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Damage and seismic intensity of the 1996 Lijiang Earthquake, China: A GIS analysis

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Abstract The damage caused by the 1996 Lijiang Earthquake in China is analyzed using Geographic Information Systems (GIS). Data for Lijiang District were collected from the local governmental offices and were converted into GIS data layers. Factors affecting the damage ratio of houses, seismic intensity and the occurrence of casualties are examined based on GIS mapping and analyses.

1. Introduction

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

In recent years, many Chinese researchers have been interested in computer applications to 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, as have been performed in Japan after the Hanshin-Awaji earthquake, although governmental offices often restrict the access to Chinese data concerning disasters.

On the 3rd of February, 1996, a severe earthquake with a magnitude of 7.0 in the Richter scale shocked Lijiang and surrounding areas of the 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). 309 people were killed and 17,057 people were wounded. More than one million civil houses were damaged and many public infrastructures and facilities were broken. The economical loss of the earthquake amounts to 2,583 billion RMB or ca. 320 million US dollars (Yunnan Seismological Bureau and Western Yunnan Earthquake Prediction Study Area, 1998). We collected available information regarding the damage of the Lijiang earthquake, and converted them into GIS data layers to perform analyses.

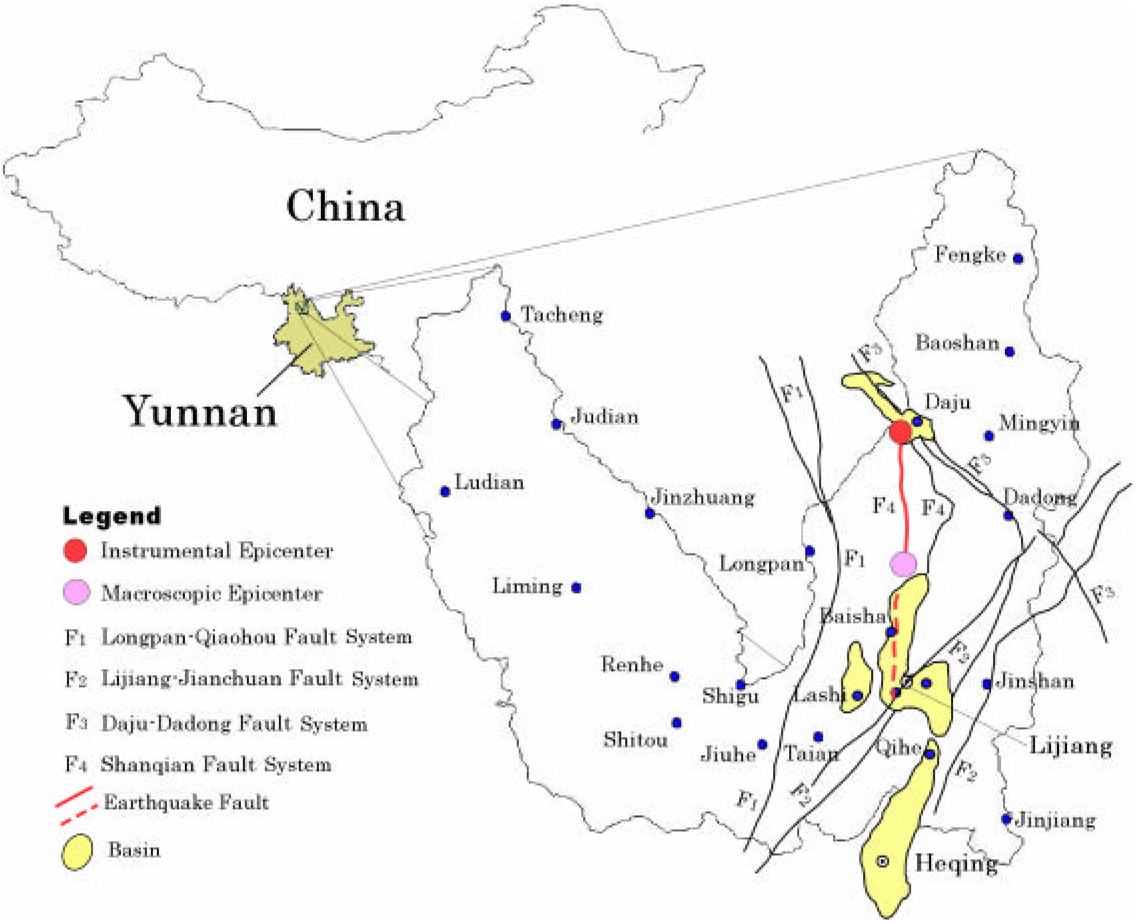

Figure 1 Map of Lijiang County

2. Data

2.1 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 and started collecting information about the damage. Although some general reports were published based on the collected data (Huangfu, 1997; Han and Zhou, 1997), many of source 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 Lijiang District.

Han and Zhou (1997) proposed the classification of buildings and damage grades applicable to the Lijiang earthquake. In China, civil buildings have been divided into three types: I, II and III (Xie, 1957; Table 1). Han and Zhou (1997) note that buildings affected by the Lijian earthquake can be correlated with the types II and III, and that they can be further divided into eight sub-types shown in Table 2.

Table 1 Classification of civil buildings in China (Xie, 1957)

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

Table 2 Classification of civil buildings in the Lijiang area (Han and Zhou, 1997)

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	National 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	National 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 the intensity VIII
III-4	Houses framed by steel and concrete, including buildings taller than four stories; usually designed to resist earthquakes with the intensity VIII or higher.

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).

