Damage and Seismic Intensity of the 1996 Lijiang Earthquake, China: A GIS Analysis

HE Honglin*, OGUCHI Takashi*, ZHOU Ruiqi**,
ZHANG Jianguo** and QIAO Sen**

*Center for Spatial Information Science, University of Tokyo, Bunkyo, Tokyo 113-0086, Japan

**Yunnan Seismological Bureau, Kunming, Yunnan 650041, China

Abstract: The damage caused by the 1996 Lijiang earthquake in China was analyzed using Geographic Information Systems (GIS). Data for the Lijiang district were collected from the local government offices and were converted into GIS data layers. The damage ratio of houses, seismic intensity and the occurrence of casualties were mapped. The results show that the distributions of seismic intensity and the damage ratio of houses reflect the occurrence of thick alluvium and the structure of fault systems.

Key words: the 1996 Lijiang earthquake, damage index, seismic intensity, GIS

Introduction

The four recent large earthquakes in Asia, the 1995 Kobe in Japan, the 1996 Lijiang in China, the 1999 Jiji in Taiwan and the 2001 Bhuj in India led to catastrophic disasters. Evaluation of such earthquake disasters serves for damage mitigation and future city planning. Studies concerning the 1995 Kobe (Hanshin-Awaji) earthquake in Japan (e.g. Usui and Konagaya 1995; Iwai et al. 1996; Hatayama et al. 1999) have shown that GIS (Geographic Information Systems) provide useful tools for evaluating earthquake disasters.

In recent years, many Chinese researchers have been interested in computer analysis of earthquake disasters. For example, China Seismological Bureau (1998) developed software "Earthquake Disaster Loss Estimation System (EDLES)" with a graphic user interface for the Windows operation system. GIS applications to earthquakes in China, however, have been limited to the mapping of seismic zones (e.g., Zhou 2001). It is necessary to analyze earthquake damage in China using GIS, although governmental restrictions generally prevent access to data for disasters in China.

On the 3rd of February, 1996, a severe earthquake with a magnitude of 7.0 in the Richter scale shook Lijiang and surrounding areas of

Yunnan Province in China (Figure 1). It affected more than one million people in nine counties of four administration districts (Lijiang, Dali, Diqing, and Nujiang), resulting in the death of 309 people and the injury of 17,057 people. More than one million houses were damaged and many public infrastructures and facilities were broken. The economic loss due to the earthquake amounts to 2.583 billion RMB or ca. 320 million US dollars (Liu 1998a). We collected information regarding the damage of the Lijiang earthquake, and converted them into GIS data for analysis.

Data

Building damage ratios and earthquake damage index

About 10 hours after the Lijiang earthquake, the field investigation team of the Yunnan Seismological Bureau arrived in Lijiang to collect information about the damage. Although some general reports were published based on the collected data (Huangfu 1997; Han and Zhou 1997), most of these data have been classified by the local government. We were, however, allowed to use the data of building damage ratios for 111 villages and death toll in the Lijiang district.

Han and Zhou (1997) proposed the classifica-

Figure 1. Map of Lijiang County.
Each fault system consists of a few faults.

Table 1. Classification of houses in China

Type	Description
I	Simple and crude sheds, made of sun-dried mud brick and/or rubble, covered with straw and mud
II	1) Low-cost houses, made of rammed earth, sun-dried mud brick and/or rubble; 2) old wood-framed houses
III	1) Firm wood-framed houses such as temples; 2) modern houses made of brick and rubble; 3) houses made of brick and concrete; 4) houses framed with concrete

Source: Xie 1957.

tion of buildings and damage grades applicable to the Lijiang earthquake. In China, houses are divided into three types: I, II, and III (Xie 1957; Table 1). Han and Zhou (1997) note that most houses affected by the Lijiang earthquake belong to the types II and III, and that they can be further divided into eight sub-types shown in Table 2.

Xie (1957) classified building damage due to earthquakes into four grades. Han and Zhou

(1997) modified this classification and applied five damage grades to the Lijiang earthquake (Table 3).

