THE STATISTICAL ANALYSES OF SEISMIC PROPERTIES OF TAIWAN

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ABSTRACT

To compare the statistical properties of labeled and total (labeled plus unlabeled) earthquakes in Taiwan is the purpose of this paper. From January 1995 to June 2017, there were 3,129 labeled as well as 9,871 total earthquakes recorded in the seismic archive of the Central Weather Bureau (CWB) of Taiwan. The statistical earthquakes properties evaluated in this paper include: yearly numbers, mean times per month, mean times per year, mean depth (km), mean magnitude (ML), maximum magnitude, time period between two earthquakes, energy released ratio, and energy equivalent to the number of atomic bombs.

Hualien, a county in the east of Taiwan, is the place with the highest frequency of earthquakes, the shortest time between two earthquakes, and the strongest released energy. The energy released from total earthquakes in Hualien in the period of January 1995 to June 2017is equivalent to 185.1 atomic bombs which were dropped in Hiroshima at the end of World War II. Most of the earthquakes in Taiwan's twenty municipal areas are categorized to be shallow (<70km), except Keelung, which has an average depth of hypocenters at 114.92km (intermediate-depth). Maybe it is because the hypocenters of Keelung are in the submerged tectonic plate. In the past 270months (January 1995 to June 2017) the strongest magnitude (Richter magnitude scale, ML) was 7.3.Although Taitung also recorded the same magnitude, its epicenter is off-island, and no major damage and injury has been filed.

This study shows that if the unlabeled earthquakes (usually small in magnitude and impact locally) are neglected, the total energy will be uncounted up to2.2E+22 ergs. Such an energy lost is equivalent to 35.36 atomic bombs. The energy gap increases with the increasing of time. Other statistical properties such as earthquakes amount order, and the interval between two earthquakes will be inaccurate if the researchers disregard those unlabeled ones. Therefore, to put all records in the CWB seismic archive in the analysis is strongly recommended to avoid obtaining inaccurate results.

Key Words: CWB Archive, Little Boy, Hypocenter, Epicenter

1. Introduction

The archive of the Central Weather Bureau (CWB, 2017) of Taiwan has two kinds of earthquake records, labeled and unlabeled. The labeled ones have stronger impact on several areas of Taiwan, and unlabeled ones only have records but without numbers given, usually less severe than the labeled ones. Each year, the labeled earthquake always starts from one. In the CWB archive, the author finds that not until May 2000 did the CWB begin to put unlabeled earthquakes into its record. Maybe the great number of aftershocks of 921-earthquake (Richter magnitude scale 7.3 ML) influenced the decision of high ranking officials at CWB.

The author is interested in how different the statistical properties of labeled and total earthquakes will be. From January 1995 to June 2017, there were 3,129 labeled and 9,871 total (labeled plus unlabeled) earthquakes occurring in 22.5 years (270 months).If their statistical properties were similar, in the future analysis, one can just pay attention to the labeled ones. Much time and cost will be saved. Please note that the difference in the number of labeled and total earthquakes will increase with the extension of time period.

Twenty (20) municipal areas of Taiwan, Republic of China (R.O.C.), are used in this study. They are Yilan, Hualien, Taitung, Nantou, Keelung, Taipei, New Taipei, Taoyuan, Hsinchu, Miaoli, Taichung, Changhua, Yunlin, Chiayi, Tainan, Kaohsiung, Pingtung, and three islets Penghu, Kinmen, and Matsu. Such an arrangement is based on the geographical locations from the east, the center, and to the west of Taiwan.

The earthquake data are obtained from the Central Weather Bureau's (CWB, 2017) public archive (CWB, 2017). The naming of an earthquake is based on which area has the shortest distance to the seismometer location of the epicenter.

2. Properties of Earthquakes of Each City/County of Taiwan

There were 9,871 earthquakes occurred from January 1995 to June 2017, but only 3,129 were labeled due to their relatively significant impact on Taiwan. Basically, as long as the magnitude of an earthquake is larger than Richter magnitude scale 4.0 and its intensity measured by one seismometer is over 4.0 (or intensity over 3.0 recorded by two seismometers in different stations) the earthquake will be labeled (CWB, 2017). The earthquake records from January 1995 to June 2017 covering 270 months or 22.5 years are analyzed in this paper. After tedious data manipulation and arrangement, the number of earthquakes in each city and county is summarized in Appendix A (for labeled earthquakes), Appendix B (for both labeled and unlabeled earthquakes), and Appendix C (for energy calculation and equivalent number of atomic bombs).In the following subsections, each property of these tables will be presented by graphs to facilitate reading.