Table 3 Classification of building damage due to the Lijiang earthquake (Han and Zhou, 1988)

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 damaged	No damage or very slight damage to non-principal parts

Investigation Team of Earthquake Influence Field of Tonghai Earthquake (1977) introduced the damage index (*DI*) to quantify the degree of earthquake disasters. The estimation of *DI* is threefold: 1) select a representative type of civil houses; 2) estimate the ratio of damage grades for the representative houses; and 3) calculate *DI* using the following formula:

$$DI = \sum_{j} p_j \cdot AR_j \qquad (1)$$

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 buildings belonging to the j-th damage grade. In the area affected by the Lijiang earthquake, Naxi national houses of the III-1 type occur widely and 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. We aggregated some of the values to derive p_j corresponding to the five damage grades of Han and Zhou (1997) (Table 4).

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

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).

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

Table 5 (continued)

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
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	LongpanXinlian	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

Table 5 (continued)

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

2.2 Seismic intensity

Xie (1957) proposed 12 grades of seismic intensity applicable to China. China Seismological Bureau (1977) revised the system to include the relation between the seismic intensity and *DI*, originally introduced by Investigation Team of Earthquake Influence Field of Tonghai Earthquake (1977). Table 6 shows the grades of seismic intensity and relevant phenomena.

Table 6 Seismic intensity grades applied to China (Xie, 1957 and China Seismological Bureau, 1977)

Intensity grade	Perception of people	Damage of general wooden houses (equivalent to the III-1 type)		Other phenomena	Seismic components	
		Change or 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 sway		

Table 6 (continued)

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 fell and some mortar gets fissured	-	Unstable things fall down	22-44	2-4
Ⅵ	Many people get frightened and some people escape out of rooms	Little or no damage to non-frame parts; some tiles fell; walls get fissured lightly	0-0.1	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	708-1414	72-141
ⅩⅠ		All destroyed	0.91-1.00	Widespread mountain landslides; an extended earthquake fault emerges; arch bridges on bedrock destroyed		
ⅩⅡ			about 1.0	Severe landscape changes		

The seismic intensity derived from *DI* for the 111 villages is shown in Table 5. Such intensity estimation requires detailed data of building damage ratios. Therefore, seismic intensity has often been estimated based on rapid field observations of the damage. In this way Han and Zhou (1997) obtained the intensity of the Lijiang earthquake in 36 towns (Table 7) to draw contours of the intensity (Figure 2).

