Correlative Study between Ground Motion Parameters and Geological Hazards Distribution in Bailong River Basin

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Abstract: Bailong river basin is located at the north-east margin of Qinghai-Tibet Plateau. It is a high seismic intensity region with a frequent occurrence of earthquakes and also a geo-hazards developed regions with intensive landslides and debris flows. Based on comprehensive isoseismal lines of historical earthquakes and the result of ground motion parameters zoning, the deterministic zoning of seismic intensity (I) and peak ground acceleration (PGA) in Bailong river watershed were given. For each zone of seismic intensity and PGA, the number of landslides and debris flows and some geological hazard statistical parameters such as hazard number, hazard develop rate, and the density of hazard occurrence were calculated and analyzed. The results show that there was a positive correlation between the geological hazard statistical indices and seismic intensity and PGA value. Higher the seismic intensity (I) and PGA value, larger the geological hazard statistical indices in a seismic zone. Using a logarithmic function method, the fitting functions between the hazard occurrence density of landslides and debris flows and the value of seismic intensity or PGA value were obtained with a high fitting degree, which can be applied as reference of geological hazards evaluation for the similar geologic environment.

1 INTRODUCTION

As a branch of Yangtze River, Bailong river is located in the northeast margin of Qinghai-Tibet Plateau and also the north section of the north south seismic belt, where active tectonics is well developed and many large historic earthquakes occurred (Figure 1). For large areas the river flows through high mountains and deep valleys with high seismic intensity. Complicated geology structure and unique landform make the Bailong river basin one of the regions with most severe debris-flow and landslide damages in China (Meng et al., 2013).

According to the investigation data, more than 80% of the landslides in Wudu County in Bailong river basin related to earthquake and the large earthquake of Ms8 in 1879 played a crucial role in the aggravated water and soil loss and development of landslide and debris-flow in the last 100 years in the middle reaches of Bailong river (Tang, 1992). In the night of Aug. 7, 2010, torrential rainfall in Zhouqu County triggered a devastating mudslides which caused heavy casualties and property losses including 1463 dead and 302 missing (Zhang and Zhang, 2011). The mudslides blocked Bailong River and a dangerous barrier lake formed. Research shows that the Wenchuan Ms8 earthquake in 2012 weakened the mountain slopes, which is the main cause of the extraordinary serious natural calamity together with half year's drought and subsequent strong rainfall. So seismic action influences and strongly controls the geological hazard in Bailong River basin (Tang, 1992; Zhang and Zhang, 2011; Chang et al., 2014; Ma et al., 2014).

To study the relationship between seismic action and geological hazard, the deterministic zoning of seismic intensity (I) and peak ground acceleration (PGA) in Bailong river watershed were given according to comprehensive isoseismal lines of historical earthquakes and the result of ground motion parameters zoning. Based on statistics of the hazard indices of landslide and debris-flow in different seismic zoning area, the relationship between seismic action and geological hazard distribution was discussed and the relation curves were fitted, which can be a reference to the statistics, assessment and forecast of geological disasters in similar geologic settings.

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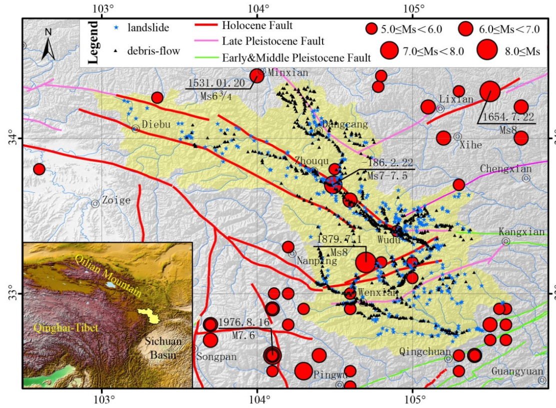

Figure 1: The regional seismotectonic map of Bailong River Basin and distribution of geological hazards. (the yellow region is Bailong River Basin).

2 SEISMIC ZONING

As the distribution of geological hazards is a cumulative result of long-time seismic geological action and the time span is much longer than the historic earthquake cycle of seismic zones, the correlative study between hazard distribution and seismic effect should be based on long-term seismic action -- i.e. deterministic seismic zoning based on tectonic activity study, which can be determined by the maximum historical earthquake method and seismo-tectonic method (Hu, 1999).