2.1 Number of Earthquakes in Each City and County

This subsection is used to find the earthquake frequencies of each city and county in Taiwan for the past 22.5 years (270 months) from January 1995 to June 2017. Both bar and PI charts are used to identify number and percentage (%) of earthquakes in each locality. The yearly number of earthquakes in Taiwan is shown in the following graphs.

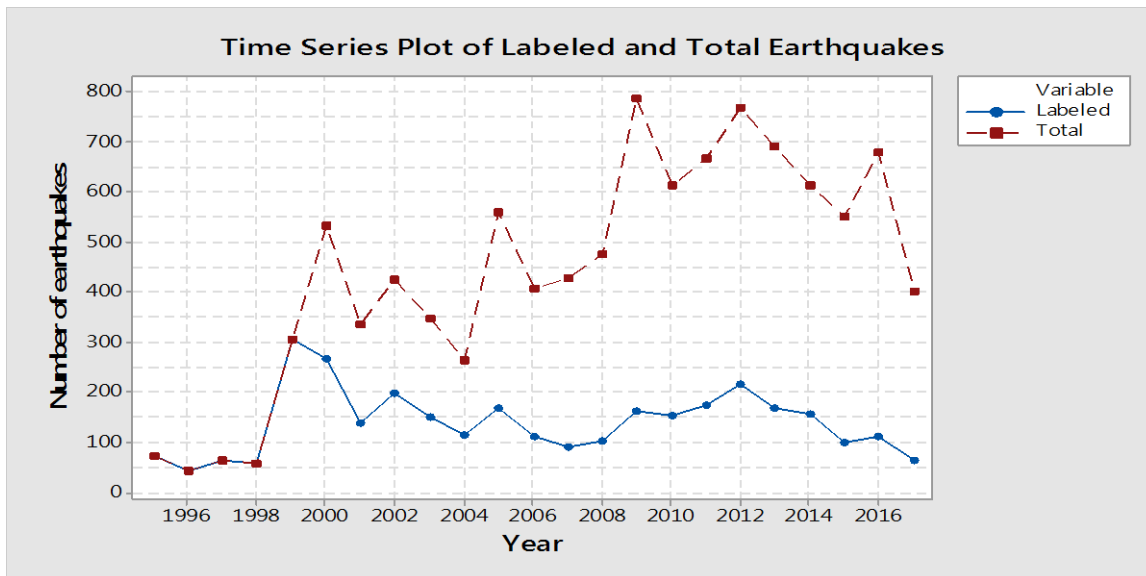### 2.1.1 Yearly Number of Earthquakes for both Labeled and Total Earthquakes

Figure 1: Labeled and total (labeled and unlabeled) earthquakes from 1995 to 2017 (expected)

