the intensity isoseismal, σ is the standard deviation.

The paper divides the study area into many square frames with same size to reflect the spatial distribution features for the seismic activities of the area and evaluate the seismic risk of each place by regarding the frame as an independent statistics unit.

Considering synthetically the region range, geology feature, density of population and so on, the study area is divided into many base units with 0.1 °× 0.1 ° in latitude. Get the sequence number of each unit by numbering it from bottom to top and from left to right. Then digitalizing every seismic intensity map with ArcGIS [11] under the Xi'an 80 geographical coordinate system to get the intensity observations distribution grid map, the sample number for the seismic intensity in each unit is from 3 to 45 (Fig. 2).

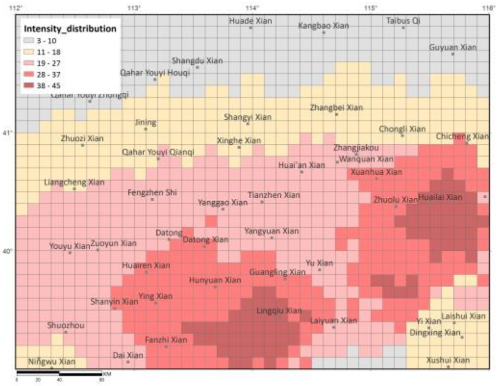

Figure 2. Distribution number of intensity observations

TABLE I. PART OF INTENSITY OBSERVATIONS

Province	Seismogenic data	Epicenter (latitude	longitude)	Toponymy	Magnitude *Ms*	Intensity *I*	Spindle direction
Shanxi	1626-06-28	39.4	114.2	Lingqiu	7.0	V-IX	16.80
Shanxi	1683-11-22	38.7	112.7	Yuanping	7.0	V-IX	21.50
Shanxi	1673-10-18	40.5	113.5	Tianzhen	6.5	V-VIII	16.84
Shanxi	1989-10-19	39.9	113.9	Datong	5.9	V-VII	8.92
Hebei	1720-07-12	40.4	115.5	Shacheng	6.8	V-VIII	14.93
Hebei	1618-11-16	39.8	114.5	Yuxian	6.5	V-VIII	19.71
Hebei	1628-10-07	40.6	114.2	Huaian	6.5	V-VIII	17.59
Hebei	1998-01-10	41.1	114.3	Shangyi	6.2	V-VIII	22.36
Hebei	1658-02-03	39.4	115.7	Laishui	6.0	V-VII	157.13
Hebei	1911-01-25	39.8	114.5	Yuxian	5.9	V-VII	19.71
Inner Mongolia	1976-04-06	40.2	112.1	Helin	6.2	V-VIII	66.03

III. SEISMIC HAZARD ANALYZING

The seismic intensity –frequency relation, namely the hazard curve to the unit could be obtained by analyzing the digitalized base unit, the relation describes the frequency of earthquake occurrence at a certain intensity degree. According to references [12], [13], the relation between the seismic magnitude and frequency obeys the Gutenberg-Richter formula, which indicates seismic events distribute adequately in all magnitude levels and Gutenberg-Richter relationship has high goodness of fit. Replacing the magnitude with the intensity, yields,

$$\lg f = a - b \times I \tag{4}$$

where I represents the intensity, f represents annual rate of the intensity occurrence when it is greater than or equals to I, a and b are parameters obtained by the least square method. Among all units with the size 0.1° × 0.1° , a varies within the range between -3.07 and 1.73, b varies between -0.08 and 0.68. Fig. 3 shows the intensity-frequency fitting curves of Fengzhen, Lingqiu, Shuozhou and Zhangjiakou, as well as the value of a and b. After the fitting finished, the curve slope is close to zero since the intensity observations of part units are much at one, which runs counter to a fact that the intensity observations distribution of any unit reduces as the intensity degree grows. On the above basis the average value of minus b, is seen as the average curve slope and applied to each unit, that is the slope for the intensity-frequency relationship of each unit equals to minus 0.29. Re-fitting the intensity-frequency curves of all the units in the study area with a certain slope minus 0.29 keeping the curves distribute on the two sides of the intensity-frequency points [14] (Fig. 3).