Investigation Team of Earthquake Influence Field of Tonghai Earthquake (1977) introduced the damage index (*DI*) to quantify the degree of earthquake damage. The estimation of *DI* is threefold: 1) selection of a representative type of house; 2) estimation of the ratio of damage grades for the house type; and 3) calculation of

Table 2. Classification of houses in the Lijiang district

Type	Description
II-1	Houses made of rammed earth including some crushed stones, covered with tiles
II-2	Houses made of sun-dried mud brick with wood frames; walls are made of sun-dried brick or rammed earth; struts consist of irregular wood frames; covered with tiles
II-3	Houses made of sun-dried mud brick with brick pillars; walls are made of sun-dried brick; struts consist of brick pillars; frames are made of wood, covered with tiles
II-4	Single-story houses made of brick; struts are made of lower-level concrete; frames are made of wood; covered with tiles
III-1	Naxi tribe's houses made of wood and earth; wood frames bear the load; walls are made of earth and covered with tiles; usually two stories and about 7 m in height; known as the Naxi national folklore houses
III-2	Naxi tribe's houses made of wood and brick; frames are similar to those of III-1; walls are made of brick
III-3	Houses made of brick and concrete; two or three stories; built after the 1980s; struts consist of steel and concrete pillars to resist earthquakes with Intensity VIII
III-4	Houses framed by steel and concrete, including buildings taller than four stories; usually designed to resist earthquakes with Intensity VIII or higher.

Source: Han and Zhou 1997.

Table 3. Classification of building damage due to the Lijiang earthquake

Grade	Description
1: collapsed	Collapsed or seriously damaged; removal and reconstruction are needed
2: terribly damaged	Serious damage to principal parts or partly collapsed; intensive repair and partial removal are needed
3: moderately damaged	Obvious damage to non-principal parts and/or some damage to principal parts; can be used after repair or reinforcement
4: slightly damaged	Damage to non-principal parts and/or slight damage to principal parts; can be used without repair
5: little damage	No damage or very slight damage to non-principal parts

Source: Han and Zhou 1997.

Table 4. Standard earthquake disaster parameter applied to the Lijiang earthquake

Damage grade	5	4	3	2	1
Standard damage parameter	0	0.2	0.4	0.7	1.0

DI using the following formula:

$$DI = \sum_j p_j \cdot AR_j \quad (1)$$

where j is the damage grade (1, 2, ..., n), p_j is the standard damage parameter for the j -th damage grade and AR_j is the areal ratio of houses belonging to the j -th damage grade. In the area affected by the Lijiang earthquake, Naxi tribe's houses of the III-1 type occurred widely, and thus they are suitable for the calculation of DI . Investigation Team of Earthquake Influence Field of Tonghai Earthquake (1977) determined

the values of p_j for such houses made of wood and earth. Using these values, we derived p_j corresponding to the five damage grades of Han and Zhou (1997) (Table 4). Table 5 shows the areal ratios of houses with different damage grades for the 111 villages, as well as the DI calculated using Eq. (1).

Seismic intensity

Xie (1957) proposed 12 grades of seismic intensity applicable to China, and China Seismological Bureau (1977) estimated DI correspond-

Table 5. Areal ratio of III-1-type houses with different damage grades, (AR_1 to AR_5), damage index (DI) and estimated seismic intensity for 111 villages