From the above figure, one finds the total earthquakes (9,871) are about 3.15 times more than the labeled (3,129) ones. After year 2000 the two records begin to separate because not until May 2000 did the CWB begin to put small-scaled earthquakes into the archive.
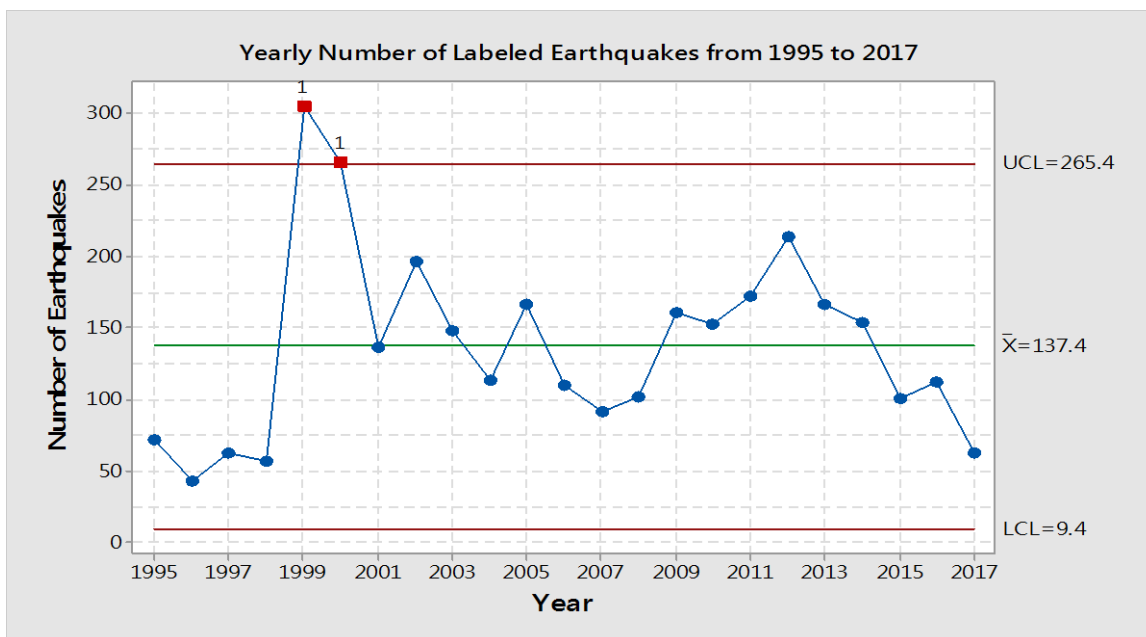

Figure2: Number of labeled earthquakes per year from years 1995 to 2017 (expected)

From the above graph, one finds the average number of earthquakes per year is 137.4 times. Year 1999 has extraordinary high number of records due to the horrible 921 earthquake, which registered with a magnitude of 7.3 in the Richter scale. The 921 Nantou earthquake took away 2,415 lives as well as injured 11,305 people (wiki/921_earthquake). Note that from 1995 to 1998, the yearly number of earthquakes is two standard errors below mean. The energy accumulated during these (and previous) periods seemed to be finally released in year 1999.
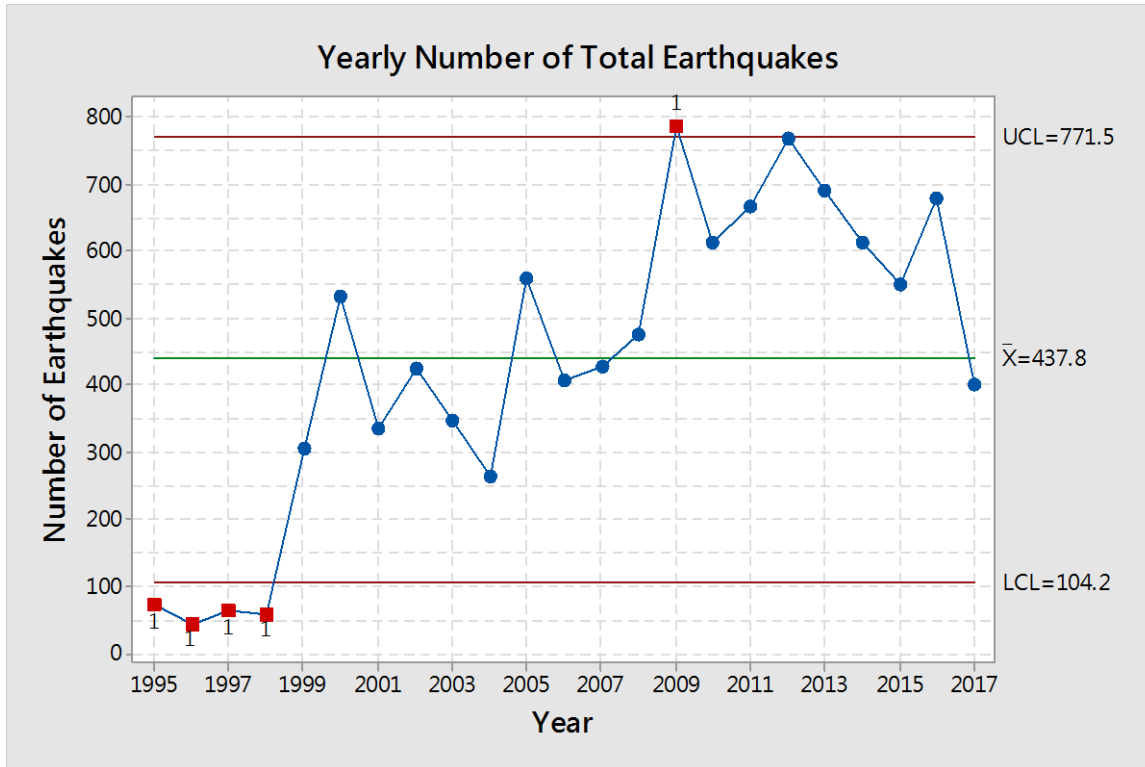