Table 7 Seismic intensity based on rapid field observations (Han and Zhou, 1997)

No	County	Town	Intensity	No	County	Town	Intensity
1	Lijiang	Huangshan	IX	19	Ninglang	Zhanhe	VI
2	Lijiang	Baisha	IX	20	Heqing	Songgui	VI
3	Lijiang	Dadong	IX	21	Ninglang	Paomaping	VI
4	Lijiang	Daju	IX	22	Heqing	Duomei	VI
5	Lijiang	Jinshan	IX	23	Zhongdian	Hutiaoxia	VII
6	Lijiang	Lijiang	IX	24	Zhongdian	Qiaotou	VII
7	Lijiang	Baoshan	VIII	25	Ninglang	Ningli	VII
8	Heqing	Xintun	VIII	26	Ninglang	Cuiyu	VII
9	Lijiang	Longpan	VIII	27	Ninglang	Hongqiao	VI
10	Zhongdian	Sanba	VII	28	Ninglang	Paomaping	VI
11	Lijiang	Longshan	VIII	29	Ninglang	Yongning	VII
12	Lijiang	Fengke	VII	30	Yongsheng	Daan	VII
13	Heqing	Jindun	VII	31	Yongsheng	Guanghua	VII
14	Ninglang	Xichuan	VII	32	Yongsheng	Songping	VII
15	Lijiang	Shigu	VII	33	Yongsheng	Jinguan	VI
16	Lijiang	Jiuhe	VII	34	Lanping	Lanping	VI
17	Zhongdian	Xiaozhongdia	VI	35	Jianchuan	Dongling	VII
18	Ninglang	Xinyingpan	VI	36	Jianchuan	Diannan	VII

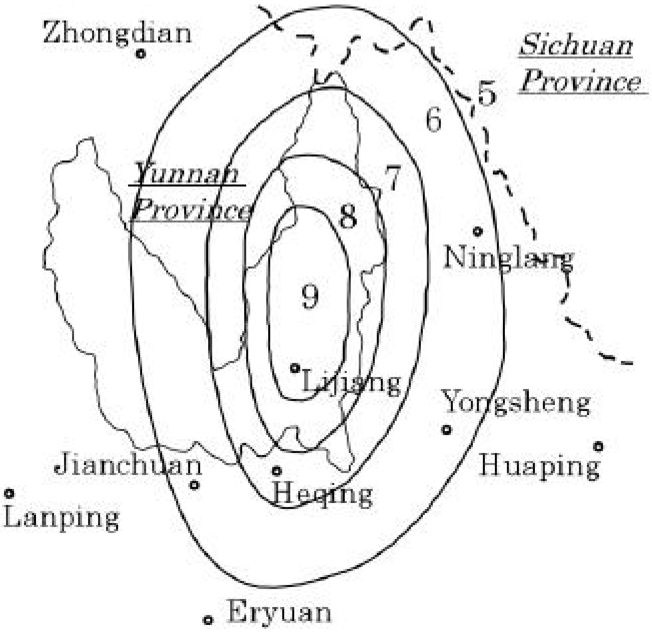

Figure 2 Contours of seismic intensity based on rapid field observations (Han and Zhou, 1997)

2.3 Death toll

Among the 309 people killed by the Lijiang earthquake, 294 died in Lijiang County, 5 in Zhongdian County, 8 in Heqing County, 1 in Ninglang County and 1 in Jianchuan County. We obtained death toll data for Lijiang County from the seismological office of the county (Table 8). Among 294 victims, 241 were directly smashed to death below the collapsed buildings, 25 died because of illness, 2 died because of fire, 3 died because of shock, 6 died because of suffocation and 16 died for other reasons. The age distribution of the killed persons (Table 9) shows that the youngest and oldest generations were major victims.