No.	Village	AR_1	AR_2	AR_3	AR_4	AR_5	DI	Est. Intensity
1	Mingyin	0.05	0.42	0.38	0.15	0	0.52	IX
2	Daju (Yingpan)	0.04	0.83	0.12	0	0	0.68	IX
3	Toutai	0	0.06	0.88	0.03	0.03	0.4	VIII
4	Guoluo	0.06	0.56	0.39	0	0	0.61	IX
5	Yuhu	0.06	0.65	0.29	0	0	0.63	IX
6	Yulong	0.09	0.64	0.27	0	0	0.65	IX
7	Wenhuazhongcun	0.19	0.43	0.26	0.12	0	0.62	IX
8	Longshan	0.13	0.42	0.33	0.11	0	0.58	IX
9	Xiacun	0.15	0.5	0.33	0.02	0	0.57	IX
10	Wenhua	0.31	0.38	0.31	0	0	0.65	IX
11	Shipingxiacun	0.25	0.32	0.42	0	0	0.64	IX
12	Jinshan	0.12	0.34	0.51	0.03	0	0.57	IX
13	Dadong	0.3	0.46	0.17	0.07	0	0.7	IX
14	Liangmei	0.36	0.26	0.32	0.06	0	0.68	IX
15	Wutai	0.11	0.81	0.08	0	0	0.69	IX
16	Shanglidu	0	0.67	0.16	0.13	0.15	0.59	IX
17	Kazi	0.04	0.11	0.18	0.41	0.26	0.27	VII
18	Mingyin (Xicaiban)	0.33	0.46	0.01	0.03	0.48	0.46	VIII
19	Boliluo	0.03	0.07	0.47	0.37	0.06	0.34	VIII
20	Buguzi	0	0.45	0.36	0.05	0.09	0.47	VIII
21	Xuehuacun	0	0.42	0.32	0.26	0	0.47	VIII
22	Laozhichang	0.07	0.81	0.12	0	0	0.67	IX
23	Qingsong	0.12	0.41	0.47	0	0	0.5	VIII
24	Longshantou	0	0.9	0.05	0.05	0	0.65	IX
25	Yiwanshui	0.13	0.8	0.07	0	0	0.71	X
26	Xinhuoshan	0.31	0.42	0.16	0.11	0	0.69	IX
27	Jiuzihai	0.41	0.53	0.06	0	0	0.78	X
28	Xiangyang	0	0.7	0.3	0	0	0.62	IX
29	Gantangzi	0.26	0.59	0.15	0	0	0.48	VIII
30	Lariguang	0.32	0.57	0.07	0	0	0.75	X
31	Wenming	0	0.61	0.38	0	0	0.58	IX
32	Xiachangshui	0	0.01	0.79	0.2	0	0.36	VIII
33	Wenbi	0.04	0.25	0.61	0.1	0	0.49	VIII
34	Xiashuhe	0	0.45	0.22	0	0	0.47	VIII
35	Zhonghe	0.05	0.81	0.12	0	0	0.66	IX
36	Xilinwa	0.06	0.87	0.03	0.05	0	0.69	IX
37	Dalai	0.06	0.4	0.46	0.08	0	0.54	IX
38	Qiliang	0.22	0.45	0.3	0.02	0	0.65	IX
39	Zegu	0.12	0.73	0.14	0.01	0	0.69	IX
40	Shangcunren	0.83	0.16	0.01	0	0	0.94	X
41	Wenzhi	0.93	0.07	0	0	0	0.93	X
42	Tuanshang	0	0.15	0.85	0	0	0.44	VIII
43	Luocheng	0	0.23	0.61	0.12	0	0.47	VIII
44	Qingxi	0.06	0.29	0.35	0.29	0	0.45	VIII
45	Meiluo	0	0.2	0.76	0.44	0	0.52	IX
46	Zhonghai	0.55	0.45	0	0	0	0.87	X
47	Qihe	0	0.43	0.32	0.25	0	0.48	VIII
48	Shudi	0	0.42	0.33	0.25	0	0.47	VIII
49	Junliang	0.06	0.27	0.62	0.04	0	0.38	VIII
50	Yachakou	0.03	0.03	0.58	0.22	0.14	0.33	VIII
51	Xinmin	0.03	0.06	0.89	0.02	0	0.43	VIII
52	Geben	0.08	0.19	0.27	0.32	0.14	0.39	VIII
53	Shengsepo	0	0.31	0.38	0.15	0.16	0.4	VIII
54	Yongan	0	0.24	0.45	0.3	0	0.41	VIII
55	Xinminzhongcun	0	0.16	0.24	0.49	0.11	0.31	VIII
56	Sangu	0	0.23	0.32	0.29	0.16	0.35	VIII
57	Zengming	0	0.2	0.35	0.3	0.15	0.34	VIII
58	Jiyu	0.03	0.05	0.44	0.43	0.05	0.33	VIII