Figure 3: Number of total earthquakes per year from years 1995 to 2017 (expected)

From the above graph, one finds the average number of total earthquakes per year is 437.8 times. Year 2009 has 786 records of earthquakes, which is three standard errors above mean. But from 1995 to 1998 the records are extremely low, which is because the CWB was not yet put small-scaled earthquakes in the archive.

2.1.2 Yearly Number of Earthquakes in Each City/County

The following bar and PI graphs plot the number of earthquakes from January 1995 to June 2017 for each city/county in Taiwan.

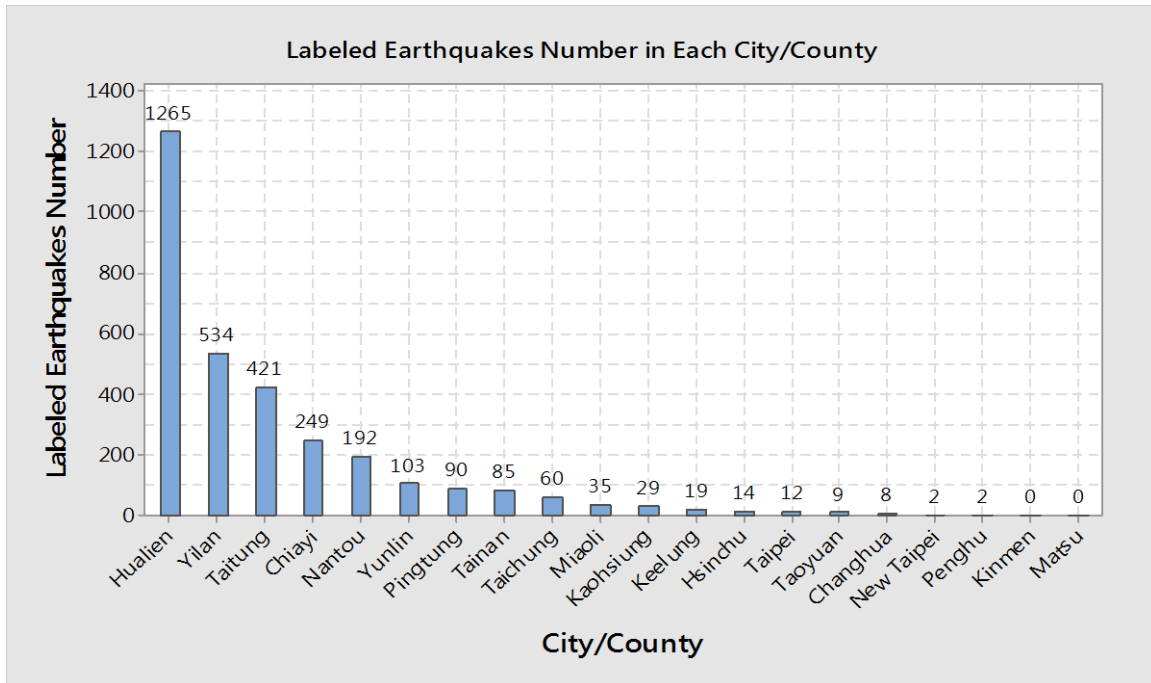**2.1.2.1 Yearly Number of Labeled Earthquakes in Each City/County**