Table 8 Death toll in Lijiang County

No	Town	Ad Village	Toll
1	Lijiang	Dayan	81
2	Lijiang	Wenzhi	24
3	Lijiang	Yihe	5
4	Lijiang	Yizheng	21
5	Lijiang	Yishang	3
6	Lijiang	Xiangyun	5
7	Lijiang	Wutai	5
8	Lijiang	Bahe	4
9	Jinshan	Jinshan	12
10	Jinshan	Dongyuan	13
11	Jinshan	Xintuan	19
12	Jinshan	Yangxi	2
13	Jinshan	Guifeng	3
14	Jinshan	Yanle	1
15	Jinshan	Liangmei	5
16	Jinshan	Lamagu	1
17	Baisha	Yuhu	2
18	Baisha	Xinshang	1
19	Baisha	Kaiwen	15
20	Baisha	Baisha	2
21	Huangshan	Zhongji	9
22	Huangshan	Baihua	9
23	Huangshan	Wenhua	1
24	Huangshan	Huangshan	9
25	Huangshan	Nanxi	1
26	Huangshan	Changshui	2
27	Lashi	Lashi	1
28	Lashi	Junliang	3
29	Lashi	Nanrao	1
30	Lashi	Meiquan	1
31	Qihe	Gonghe	2
32	Qihe	Qianshan	2
33	Qihe	Qihe	1
34	Qihe	Wufeng	1
35	Qihe	Longtan	1
36	Qihe	Xinming	1
37	Shigu	Shigu	2
38	Daju	Toutai	5
39	Daju	Baimai	1
40	Daju	Peiliang	1
41	Longshan	Longxing	1
42	Longshan	Guangle	1
43	Longshan	Longshan	2
44	Dadong	Dadong	4
45	Dadong	Baishui	3
46	Dadong	Jiazi	5

Table 9 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

3 Mapping and analysis of earthquake damage using GIS

The tabulated data concerning house damage and death toll were converted into GIS data layers with geographic coordinates. Some paper maps were also digitized to provide the electronic data files of basic map components such as administrative 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.

3.1 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). Using the interpolation capability of ArcView, we also constructed contours from the data collected by Han and Zhou (1997). The resultant map (Figure 3) indicates that the distribution of seismic intensity is more complex than the nearly elliptical pattern suggested by Han and Zhou (1997)

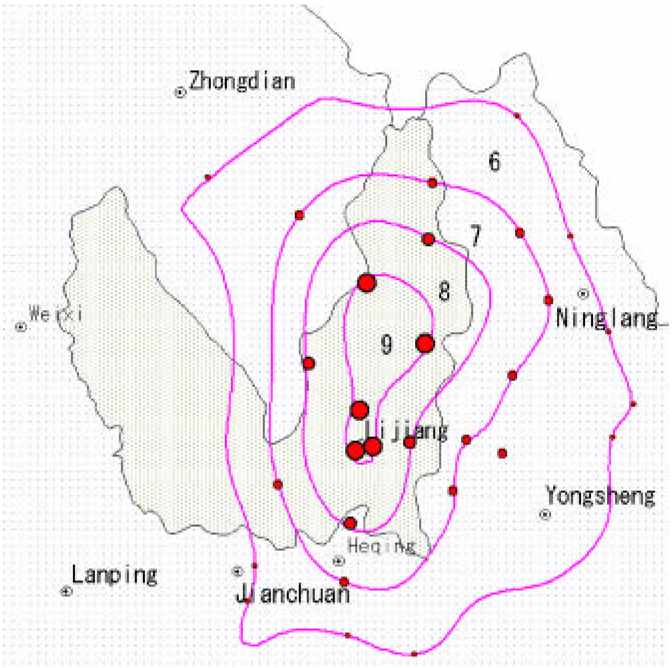

Figure 3 GIS-produced seismic intensity map based on data from rapid field observations

Seismic intensity was also derived from the damage index values (Table 5). Figure 4 shows the map of seismic intensity based on the data in Table 5. The damage index values depend on the detailed house damage ratios, and the number of data in Table 5 is much larger than that in Table 7. Accordingly, Figure 4 can be more trustable than Figures 2 and 3. Figure 4 indicates that the actual distribution of seismic intensity is further complex. For example, Intensity X occurs in three separated areas: around Lijiang (1 in Figure 4), near Dadong (2) and near Daju (3). The above (1) and (3) correspond to basins with thick alluvium as well as the inferred epicenter along the earthquake fault (Figure 1), indicating that these two factors account for the high intensity. The thickness of the alluvium in Lijiang Basin attains 1,200 m (PLA 00939 Troops, 1979). Intensity IX around Qihe (4 in Figure 4) also occurs in and around a basin with 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), suggesting that such complex tectonic structure was responsible for the enhanced ground movement. The extended distribution of Intensity X to the NNE of Lijiang (1) appears along the eastern side of the eastward dipping earthquake fault. This observation indicates that more serious damage took place on the hanging wall of the fault, as have been often observed elsewhere. The comparison between Figures 1 and 4 shows that Intensity IX and X mostly occur within a triangular tectonic block bordered by three major fault systems: Longpan-Qiaohou (F1), Lijiang-Jianchuan (F2) and Daju-Dadong (F3). The prolongation of the earthquake fault (F4) is also confined within the tectonic block. Consequently, the existing structure of fault systems has played an important role in determining the spatial distribution of the earthquake fault, seismic intensity and building damage.

