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Evaluating critical rainfall conditions for large-scale landslides by detecting event times from seismic records

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S1. List of rainfall events chosen in the study

In the study, totally nineteen rainfall events including seventeen typhoons and two heavy rainfall events occurring in the period of 2005-2014 were chosen to examine the seismic records and identify landslide-induced signals (Table S1).

Table S1. Heavy Rainfall Event List

	Event	Date (year/month/date)
1	Haitang	2005/07/16-07/20
2	Talim	2005/08/30-09/01
3	0609 Rain	2005/06/09
4	Bilis	2005/07/12-07/15
5	0604 Rain	2006/06/04
6	Kalmaegi	2006/07/16-07/18
7	Fung-Wong	2008/07/26-07/29
8	Sinlaku	2008/09/11-09/16
9	Morakot	2009/08/05-08/10
10	Fanapi	2010/09/17-09/20
11	Megi	2010/10/21-10/23
12	Nanmadol	2011/08/27-08/31
13	Talim	2012/06/19-06/21
14	Saola	2012/07/31-08/03
15	Tembin	2012/08/21-08/25
16	Soulik	2013/07/11-07/13
17	Trami	2013/08/20-08/22
18	Matmo	2014/07/21-07/23
19	Fung-Wong	2014/09/19-09/22

S2. Waveforms and spectrograms of the seismic signals induced by ID 1 landslide that occurred in 2005