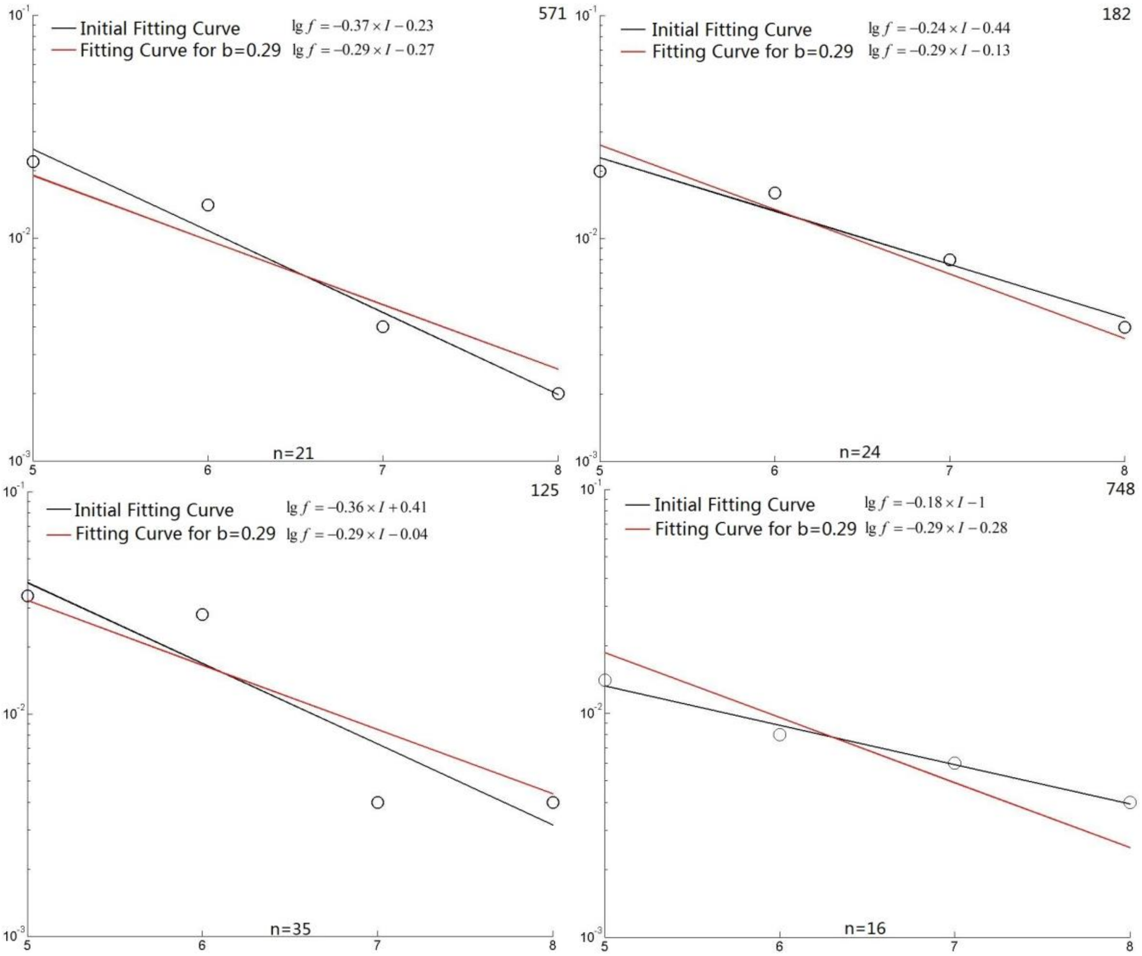

Figure 3. The frequency-intensity curves for Fengzhen, Lingqiu, Shuozhou and Zhangjiakou cell