Table 5. Continued

No.	Village	AR_1	AR_2	AR_3	AR_4	AR_5	DI	Est. Intensity
59	Lashi	0.08	0.1	0.17	0.36	0.29	0.3	VII
60	Haidong	0.08	0.28	0.53	0.05	0.06	0.59	IX
61	Enzuo	0	0.01	0.44	0.44	0.11	0.37	VIII
62	Lijiang	0.01	0.01	0.31	0.69	0.01	0.26	VII
63	Changsong	0	0.03	0.04	0.5	0.43	0.26	VII
64	Jiangbian	0.2	0.14	0.48	0.15	0.03	0.59	IX
65	Haba	0.02	0.06	0.43	0.45	0.28	0.33	VIII
66	Baidi	0.01	0.3	0.2	0.39	0.09	0.39	VIII
67	Meizi	0.45	0.36	0.13	0.02	0.04	0.7	IX
68	Xintun	0	0.21	0.38	0.36	0.05	0.37	VIII
69	Jinsuo	0	0.17	0.18	0.65	0	0.32	VIII
70	Zhongjicun	0	0.03	0.07	0.89	0	0.23	VII
71	Tianxin	0.01	0	0.13	0.86	0	0.23	VII
72	Qiaotou	0	0	0.06	0.9	0.04	0.2	VII
73	Gaoshicun	0.07	0	0.08	0.5	0.35	0.2	VII
74	Guifeng (Sanyuan)	0.05	0.39	0.56	0	0	0.55	IX
75	Shounan	0.01	0.15	0.65	0.19	0	0.41	VIII
76	Baojicun	0.01	0.04	0.7	0.25	0	0.37	VIII
77	Guangming	0	0.08	0.24	0.27	0.41	0.21	VII
78	Shimenkan	0	0.09	0.19	0.2	0.52	0.18	VII
79	Xichuan	0	0.13	0.25	0.21	0.41	0.23	VII
80	Changping	0	0.1	0.3	0.24	0.36	0.24	VII
81	Guantian	0	0.12	0.25	0.29	0.34	0.24	VII
82	Jiuhe	0	0.06	0.27	0.3	0.37	0.21	VII
83	Xinren	0	0.08	0.22	0.39	0.31	0.22	VII
84	Sanba	0	0.09	0.25	0.35	0.31	0.23	VII
85	Yitou	0	0.12	0.24	0.28	0.37	0.24	VII
86	Hongmai	0	0	0.4	0.47	0.13	0.25	VII
87	Daan	0	0.09	0.36	0.18	0.36	0.24	VII
88	Songping	0	0.13	0.26	0.23	0.38	0.24	VII
89	Puzi	0	0	0.06	0.47	0.47	0.12	VII
90	Longpan (Xinlian)	0	0.1	0.4	0.32	0.18	0.29	VII
91	Tuguancun	0	0	0.22	0.33	0.45	0.16	VII
92	Runan	0.04	0.08	0.36	0.4	0.12	0.33	VIII
93	Jizi	0	0.11	0.28	0.39	0.22	0.27	VII
94	Dachang	0	0	0.17	0.23	0.6	0.11	VII
95	Qingkou	0	0	0.08	0.12	0.8	0.05	VI
96	Shigu	0	0.02	0.03	0.05	0.9	0.03	VI
97	Dongling	0	0	0.2	0.05	0.75	0.09	VI
98	Diannan	0	0.01	0.07	0.37	0.55	0.1	VI
99	Xiaozhongdian	0	0	0	0.68	0.32	0.13	VII
100	Songgui	0	0	0.11	0.21	0.68	0.08	VI
101	Meiyuan	0	0	0.16	0.27	0.57	0.11	VII
102	Xiyi	0	0	0.09	0.3	0.61	0.1	VI
103	Duomei	0	0	0.12	0.18	0.7	0.08	VI
104	Lanping	0	0	0.1	0.2	0.7	0.08	VI
105	Hongqiao	0	0	0.04	0.33	0.63	0.09	VI
106	Jiulong	0	0	0	0.75	0.25	0.15	VII
107	Annan	0	0	0	0.38	0.62	0.08	VI
108	Paomaping	0	0	0	0.2	0.8	0.04	VI
109	Yongning	0	0	0.15	0.82	0.03	0.22	VII
110	Jinguan	0	0	0.1	0.29	0.61	0.09	VI
111	Junhe	0	0	0.01	0.51	0.48	0.1	VI

ing to these grades (Table 6). The seismic intensity estimated from DI for the 111 villages in the Lijiang district is shown in Table 5. Although such intensity estimation requires de-

tailed data of building damage ratios, seismic intensity has often been approximated based on rapid field observations of the damage. For example, Han and Zhou (1997) drew contours of