Figure 4: Labeled number of earthquakes from January 1995 June 2017 for each city/county in Taiwan
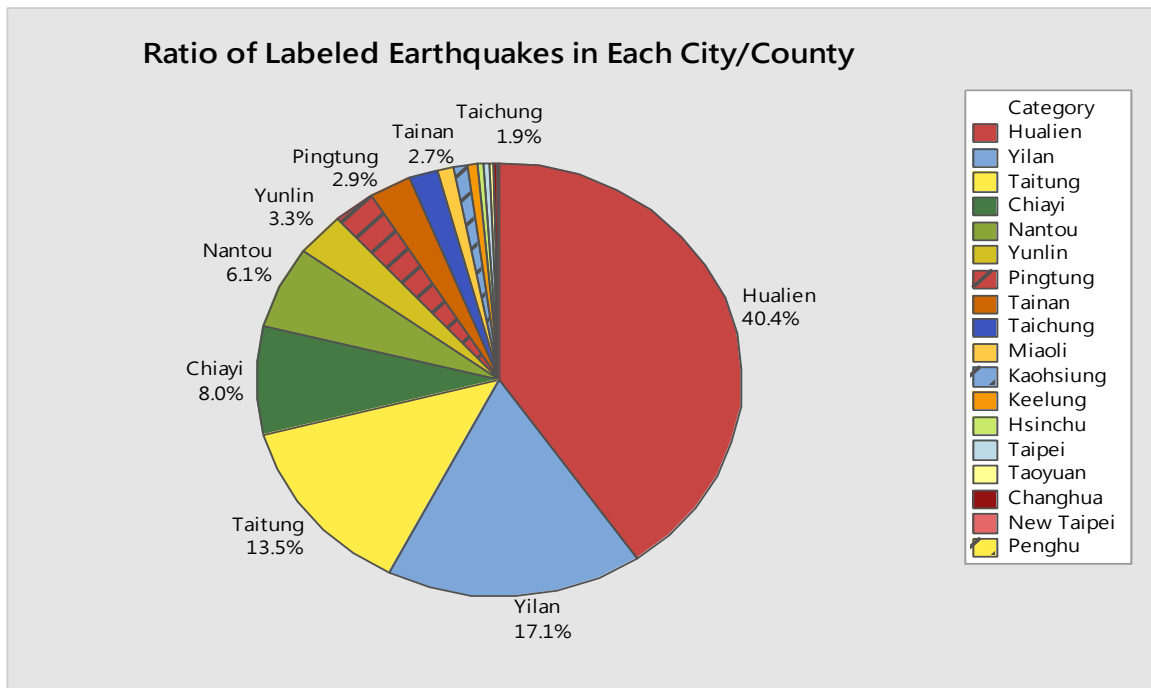

Figure 5: Percentage (%) of frequency of earthquakes of each city/county of labeled earthquakes from January 1995 to June 2017

From the above figures, one finds that there are 71% of labeled earthquakes occurred in the three eastern coast areas of Taiwan. They are Hualien, Yilan, and Taitung in the past 22.5 years.

Hualien is the most active place for earthquakes in Taiwan. There are 1,265 out of a total of 3,129labeled earthquakes in Hualien, and the ratio is 40.4%. Yilan takes the second place, with 534 times (17.1%), and Taitung is the third, with 421 times (13.5%). In other words, about 71.0% of labeled earthquakes occur in the eastern coast of Taiwan.