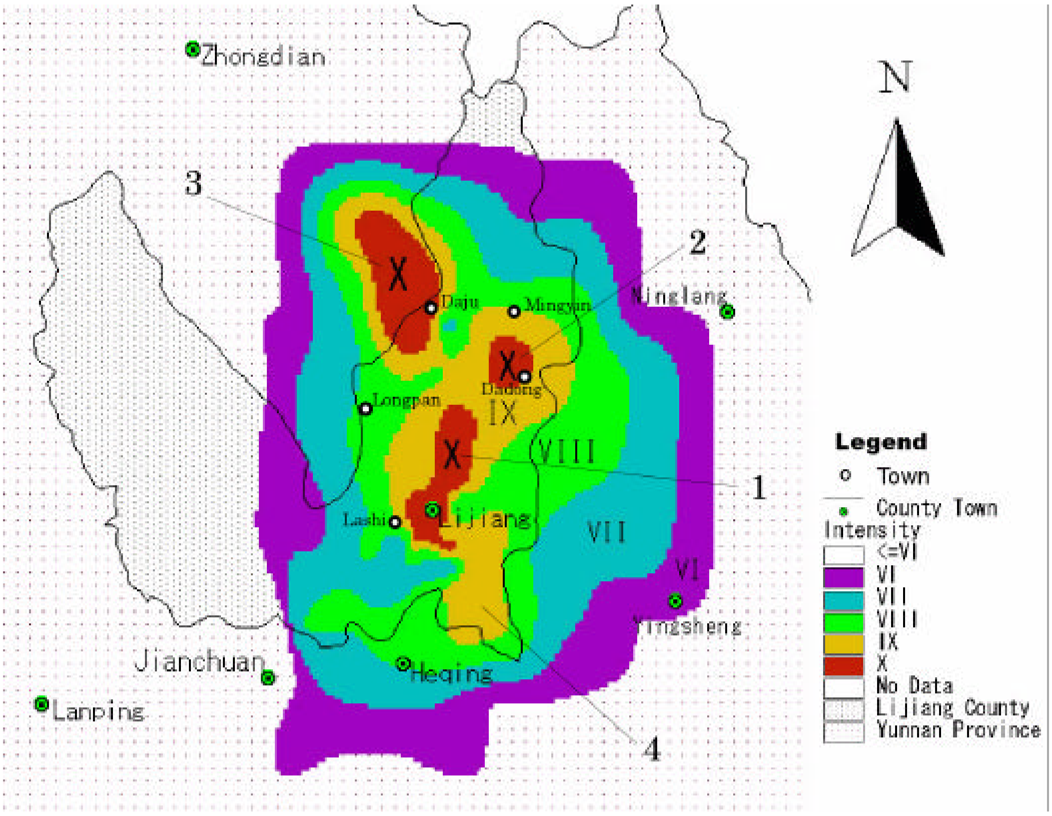

Figure 4 Distribution of seismic intensity based on the damage index

3.2 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. Figure 5 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 4). Very dense distribution occurs along a NNE-SSW line through Lijiang. The line corresponds to the Lijiand-Jianchuan fault system (F2 in Figure 1) indicating that the ground motion was accelerated along the fault. Terribly damaged houses occur distinctly near Daju and Qihe (3 and 4 in Figure 4) as well as the area to the NNE of Lijiang. These observations and the distribution of seismic intensity (Figure 4) show that the same intensity grade may result from different types of house damage, depending on physical settings such as fault distribution. The ratio of moderately damaged houses is high in the area between Lijiand and Heqing. Despite the proximity to the epicenter, the area experienced relatively weak damage because of the inter-basin condition without thick alluvium.