The historic earthquake records and modern seismic activities show that the earthquakes controlling the distribution of maximum seismic intensity in Bailong River basin mainly include the earthquake Ms7-71/4 in -186A.D. west to Wudu, earthquake Ms63/4 in 1537 near Minxian, earthquake Ms8 in 1654 South to Tianshui, earthquake Ms8 in 1879 south to Wudu, earthquake Ms7.2 in 1976 near Songpan and Pingwu, earthquake Ms5.9 in 1987 north to Diebu (Figure 1) and Wenchuan Ms8 earthquake in 2008. Summarizing these earthquakes' records and isoseismal lines (Yuan et al., 2007; Zheng et al., 2007; Yuan et al., 2017; Yuan et al., 2014; Hou, 1989; Xing and Xu, 2011), the comprehensive isoseismals of historical earthquakes can be obtained by determining the maximum seismic intensity suffered from all the history earthquake for each place.

Seismic ground motion parameter zonation uses probability method (Hu, 1999), which has an overall consideration of seismogenic structure, potential earthquake capacity, historic earthquake and elapsed time, etc. Paleo-earthquake research revealed that the earthquake recurrence period is about hundreds to thousands years (James, 2009), so the seismic ground motion parameters under exceeding probabilities of 0.01% can be seem as the deterministic seismic parameters based on tectonic activity study.

By using the results of the division of potential seismic source areas, ground motion attenuation relationship and seismic activity parameters adopted in the latest version of seismic zoning map of China (GB18306-2015, 2015), the distribution of seismic intensity (I) and horizontal peak ground acceleration (PGA) under exceeding probabilities of 0.01% in Bailong River Basin were calculated. Combining with the comprehensive isoseismals of historical earthquakes above, the deterministic zoning map of seismic intensity I and PGA in Bailong river basin were achieved. Figure 2 shows the zoning results and also the distribution of landslides and debris flows.

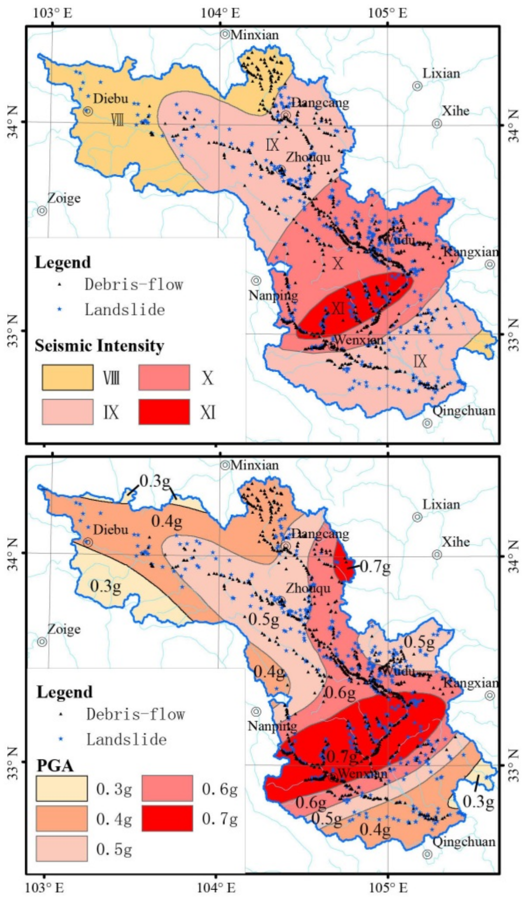

Figure 2: The deterministic zoning map of seismic intensity I and PGA in Bailong River basin.

3 GEOLOGICAL HAZARD STATISTICAL INDICES

There are many factors influencing the occurrence of seismo-geological hazard (Chen et al., 2013; Qi et al., 2009). Aiming at the correlations between ground motion parameters and geological hazards distribution in Bailong River Basin, this study used the following geological hazard statistical indices.

- Hazard Number DA_{ji}

DA_{ji} means the hazard number of category or data section *j* (such as *I* or *PGA* value) to factor *i* (such as landslide or debris flow) in the research area.