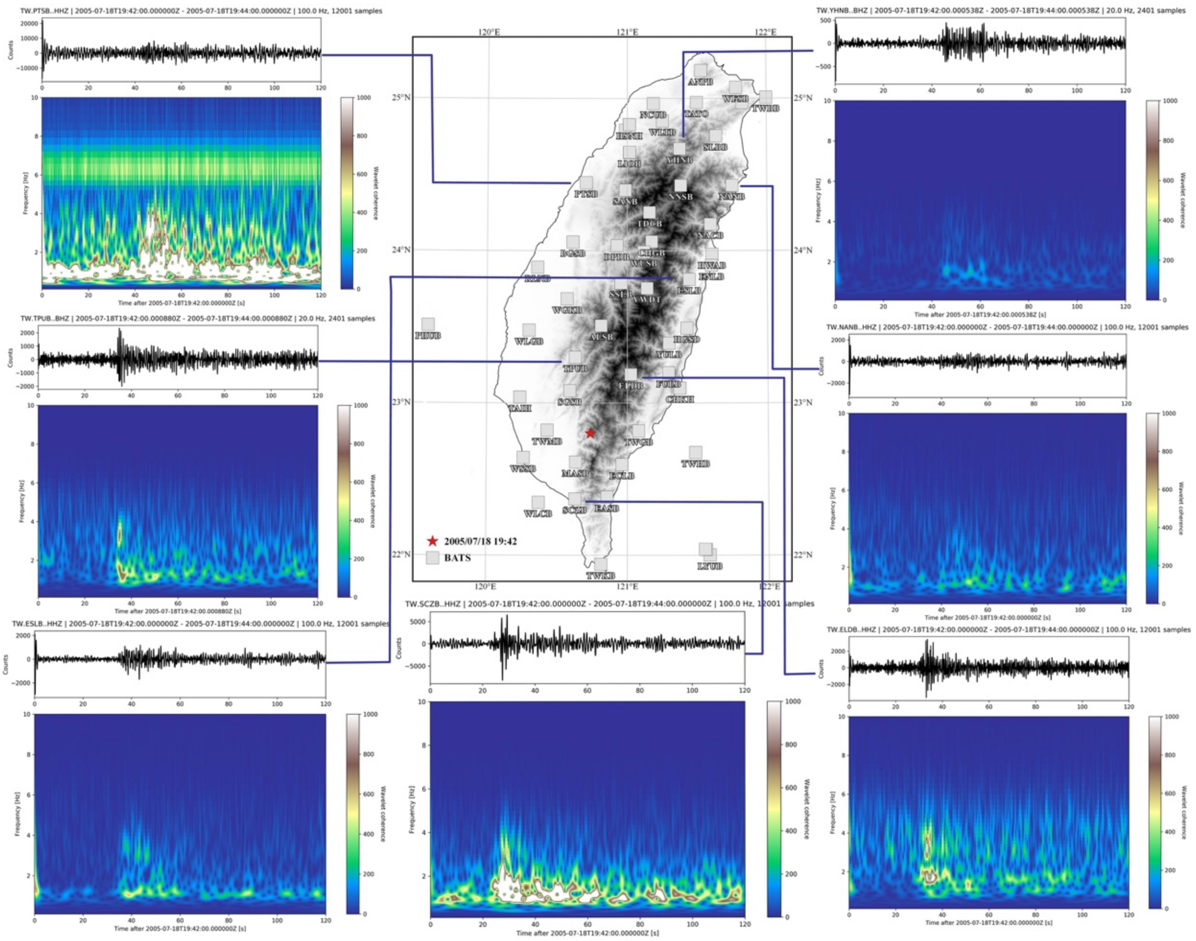

Fig S1. A sequence of original waveforms and spectrograms of the vertical-component signals induced by ID 1 landslide that occurred in 2005.

S3. Validation of the selection method for rainfall stations

The effect of rain gauge distribution over the accuracy of rainfall has been assessed using gauge observation in a 35 km × 50 km region of south Taiwan (Fig. S1). The amounts of daily rainfall during 2009 Typhoon Morakot (8/6-8/11) recorded at 19 rain gauge stations were selected to validate the accuracy of rainfall. At first, the amounts of daily rainfall were interpolated to 01V040 station using IDW methods. The errors between measurements and interpolated data were smaller than 15 %. It indicates IDW method can be used to interpolate rainfall to a selected location in our study area.

Secondly, the amounts of daily rainfall at the central point of the 35 km × 50 km region were estimated. The errors of daily rainfall between the central point and the nearest rain gauge station (01V040) were smaller than 10 % (0.5%-10% at different date). Besides, the correlation coefficients would keep at 90% as a distance between the central point and rain gauge stations less than 20 km, and even keep at 98% as a distance less than 10 km (Fig. S2). Therefore, in the study, an upper limit of basin area smaller than 100 km2 (10 km × 10 km was adopted to avoid a significant decrease of the accuracy of rainfall.

The influence of topography on rainfall variability has been analyzed in the same 35 km × 50 km region of south Taiwan. The highest station elevation is 1792 m a.s.l. at C1V270, and the lowest station elevation is 105 m a.s.l. at C10830. The standard deviation of station elevation is 561 m. The values of standard deviation of daily rainfall at the 19 stations were calculated, and less than 13% except a high standard deviation, 45%, on sixth August (average daily rainfall less than 2 mm). The results demonstrated that high and even extreme rainfall are less influenced by elevation, while low and medium rainfall events are significantly influenced by elevation variation, with most of the rainfall appearing on high elevations. Similar results have also been reported by some previous studies (Sanchez-Moreno et al., 2014; Ge et al., 2017). Because the study only considered the rainfall events with total cumulated rainfall greater than 500 m, the elevation effect was ignored as selecting rain station.