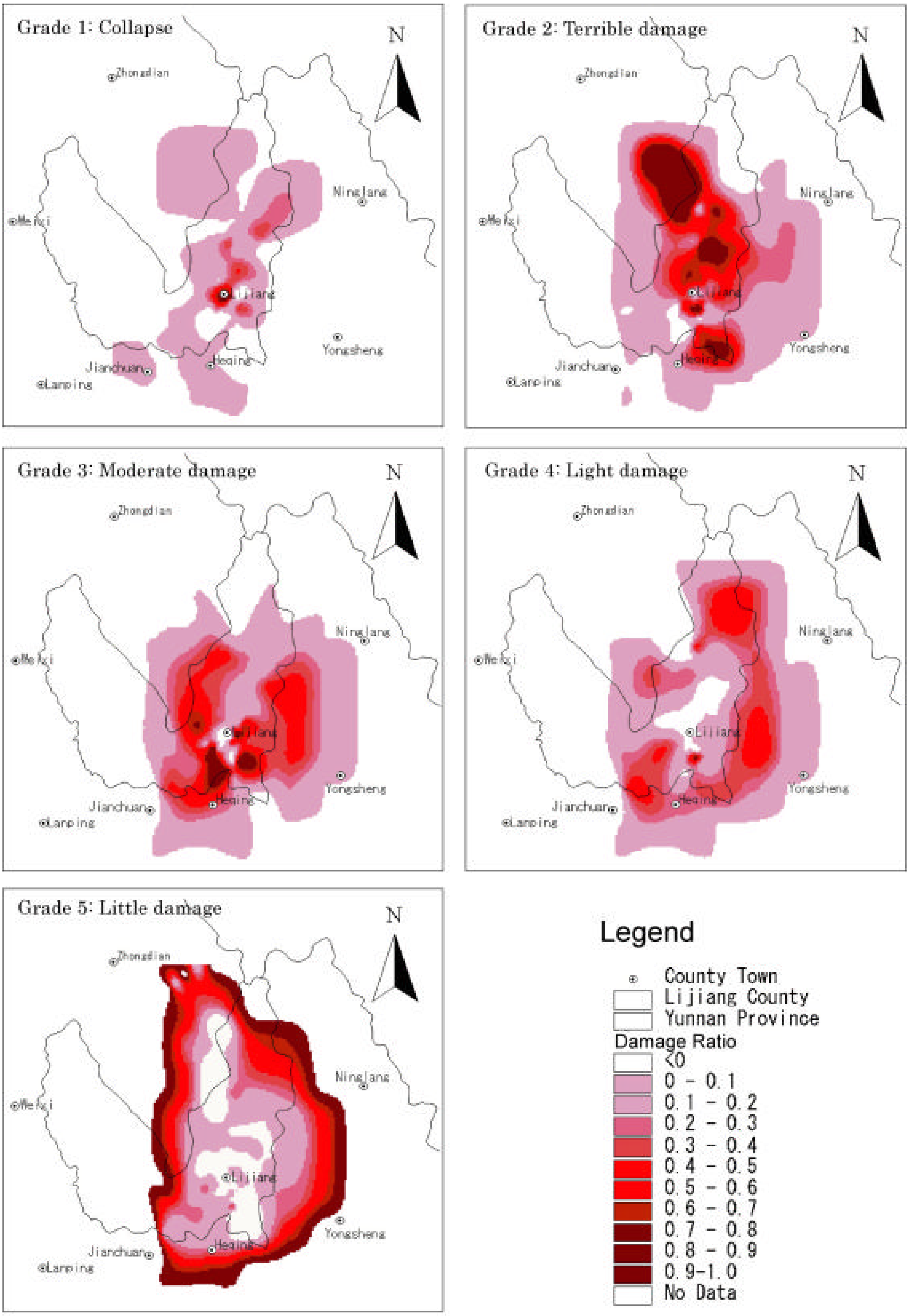

Figure 5 Distribution of areal ratio of buildings belonging to each damage grade

3.3 Distribution of persons killed

Most people killed in Lijiang County due to the earthquake occurred around Lijiang (Figure 6) where many buildings were collapsed (Figure 5). In contrast, areas with less collapsed houses but abundant terribly damaged houses show much smaller death toll, reflecting the fact that most victims were smashed below the collapsed buildings.