Table 6. Seismic intensity grades applied to China

Intensity grade	Perception of people	Damage of general wooden houses (equivalent to the III-1 type)		Other phenomena	Seismic components	
		Change and damage	Damage index (DI)		Horizontal acceleration (cm/s ²)	Horizontal velocity (cm/s)
I	Not perceptible		—			
II	Less than 10% of unmoving people in rooms perceive		—			
III	50-70% of unmoving people in rooms perceive	Doors and windows lightly tremble	—	Hanging things lightly sway		
IV	50-70% of people in rooms and 10-50% of people outside perceive; 10-50% of sleeping people are shaken up	Doors and windows tremble	—	Hanging things obviously away		
V	Almost all people in rooms and 50-70% of people outside perceive; 50-70% of sleeping people are shaken up	Doors, windows, roofs and roof trusses tremble; dust falls and some mortar gets fissured	—	Unstable things fall down	22~24	2~4
VI	Many people get frightened and some people escape out of rooms	Little or no damage to non-frame parts; some tiles fall; walls get fissured lightly	0~0.11	Fissures emerge on banks or weak soil; sand and water spout from saturated sand layers; chimneys get fissured	45~89	5~9
VII	70-90% people escape out of rooms	Light to moderate damage to non-principal parts, or slight damage to principal parts	0.11~0.30	Banks partly collapse; sand and water spout from saturated sand layers; many fissures emerge on weak soil; 70-90% of chimneys get damaged	90~177	10~18
VIII	Difficult to walk because of land swaying and jolting	Obvious damage to non-principal parts, or some damage to principal parts	0.31~0.50	Some fissures emerge on dry and hard soil; 70-90% of chimneys get terribly damaged	178~353	19~35
IX	Impossible to keep seated; moving people may fall down	Serious damage to principal parts, or partly collapse	0.51~0.70	Fissures emerge on hard soil and bedrock; widespread slope failures	354~707	36~71
X	People riding on bicycles may fall down	Collapse or serious damage to almost all buildings	0.71~0.90	Mountain landslides and an earthquake fault emerge; arch bridges on bedrock get damaged; 70-90% of chimneys are destroyed	708~1,414	72~141
XI		All destroyed	0.91~1.00	Widespread mountain landslides; an extended earthquake fault emerges; arch bridges on bedrock destroyed		
XII			about 1.00	Severe landscape changes		

Source: Xie 1957 and China Seismological Bureau 1977.

the intensity of the Lijiang earthquake based on rapid observations in 36 towns (Figure 2).

Death toll

Among the 309 people killed by the Lijiang earthquake, 294 died in Lijiang County. We obtained the death toll data for Lijiang County from the seismological office of the county. Among 294 victims, 241 were directly crushed to death below the collapsed buildings, 25 died because of injury, 2 died because of fire, 3 died because of shock, 6 died because of suffocation and 16 died for other reasons. Major victims were children and aged people (Table 7).

Mapping and Analysis of Earthquake Damage Using GIS

The tabulated data concerning house damage and death toll were converted into GIS data with geographic coordinates. Some paper maps

were also digitized to provide the electronic files of basic map components such as adminis-

Figure 2. Contours of seismic intensity based on rapid field observations.

Source: Han and Zhou 1997.

Table 7. Death toll according to age

Age	<10	10-19	20-29	30-39	40-49	50-59	60-69	>70	unknown
Number	58	23	18	19	16	28	42	61	29

Figure 3. Distribution of seismic intensity based on the damage index.

Figure 4. Distribution of areal ratio of buildings belonging to each damage grade.

Figure 5. Distribution of persons killed in Lijiang County.

trative boundaries, locations of towns and villages, transportation networks and drainage networks. The maps used are "Administrative Division of Lijiang County" (Comprehensive Scientific Investigation Team of Qinghai-Xizang Plateau and Institute of Geography, Chinese Academy of Science 1990), "Administrative Division of Lijiang Administrative District" (Toponym Office of Lijiang Administrative Region 1999) and "Yunnan Province" (Yunnan Institute of Geography 1997). The mapping and analyses of the data were performed with ArcView, a GIS software package from ESRI, USA.

Distribution of seismic intensity

As noted above, Han and Zhou (1997) manually produced the contours of seismic intensity based on field observations in 36 towns (Figure 2). We constructed another map of seismic intensity based on the data in Table 5 (Figure 3). The intensity was derived from the detailed house damage ratios, and the number of the data in Table 5 is larger than that in Han and

Zhou (1997), indicating that Figure 3 is more reliable than Figure 2. Figure 3 shows that the distribution of seismic intensity is complex. For example, Intensity X occurs in three separated areas: around Lijiang (1 in Figure 3), near Dadong (2) and near Daju (3). The areas 1 and 3 correspond to basins with thick alluvium as well as the inferred epicenter along the earthquake fault (Figure 1). The thickness of the alluvium in Lijiang Basin attains 1,200 m (PLA 00939 Troops 1979). Intensity IX around Qihe (4 in Figure 3) also occurs in and around the basin with thick alluvium (Figure 1).