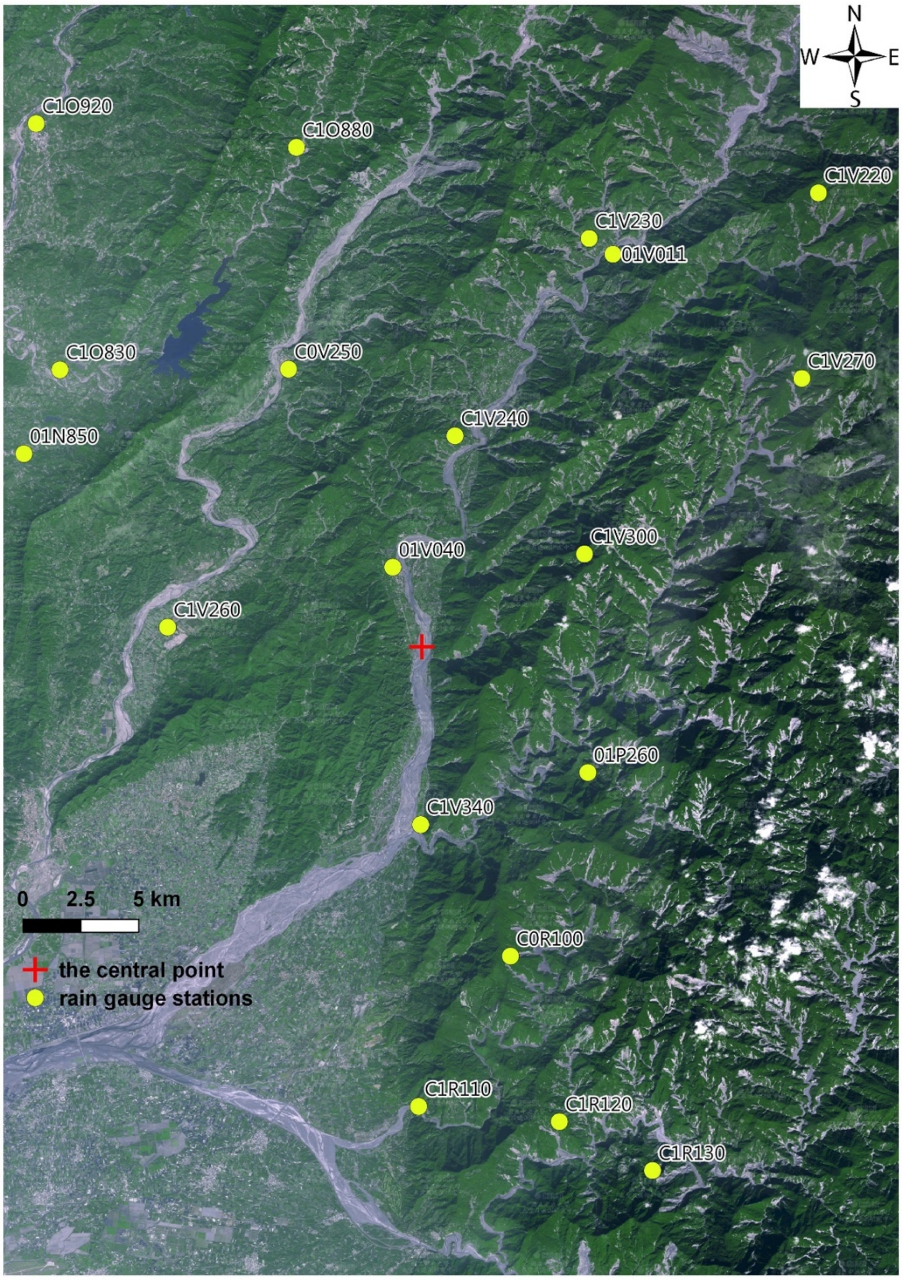

Fig. S2. The distribution of rain gauge stations and the location of the central point of the testing area for validating the influence of the distance between rain gauge and a given point.