Figure 7 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 4) also has the high ratio of collapse, the death ratio and number are much lower than those around Lijiang. One possible explanation for this difference is the differing density of houses. The death distribution in Lijiang is concentrated in the town center (Figure 8) where many wooden houses stand closely together along narrow streets. Under such a situation, quick escape to safe places may have been more difficult than rural areas. Another possible explanation is that the collapse of houses on alluvium around Lijiang may have proceeded more dangerously or immediately than that of houses on consolidated rocks near Dadong. More than 69% of deaths around Lijiang occurred within Lijiang Basin with thick alluvium (Figure 8).

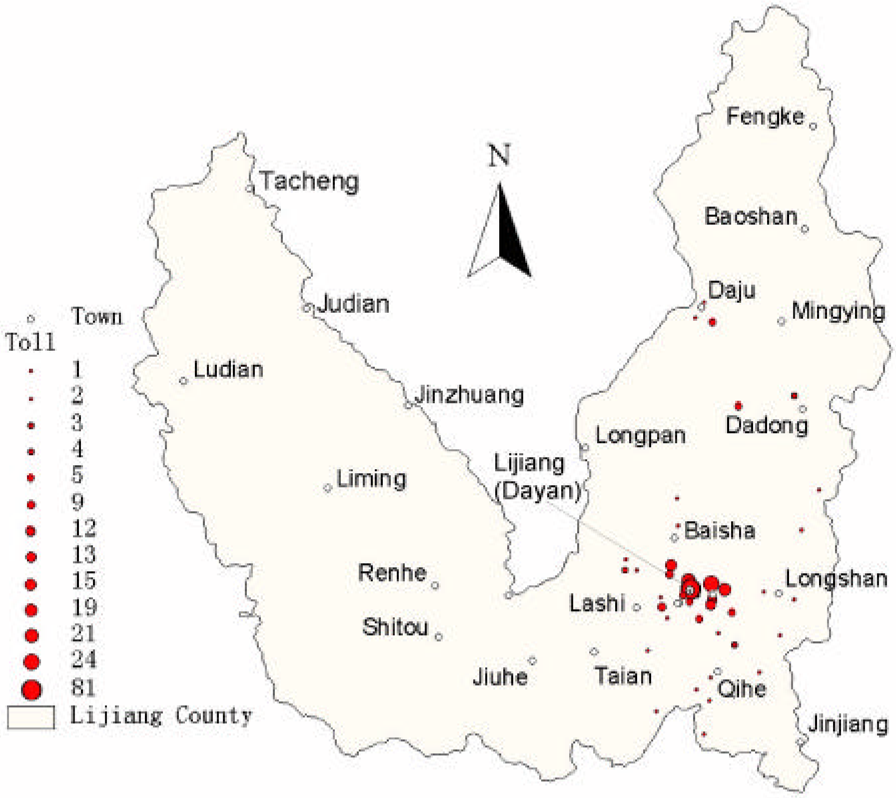

Figure 6 Distribution of persons killed in Lijiang County

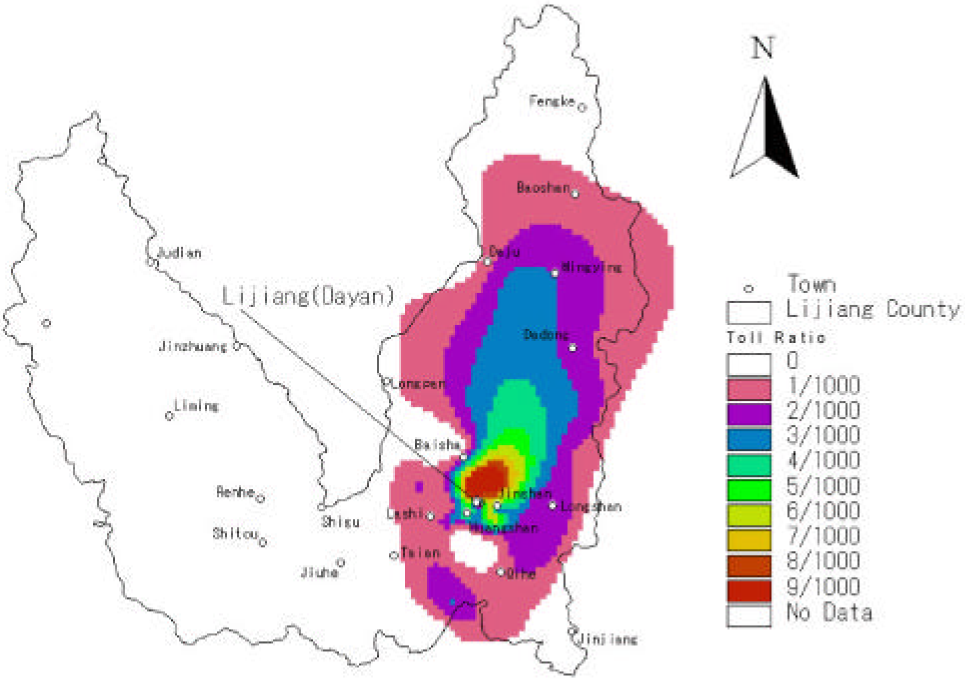

Figure 7 Distribution of death toll ratio

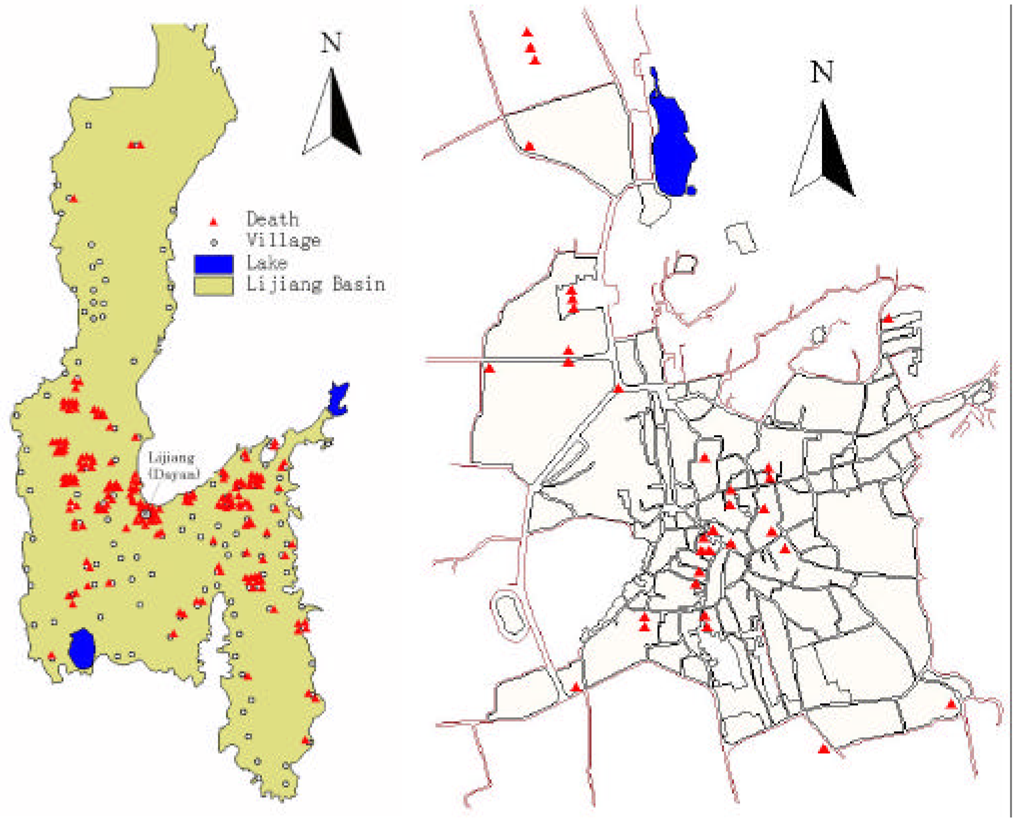

Figure 8 Death distributions Lijiang Basin (left) and Lijiang town (right)

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 previous studies. Seismic intensity and the damage ratio of houses do not decrease simply with an increasing distance from the epicenter, but shows 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.

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