In contrast, Intensity X near Dadong (2) occurs in an area without thick alluvium. This area is characterized by the tectonic intersection of the Lijiang-Jianchuan fault system (F2 in Figure 1) and the Daju-Dadong fault system (F3). F2 underwent left-lateral strike slip with a rate of 1–2 mm/yr and vertical displacement with a rate of 0.2–0.5 mm/yr (Wang 1990). F3, characterized by right-lateral strike slip, caused three large earthquakes in the twentieth century with magnitudes between 6 and 6.4 (Liu

Figure 6. Distribution of death toll ratio.

1998b). Such a complex tectonic structure at the junction of the major active fault systems may have accounted for the enhanced ground movement. The extended distribution of Intensity X to the NNE of Lijiang (1) appears along the eastern side of the east-dipping earthquake fault. This observation indicates that more serious damage took place on the hanging wall of the fault, as has been often observed elsewhere. The comparison between Figures 1 and 3 shows that Intensity IX and X mostly occur within the triangular tectonic block bordered by the three major fault systems: Longpan-Qiaohou (F1), Lijiang-Jianchuan (F2) and Daju-Dadong (F3). F1 is characterized by left-lateral strike slip with a rate of 2.2 mm/yr in the Quaternary (Ran 1990). In addition, the prolongation of the earthquake fault (F4), which also underwent Quaternary left-lateral strike slip, is confined within the tectonic block. Consequently, the structure of fault systems seems to have played an important role in determining the spatial distribution of the earthquake fault,

seismic intensity and building damage.

Distribution of building damage ratios

The damage index (*DI*) and seismic intensity estimated from *DI* can be regarded as generalized parameters of earthquake disasters. Mapping of the original building damage ratios permits more precise investigation of disasters. Figure 4 is GIS-produced maps showing the areal ratio of houses belonging to each damage grade. Collapsed houses tend to occur abundantly around Lijiang, Baisha, and Dadong (1 and 2 in Figure 3). Very dense distribution occurs along a NNE-SSW line through Lijiang. The line corresponds to the Lijiang-Jianchuan fault system (F2 in Figure 1) suggesting that the ground motion was accelerated along the fault. Terribly damaged houses occur distinctly near Daju and Qihe (3 and 4 in Figure 3) as well as the area to the NNE of Lijiang. These observations and the distribution of seismic intensity (Figure 3) show that the same intensity grade may result from different types of house

Figure 7. Death distributions in Lijiang Basin (left) and Lijiang town (right).

damage, depending on physical settings such as fault distribution. The ratio of moderately damaged houses is high in the area between Lijiang and Heqing. Despite the proximity to the area of higher intensity, the area experienced relatively weak damage because of the inter-basin condition without thick alluvium.

Distribution of persons killed

Most deaths due to the earthquake occurred around Lijiang (Figure 5) where many buildings collapsed (Figure 4). In contrast, areas with fewer collapsed houses and abundant terribly damaged houses show a much smaller death toll, reflecting the fact that most victims were crushed below the collapsed buildings.

Figure 6 is a contour map showing the ratio of deaths to total population. The area around Lijiang has high death ratios as well as large death numbers. Although the area close to

Dadong (2 in Figure 3) also has the high ratio of collapse (Figure 5), the death ratio and toll are much smaller than those around Lijiang. This difference may reflect the density of houses. The death distribution in Lijiang is concentrated in the town center (Figure 7) where many wooden houses stand closely along narrow streets. Under such a situation, quick escape to safe places may have been more difficult than in rural areas.

Conclusions

This paper has applied GIS to the evaluation of the damage caused by the Lijiang earthquake in China. The mapping and interpolation functions of GIS have facilitated the analyses of earthquake damage and seismic intensity in more detail than the previous studies. Seismic intensity and the damage ratio of houses do not

decrease simply with an increasing distance from the epicenter, but show complex distribution patterns. Thick alluvium in basins and the structure of fault systems mainly account for this complexity. The density of houses may also have affected the distribution of people killed by the earthquake.