- Hazard Develop Rate R_{ji}

The definition of R_{ji} is

$$R_{ji} = \frac{DA_{ji}/DA}{A_{ji}/A} \quad (1)$$

Where A is the area of study region, A_{ji} is the area of category or data section j to factor i, and DA is the total hazard number.

- Density of Hazard Occurrence ρ_{ji}

Density of hazard occurrence means the hazard number in unit area, i.e.

$$\rho_{ji} = DA_{ji}/A_{ji} \quad (2)$$

Where A_{ji} is the area of category or data section j to factor i, and DAji is the hazard number of category or data section j to factor i in the research area.

For each seismic intensity zone and horizontal PGA zone, Table 1 and Table 2 list the above three indices calculated separately.

Table 1: Geological hazard statistical indices in different seismic intensity zone.

Seismic intensity	Area /Km^2	Landslide number DA_{j1}	Debris-flow number DA_{j2}	Landslide develop rate R_{j1}	Debris-flow develop rate R_{j2}	Density of Landslide Occurrence ρ_{j1}	Density of Debris-flow Occurrence ρ_{j2}
8	4546	25	83	0.264	0.496	0.0055	0.0183
9	9515	186	245	0.938	0.699	0.0195	0.0257
10	5533	164	361	1.422	1.772	0.0296	0.0652
11	1184	58	76	2.351	1.743	0.0490	0.0642
Sum	20778	433	765				

Table 2: Geological hazard statistical indices in different PGA zone.

Seismic intensity	Area /Km^2	Landslide number DA_{j3}	Debris-flow number DA_{j4}	Landslide develop rate R_{j3}	Debris-flow develop rate R_{j4}	Density of Landslide Occurrence ρ_{j3}	Density of Debris-flow Occurrence ρ_{j4}
0.3g	1608	2		0.060		0.0012	
0.4g	6086	78	117	0.615	0.923	0.0128	0.0192
0.5g	5874	129	179	1.054	1.462	0.0220	0.0305
0.6g	3830	123	264	1.541	3.308	0.0321	0.0689
0.7g	3382	101	205	1.433	2.909	0.0299	0.0606
Sum	20778	433	765				

4 CORRELATIVE STUDY

Figure 3 shows the statistical relationships between ground motion parameters and geological hazards statistical indices. The figures indicate that the hazard number DA relates to area of zone as same as ground motion parameters I and PGA. Except PGA zone 0.7g due to epicenter magnitude saturation in seismic risk assessment, Landslide develop rate R has positive correlation with seismic intensity (I) and PGA value, higher I and PGA value, larger R in a seismic zone. Debris-flow develop rate R has also positive correlation with I and PGA value, but obviously influenced by other factors meanwhile. Hazard occurrence ρ of landslide and debris-flow has more consistent positive correlations with ground motion parameters I and PGA. Well correlative relations show that the seismic action in Bailong River basin greatly influences and controls the occurrence and distribution of landslide and debris-flow.

Comparing the results of the three indices, density of hazard occurrence ρ can show the correlative relationship between ground motion parameters and geological hazards better. Refer to the relation between seismic energy and seismic parameter I and PGA, the logarithmic function was adopted to fit the relation between density of landslide and debris flow occurrence and seismic parameter I and PGA, separately. Figure 4 shows the fitting curves and original scattered data and the fitting equations as following.