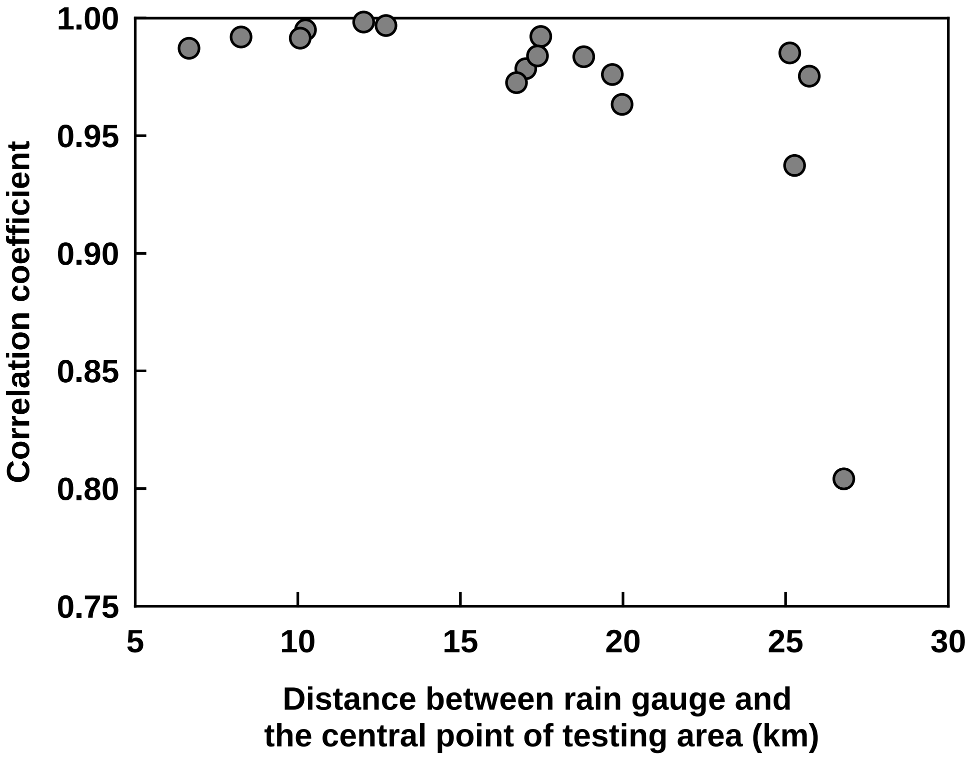

Fig. S3. Variation of correlation coefficient

Reference

Mishra, A.K. (2013) Effect of rain gauge density over the accuracy of rainfall: a case study over Bangalore, India. SpringerPlus, 2, 311.

Sanchez-Moreno, J.F., Mannaerts, C.M., and Jetten, V. (2014) Influence of topography on rainfall variability in Santiago Island, Cape Verde. International Journal of Climatology, 34, 1081-1097.

Ge, G., Shi, Z., Yang, X., Hao, Y., Guo, H., Kossi, F., Xin, Z., Wei, W., Zhang, Z., Zhang, X., Liu, Y., and Liu, J. (2017) Analysis of Precipitation Extremes in the Qinghai-Tibetan Plateau, China: Spatio-Temporal Characteristics and Topography Effects. Atmosphere, 8(7), 127, doi:10.3390/atmos8070127.

S4. Detailed information on the 62 detected large landslides

Table S2. List of the 62 detected large landslides

ID	Date and time (UTC)	Longitude	Latitude	Disturbed area (km^2)	Elev. of landslide (m)	Rain station	Distance (km)	Elev. of rain station (m a.s.l.)	Reactive landslide (R or N)	Date of satellite image
1	2005/07/18 19:42	120.74	22.80	0.13	1388.6	C1R120	5.3	820	N	2005/07/25
2	2005/07/20 18:15	120.75	22.74	0.13	813.7	C1R130	0.9	1040	N	2005/07/25
3	2005/07/20 21:55	120.82	22.88	0.12	1535.0	01P260	10.8	458	N	2005/07/25
4	2005/07/21 06:33	120.72	22.85	0.18	950.1	C0R100	3.9	1006	R	2006/07/29
5	2006/06/09 16:53	121.33	24.29	0.11	2304.6	C1H860	24.1	1840	R	2006/07/19
6	2008/07/18 21:30	121.01	23.82	0.10	1093.8	C1I040	1.6	1693	R	2008/11/20
7	2008/07/18 23:55	120.66	23.15	0.12	749.0	C1V230	6.0	760	N	2008/11/25
8	2008/09/15 02:45	121.38	24.35	0.14	2236.4	41U090	5.7	1930	R	2008/12/03
9	2008/09/17 18:50	121.00	24.10	0.89	1104.3	01F100	2.6	1600	N	2008/11/15
10	2009/08/08 00:04	120.72	22.57	0.39	1207.1	C1R240	10.9	74	R	2010/04/10
11	2009/08/08 00:35	120.73	22.49	0.12	950.2	01Q350	6.2	700	N	2010/04/10
12	2009/08/08 01:20	120.77	23.49	0.14	1411.2	H1M240	5.2	1850	N	2010/02/23
13	2009/08/08 02:20	120.85	22.98	0.11	2167.4	01P260	15.2	458	R	2010/04/10
14	2009/08/08 03:55	120.75	23.08	0.33	923.5	C1V270	5.4	1792	R	2010/02/23
15	2009/08/08 05:35	120.83	23.52	0.50	1903.4	C0H9A0	2.4	1595	N	2010/02/23
16	2009/08/08 06:25	120.82	23.06	0.39	1726.3	01V040	20.8	265	N	2010/02/23