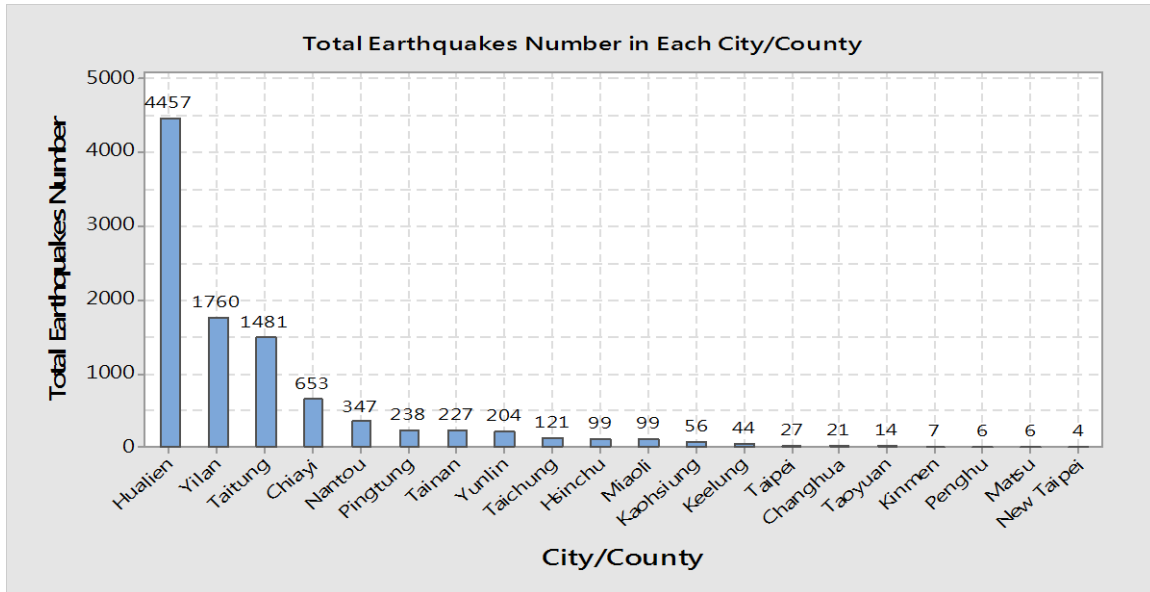### 2.1.2.2 Yearly Number of Total Earthquakes in Each City/County

Figure 6: Total number of earthquakes from January 1995 June 2017 for each city/county in Taiwan
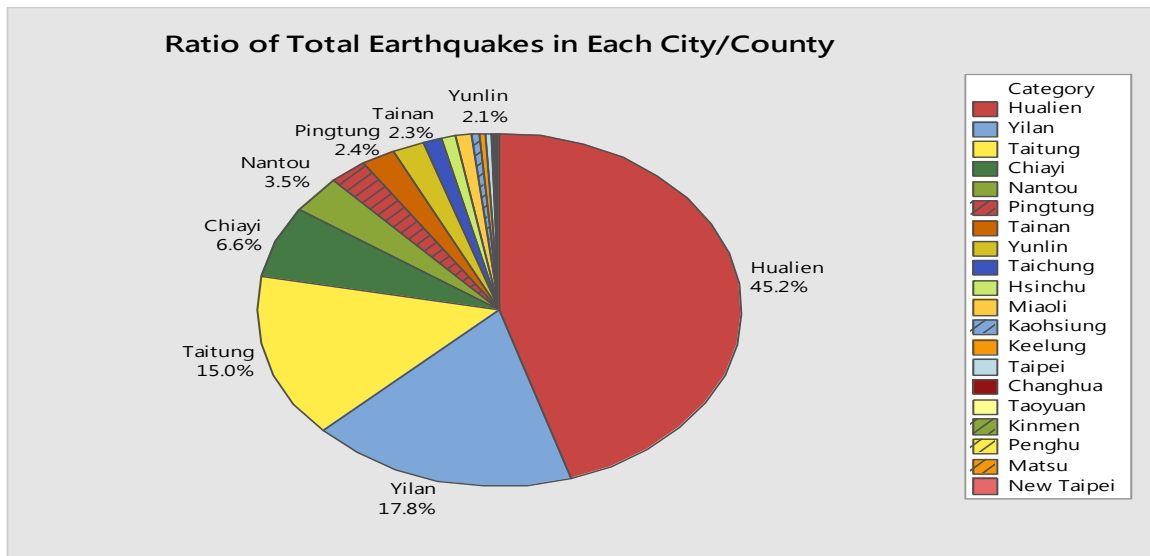

Figure 7: Percentage (%) of frequency of total earthquakes of each city/county from January 1995 to June 2017

From the above figures, one finds that there are 78% of total earthquakes in the three eastern coast areas of Taiwan. They are Hualien, Yilan, and Taitung in the past 22.5 years.

Hualien is the most active place for earthquakes in Taiwan. There are 4,457 out of a total of 9,871earthquakes in Hualien, and the ratio is 45.2%. Yilan takes the second place, with 1,760times (17.8%), and Taitung is the third, with 1,481 times (15.0%). In other words, about 78.0% of total earthquakes occur in the eastern coast of Taiwan.