Automated mapping and quantitative data analyses using GIS have been successfully applied to the investigation and mitigation of natural disasters in various countries. In recent years, earthquake disasters repeatedly occurred in China especially in Yunnan Province. It is hoped that modern GIS facilities and spatial databases devoted to Chinese earthquake disasters will be provided in the near future.

Acknowledgment

Honglin He acknowledges the financial support from the Postdoctoral Fellowship Program of the Japan Society for the Promotion of Science (No. P00094). Thanks are due to G. Huangfu, X. An, and other people in the China Seismological Bureau for their kind help during our investigation in China. We also thank A. He, Department of Agriculture, University of Tokyo for supplying maps of Lijiang County.

(Received 5 June 2001)

(Accepted 31 October 2001)

References

- China Seismological Bureau. 1977. *Zonation map of seismic intensity in China, 1 : 3,000,000*. (C)
- China Seismological Bureau. 1998. *Technique guide book and outline of field work in an earthquake disaster*. Beijing: Seismological Press. (C)
- Comprehensive Scientific Investigation Team of Qinghai-Xizang Plateau and Institute of Geography, Chinese Academy of Science. 1990. *The serial agriculture maps of Naxi's Autonomic County, Lijiang, Yunnan Province*. Beijing: Science Press. (C)
- Han, X., and Zhou, R. 1997. Intensity distribution of the M 7.0 Lijiang earthquake. *Journal of Seismological Research* 20-1: 33-46. (C)
- Hatayama, M., Matsuno, F., Kakumoto, S., and Kameda, H. 1999. Development of spatial temporal information system DiMSIS. *Theory and Application of GIS* 7-2: 25-33. (J)
- Huangfu, G. 1997. The M 7.0 Lijiang earthquake in Yunnan on February 3, 1996. *Journal of Seismological Research* 20-1: 1-8. (C)
- Investigation Team of Earthquake Influence Field of Tonghai Earthquake. 1977. Intensity distribution and site effect of Tonghai Earthquake. *Bulletin of Seismic Engineering Research* 3: 1-14. (C)
- Iwai, S., Kameda, H., Usui, T., and Morikawa, H. 1996. GIS application to data management for analysis of urban facility damage in Nishinomiya City by the 1995 Hyokoken-Nambu earthquake. *Theory and Application of GIS* 4-2: 63-73. (J)
- Liu Z. 1998a. Earthquake losses. In *Lijiang Earthquake of 1996*, ed. Yunnan Seismological Bureau and Western Yunnan Earthquake Prediction Study Area, 47-53. Beijing: Seismological Press. (C)
- Liu Z. 1998b. Seismotectonics in the shaken area. In *Lijiang Earthquake of 1996*, ed. Yunnan Seismological Bureau and Western Yunnan Earthquake Prediction Study Area, 64-67. Beijing: Seismological Press. (C)
- PLA 00939 Troops. 1979. *Reconnaissance Survey Report of Hydrogeology, Lijiang, with 1 : 200,000 Maps*. Beijing, Geological Publishing House. (C)
- Ran R. 1990. Lonpan-Qiaohou fault zone. In *Active faults in Northwest Yunnan Province*, ed. Institute of Geology, China Seismological Bureau and Yunnan Seismological Bureau, 83-91. Beijing: Seismological Press. (C)
- Toponym Office of Lijiang Administrative Region. 1999. *Map of Administrative Division of Lijiang Administrative District*. Chengdu: Chengdu Cartographic Publishing House. (C)
- Usui, T., and Konagaya, K. 1995. The distribution pattern of debris in the Hansin-Awaji earthquake: A GIS analysis. *Geographical Review of Japan* 68A-9: 621-633. (J)
- Wang J. 1990. Lijiang-Jianchuan fault zone. In *Active faults in Northwest Yunnan Province*, ed. Institute of Geology, China Seismological Bureau and Yunnan Seismological Bureau, 91-106. Beijing: Seismological Press. (C)
- Xie, Y. 1957. A new scale of seismic intensity adapted to the conditions in Chinese territories. *Acta Geophysica Sinica* 6-1: 35-47. (C)
- Yunnan Institute of Geography 1997. *Map of Yunnan Province*. Chengdu: Chengdu Cartographic Publishing House. (C)
- Zhou, Q. 2001. *Application of artificial intelligence to delineation of potential sources*. PhD dissertation, Institute of Geology, China Seismological Bureau. (C)

(C): written in Chinese

(J): written in Japanese