TABLE II. RETURN PERIOD OF DIFFERENT INTENSITY FOR VARIOUS CITIES AND COUNTIES OF THE STUDY AREA

Toponymy	Epicenter		No.	observations	Return period (years)			
	Latitude	longitude			I = Ⅴ	I = Ⅵ	I = Ⅶ	I = Ⅷ
Jining	41.05 °	113.15 °	812	18	45	87	170	331
Fengzhen	40.45 °	113.04 °	571	21	52	102	199	389
Yanggao	40.34 °	113.64 °	537	25	37	72	141	275
Hunyuan	39.65 °	113.76 °	258	29	37	72	141	275
Yuxian	39.76 °	114.45 °	305	22	59	115	224	437
Lingqiu	39.45 °	114.15 °	182	39	38	74	145	282
Shangyi	41.04 °	114.05 °	821	14	68	132	257	501
Zhangbei	41.15 °	114.65 °	867	18	51	100	195	380
Shuozhou	39.36 °	112.45 °	125	25	31	60	117	229
Zhangjiakou	39.37 °	114.15 °	748	26	54	105	204	398

The minimum variance of the curve is given by

$$\prod=\frac{\sum(\lg f_i-\lg f_c)^2}{N_I} \tag{5}$$

where N_I represents the intensity observation number, f represents the annual occurrence rate (f_i represents the frequentness by intensity observations, f_c represents the frequentness by the fitting curve). The minimum variance varies between 0.0001 and 0.8471, there will be giant difference between the fitting value of the intensity-frequency relation and the truth while the unit contains no enough intensity observations, which leads to low correlation (Fig. 4).

The annual occurrence rate f or the average return period τ corresponding to a certain intensity could be estimated with the slope value–b and intercept value a according to the hazard curve formula (4), the above process also can be used for calculating the intensity corresponding to the certain annual occurrence rate or the average return period [15], for example, the intensity value corresponding to an average return period of 100 years could be given by the formula (6) using the relation that the τ and f are the inverse of each other,

$$I = \frac{a+2}{b} \tag{6}$$

the return periods corresponding to the intensity value *V*, *VI*, *VII* and *VIII* in the main counties and cities of the study area are listed in Table II, the intensity distribution to the average return period of 100 years is shown in Fig. 5.

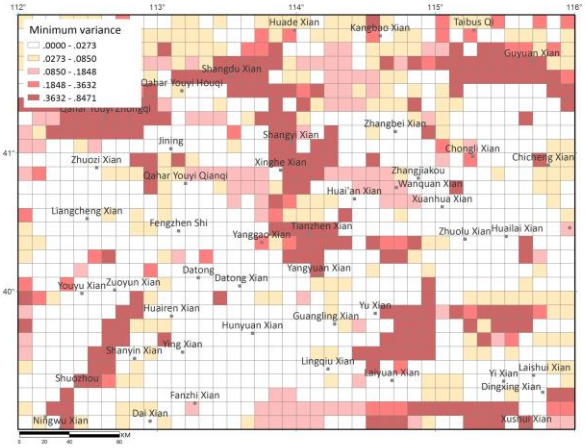

Figure 4. The least squares residual (Π)

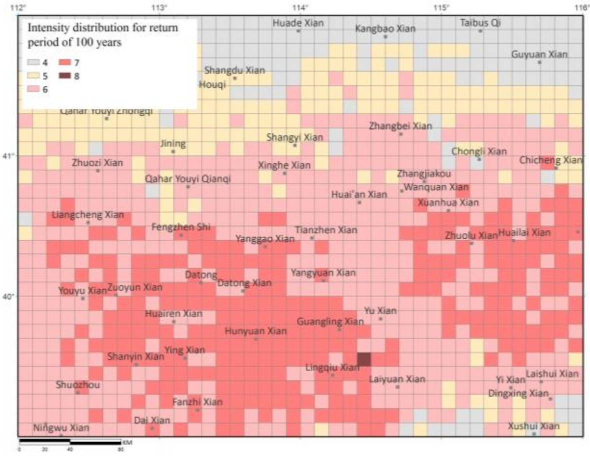

Figure 5. Intensity distribution for return period of 100 years

It is shown in Table II that, (a), except Shangyi area, the return periods in the main cities and counties spread from 60 to 100 years under the premise the intensity *I* reaches *VI*. (b), under the premise the intensity *I* reaches *VII* the return periods within the same region spread from 110 to 260 years. (c), when the intensity *I* reaches *VIII*, except a minority of places, such as Yanggao, Hunyuan, Shuozhou and so on, most counties and cities have the return periods of over 300 years.