ID	Date and time (UTC)	Longitude	Latitude	Disturbed area (km^2)	Elev. of landslide (m)	Rain station	Distance (km)	Elev. of rain station (m a.s.l.)	Reactive landslide (R or N)	Date of satellite image
17	2009/08/08 06:28	120.67	23.01	0.15	517.2	01V040	4.0	265	N	2010/02/23
18	2009/08/08 07:15	120.70	23.01	0.23	903.9	C1V300	1.5	1637	N	2010/02/23
19	2009/08/08 07:35	120.70	22.75	0.49	647.8	C1R120	1.0	820	R	2010/02/23
20	2009/08/08 08:10	120.81	23.00	0.19	2007.5	C1V300	10.1	1637	R	2010/02/23
21	2009/08/08 08:20	120.91	23.33	0.41	1703.8	01V070	6.3	2230	N	2010/01/11
22	2009/08/08 09:01	120.79	22.61	0.62	1222.0	01Q910	13.4	1158	R	2010/04/10
23	2009/08/08 10:40	120.86	22.80	0.16	1424.2	01Q910	12.8	1158	R	2010/04/10
24	2009/08/08 11:35	120.95	23.33	0.22	2029.6	C1V170	15.1	3340	N	2010/01/11
25	2009/08/08 13:56	120.66	22.96	0.11	407.3	01V040	5.0	265	N	2010/02/23
26	2009/08/08 16:15	120.88	23.18	0.14	2162.1	C1V220	7.4	1781	R	2010/01/11
27	2009/08/08 17:05	120.71	22.49	0.94	1168.5	C1R240	9.3	74	N	2010/04/10
28	2009/08/08 17:21	120.90	23.07	0.28	2606.3	C1V270	9.8	1792	R	2010/04/10
29	2009/08/08 17:53	120.91	23.08	0.19	2459.5	C1V270	10.7	1792	R	2010/04/10
30	2009/08/08 18:11	120.79	23.51	1.12	1763.8	467530	2.8	2413.4	N	2010/02/23
31	2009/08/08 18:16	120.83	22.63	0.72	1055.7	01Q910	13.5	1158	R	2010/04/10
32	2009/08/08 18:19	120.72	22.70	0.56	603.4	01Q910	5.3	1158	R	2010/03/06
33	2009/08/08 18:28	120.66	22.95	0.12	554.4	01V040	5.8	265	R	2010/02/23
34	2009/08/08 19:19	120.71	22.67	0.64	705.7	01Q910	7.6	1158	R	2010/03/06
35	2009/08/08 20:15	120.73	22.59	0.73	1509.7	C1R240	12.8	74	N	2010/04/10