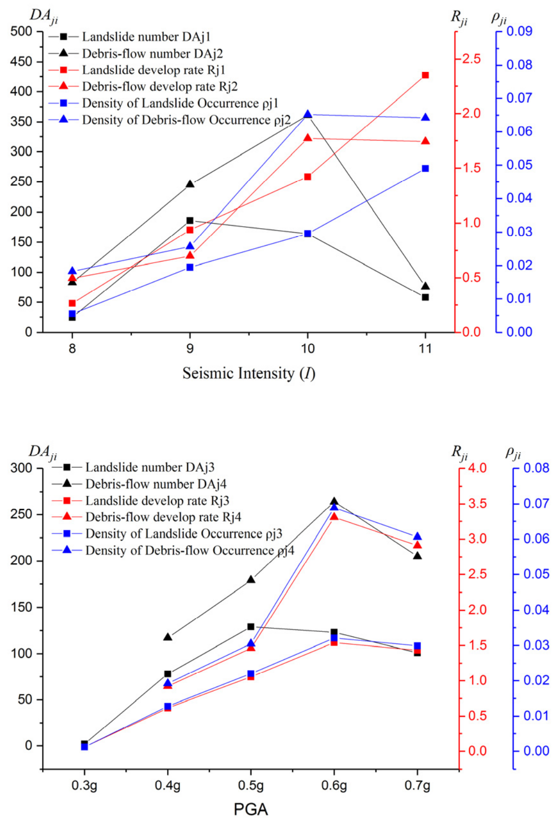

Figure 3: Statistical relationship between ground motion parameters and geological hazards statistical indices.

Fitting equation between seismic intensity I and density of landslide occurrence is as:

$$\log_{10}\rho_1 = 0.30301I - 4.58023 \quad R=0.963 \quad (3)$$

Fitting equation between seismic intensity I and density of debris flow occurrence is as:

$$\log_{10}\rho_2 = 0.20418I - 3.36618 \quad R=0.938 \quad (4)$$

Fitting equation between PGA and density of landslide occurrence is as:

$$\log_{10}\rho_3 = 1.99472PGA - 2.67865 \quad R=0.995 \quad (5)$$

Fitting equation between PGA and density of debris flow occurrence is as:

$$\log_{10}\rho_4 = 2.77276PGA - 2.85099 \quad R=0.987 \quad (6)$$

In Equation1, Equation 2, Equation 3 and Equation 4, R is the correlation coefficient.

These equations can be used to evaluate the landslide and debris-flow hazard around Bailong river or for the similar geologic environment region.

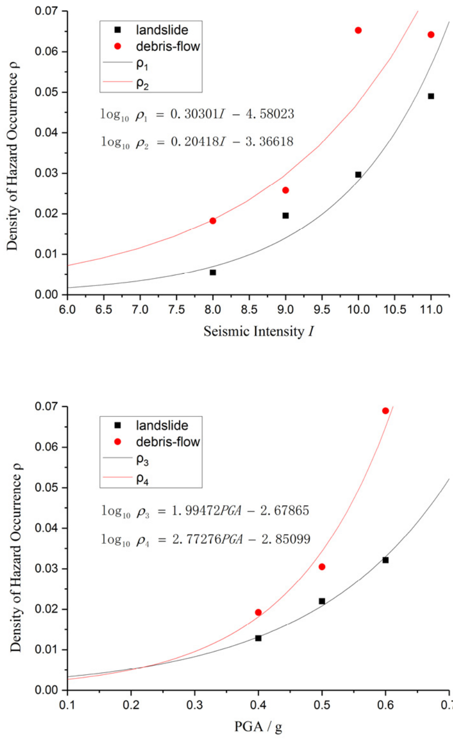

Figure 4: The fitting curves between density of hazard occurrence and I and PGA.

5 DISCUSSION AND CONCLUSIONS

Bailong River basin belongs to high seismic intensity region with frequent occurrence of earthquakes and also regions with most severe debris-flow and landslide damages in China. The developments of landslide and debris flow hazard are well related to seismic action. The results show that there is a positive correlation between the geological hazard statistical indices and seismic intensity (I) and PGA value in Bailong River basin, higher I and PGA value, larger the geological hazard statistical indices in a seismic zone. The fitting equations also show that density of landslide and debris flow occurrence ρ and seismic parameter I and PGA have well logarithmic relationship.

The main causes of widely developed landslide and debris flow hazards in Bailong River basin are not only the active geology structures and strong earthquake activities but also the steep and high topography, weak and broken rock stratum, intensive rainfall, sharp river cutting, lower vegetation coverage and unreasonable human engineering activities (Tang, 1992). This research discussed only the relation between earthquake intensity and geological hazard distribution, and ignored the scale and time of the landslides and debris flows, which is not extremely scientific and rational. Anyway the well positive correlation and fitting equations between the geological hazard statistical indices and seismic intensity (I) and PGA can be applied as reference of geological hazards evaluation around Bailong river basin or for regions with similar geologic environment.

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