As shown in Fig. 5, (a), only the intensity in No. 225 unit of Lingqiu reaches *VIII* with the return period of 100 years. (b), the intensity in most parts of Shanxi, part of Hebei and Beijing in the study area reaches *VII*. (c), the intensity decreases when the latitude grows and the minimum intensity value is *IV*.

IV. Seismic Risk Evaluation

The key phases for making the anti-seismic standard or other anti-seismic actions are evaluating the upper magnitude limit and the criticality for the researching place to predict the location and intensity of the earthquake in the future several decades, the above process is called evaluation for the seismic risk. The paper proposed the Poisson Model to take the evaluation under the assument that occurrence of two different earthquakes independent to each other. The seismic risk, namely the seismic probability *P* of some certain place over a specific intensity(*I*) over a period of time(*t*) can be calculated by,

$$p = 1 - \exp(-t/\tau) \tag{7}$$

where τ expresses the mean return period for *I* is greater than or equals to *I*, *t* expresses the existence time of the certain buildings or facilities. The steady Poisson process for the earthquake indicates the earthquakes could be seen as a series of independent events in time and space. After a massive earthquake happened, the occurrence probability of another massive earthquake will not be changed. The formula (7) could also be used to evaluate the risk of other types of natural hazard, such as the flood and hurricane.

Using the formula (4) and (7) to estimate the seismic risk of each unit. The different exceeding probability in the future 50 years is shown in Fig. 6 and Table III when the intensity *I* is greater than or equals to *VI*, *VII* and *VIII*, respectively.

The overall distribution trend for the exceeding probability in the next 50 years with the different intensity varying between *VI* and *IX* is described as following: the intensity of the medium and southern part of the study area is higher than that in the north part, the highest intensity value is mainly in Liangcheng-Helin district, most of Shanxi and Zhuolu-Yanqing district. There is a high probability with the intensity greater than of equals to *VI*, the value in the area south of 41.2° N reaches more than 50%, Liangcheng-Helin district, enclosed area by Lingqiu-Guangling-Fengzhen-Youyu-Shuozhou and Yanqing-Xuanhua-Zhuolu district has a probability over 70%, by comparison, the probability value in the area north of 41.2°N decreases when the longitude increases; the distribution areas keeping the highest probabilities varying between 40% and 60% with the intensity greater than or equals to *VII* are Liangcheng-Helin district, enclosed area by Hunyuan-Datong-Youyu-Shangyin-Daixian-Fanzhi, Guangling-Lingqiu district and Zhuolu-Huailai-Yanqing district; most parts of the study area have low probabilities under 15% with the intensity greater than or equals to *VIII* except the Datong-huairen and Yanqing district, which have the exceeding probability over 30%.

V. Conclusions

The key to seismic risk evaluation is establishing the curve of the seismic intensity and its frequency(in year), which mainly based on (a), rich historical seismic intensity data is the reliable resource for evaluating seismic risk, (b), evaluation results in the form of probability could be applied for anti-seismic project construction appropriately [16]. It is noted that from the return periods to different intensity in the study area in Table II the return periods to the intensity *VI*of most parts of the study area is less than or equals to 100 years; the return periods to the intensity *VII* vary between 100 and 300 years; while the return periods to the intensity *VIII* change from 200 to 500 years.

TABLE III. SEISMIC RISK FOR MAJOR COUNTIES IN THE STUDY AREA

Toponymy	Epicenter		No.	Exceeding probability to $I \geqslant VI$(%)	Exceeding probability to $I \geqslant VII$(%)	Exceeding probability to $I \geqslant VIII$(%)
	Latitude	longitude				
Jining	41.00 °	113.10 °	812	66	36	9
Fengzhen	40.45 °	113.04 °	571	63	27	12
Yanggao	40.35 °	113.74 °	538	52	38	15
Hunyuan	39.65 °	113.75 °	258	72	36	18
Yuxian	39.76 °	114.45 °	305	57	37	14
Lingqiu	39.45 °	114.15 °	182	75	46	20
Shangyi	41.05 °	113.95 °	820	31	24	13
Zhangbei	41.15 °	114.64 °	867	59	34	14
Shuozhou	39.36 °	112.45 °	125	84	32	18
Zhangjiakou	40.85 °	114.84 °	748	59	39	20