ID	Date and time (UTC)	Longitude	Latitude	Disturbed area (km^2)	Elev. of landslide (m)	Rain station	Distance (km)	Elev. of rain station (m a.s.l.)	Reactive landslide (R or N)	Date of satellite image
36	2009/08/08 20:27	120.92	23.40	0.12	2278.6	C1V460	4.5	1949	N	2010/01/11
37	2009/08/08 21:11	120.90	23.46	0.15	1904.4	C1V460	2.3	1949	R	2010/02/23
38	2009/08/08 21:30	120.92	23.49	0.12	2450.4	C1V460	6.4	1949	N	2010/02/23
39	2009/08/08 21:42	120.91	23.10	0.25	2274.1	C1V460	37.3	1949	R	2010/04/10
40	2009/08/08 22:16	120.66	23.17	2.50	681.3	C1R880	6.4	223	R	2010/02/23
41	2009/08/08 22:52	120.90	23.54	0.12	1936.8	C1I340	4.5	897	R	2010/02/23
42	2009/08/08 23:02	120.60	23.03	0.13	747.9	C0V250	5.2	298	N	2010/04/10
43	2009/08/08 23:14	120.75	23.29	0.56	1525.1	C1V200	7.7	860	R	2010/02/23
44	2009/08/08 23:15	120.77	22.63	0.15	2309.0	01Q250	8.2	950	R	2010/04/10
45	2009/08/08 23:41	120.84	22.63	0.12	825.0	01Q910	13.9	1158	R	2010/04/10
46	2009/08/09 00:34	120.77	23.22	2.24	1352.5	C1V210	4.0	700	R	2010/02/23
47	2009/08/09 02:52	120.77	23.23	0.81	1559.3	C1V210	4.1	700	R	2010/02/23
48	2009/08/09 03:55	120.72	22.60	0.63	923.5	01Q250	2.5	950	N	2010/04/10
49	2009/08/09 09:37	120.81	22.56	2.31	1144.3	01Q350	14.3	250	N	2010/04/10
50	2009/08/09 11:00	120.77	22.82	0.13	1669.4	C1R120	9.0	820	R	2010/04/10
51	2009/08/10 03:54	120.80	23.25	0.20	1227.6	C1V210	2.8	700	R	2010/02/23
52	2009/08/10 04:22	120.76	23.31	1.52	1387.2	C1V160	6.3	1040	R	2010/02/23
53	2010/09/19 23:24	120.73	22.85	0.15	1135.0	01Q910	13.9	1158	R	2011/04/16
54	2011/08/30 07:10	120.93	22.86	0.12	849.8	01Q350	44.9	1275	R	2012/02/27

ID	Date and time (UTC)	Longitude	Latitude	Disturbed area (km^2)	Elev. of landslide (m)	Rain station	Distance (km)	Elev. of rain station (m a.s.l.)	Reactive landslide (R or N)	Date of satellite image
55	2011/08/30 09:13	121.18	23.69	0.11	1811.5	C1T940	19.6	1570	R	2012/02/27
56	2011/08/31 09:37	120.98	23.33	0.11	2714.0	01V070	8.5	2230	R	2012/02/27
57	2012/08/01 18:40	121.42	24.58	0.12	1512.0	01U050	8.1	400	R	2013/07/11
58	2012/08/02 10:00	121.85	24.52	0.12	83.3	C0U710	33.3	1810	N	2013/06/28
59	2012/08/02 19:00	120.95	23.74	0.25	1677.9	C1I310	6.6	1001	N	2013/06/03
60	2012/08/03 01:02	121.38	24.36	0.19	2356.6	41U090	4.7	1930	N	2013/07/11
61	2013/07/13 14:27	120.89	23.02	0.40	2604.8	C1V270	10.1	1792	R	2014/07/13
62	2013/08/22 19:05	121.07	23.38	0.18	2114.6	C1I140	41.2	1700	R	2014/07/13

The average location error (the distance between the actual and estimated location) was 10.9 km. The best location estimate was for the ID 40 landslide with an error of 0.5 km, while the worst location estimate was for ID 35 landslide with an error of 49.3 km.

S5. Physically-based I-D thresholds reported by the previous studies

Table S3. Three physically-based I-D thresholds reported by the previous studies

	Reference	Equation	Study area
1	Salciarini et al. (2012)	$I = 276.2D^{-0.99}$	Model
2	Chen et al. (2013c)	$I = 24.4D^{-0.28}$	Taiwan
3	Napolitano et al. (2016)	$I = 287.8D^{-1.09}$	southern Italy