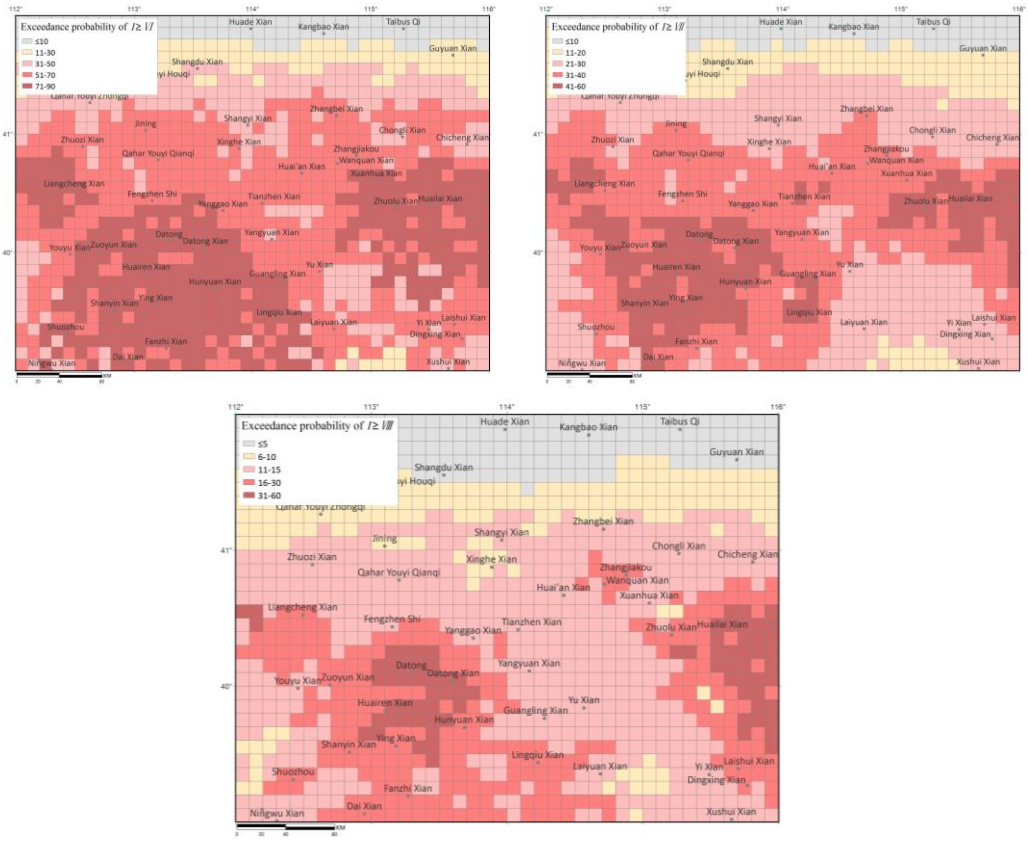

Figure 6. Exceedance probability of I ≥VI, VII, VIII in 50 years in the study area

Evaluation results for seismic risk of the study area are listed as following; (a), the exceeding probability in the next 50 years with the intensity greater than or equals to *VI* in most region of the study area except the Shangyi area is over 50%, the highest probability value is 84% in Shuozhou; (b), the exceeding probability in the next 50 years with the intensity greater than or equals to *VII* varies between 20% and 50%, in a word, its value decreases when the latitude increases; (c), the exceeding probability in the next 50 years with the intensity greater than or equals to *VIII* is less than or equals to 20%, the lowest value is 9% in Jining and the highest value is 20% in Lingqiu and Zhangjiakou. According to the seismicity trend at present, in the future 50 years, the probability encountering the intensity *VI*, *VII* and *VIII*of the study area is greater than 53%, 30% and 14%, respectively(Fig. 6).

The intensity-frequency relationship from G-R empirical correlation is suitable for most types of earthquakes. Since the actual magnitude distributions have great deviations with that by G-R relationship[17], based on which, then intensity-frequency curve has the same defects. The magnitude and frequency relation of the sensible and weak shocks happened in the incubation of the few strong earthquakes does not obey G-R relationship[18]. The bias of the two relationships should be discussed in the future work to provide the right supplement.

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