The five most frequent earthquake areas in Taiwan are Hualien, Yilan, Taitung, Chiayi, and Nantou. Two islets Kinmen and Matsu have no labeled earthquake, but still have a few tremors in the past 270 months.

2.2 Mean Times per Month in Each City/County

Mean times per month is the average frequency of earthquakes occurring in each municipal area.

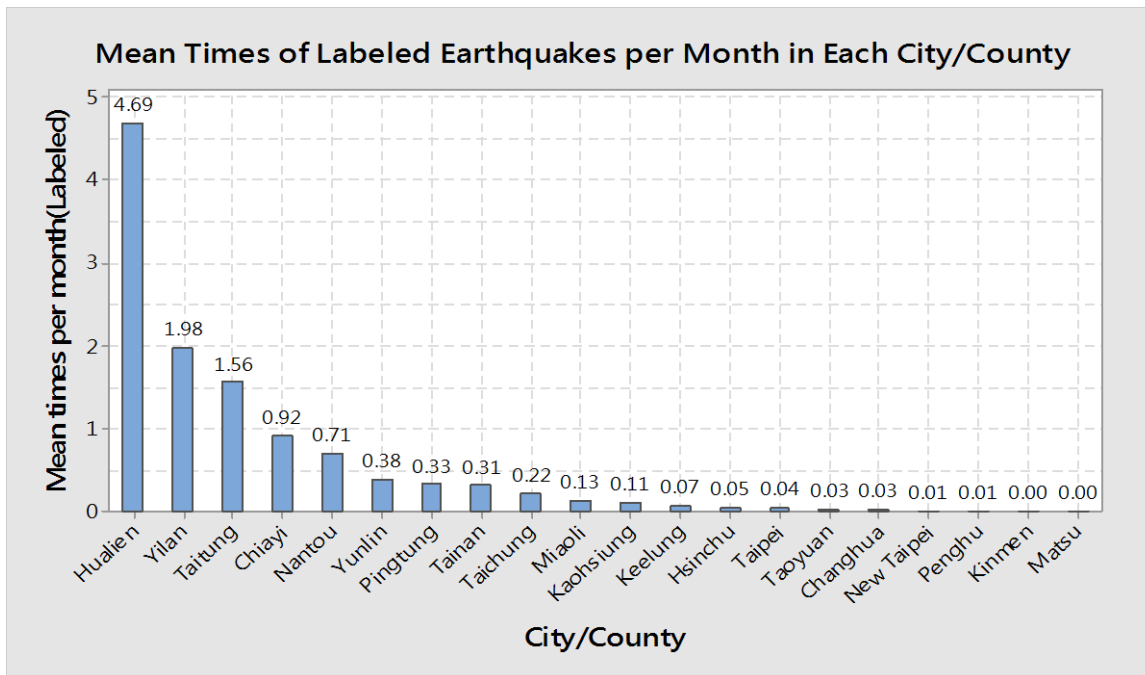### 2.2.1 Mean Times per Month of Labeled Earthquakes in Each City/County

Figure 8: Mean times of labeled earthquakes per month for each city/county in Taiwan from January1995 to June 2017

No doubt, Hualien is the champion of the mean times per month. In each month, there are 4.69 times of labeled earthquakes there. Yilan and Taitung have 1.98 and 1.56 times respectively.

2.2.2 Mean Times per Month of Total Earthquakes in Each City/County

Figure 9: Mean times of total earthquakes per month for each city/county in Taiwan from January1995 to June 2017

Hualien is the area with the highest mean times per month. In each month there are 16.51 times of labeled earthquakes there. Yilan and Taitung have 6.52 and 5.49 times respectively.

2.3 Mean Times per Year

Mean times per year is the average yearly number of earthquakes occurring in each municipal area.

2.3.1 Mean Times per Year of Labeled Earthquakes in Each City/County

Figure 10: Mean times of labeled earthquakes per year for each city/county in Taiwan from January 1995 to June 2017

Hualien has the most frequent earthquakes per year with the number of 56.22, then followed by Yilan (23.73), and Taitung (18.71).

2.3.2 Yearly Mean Times of Total Earthquakes in Each City/County
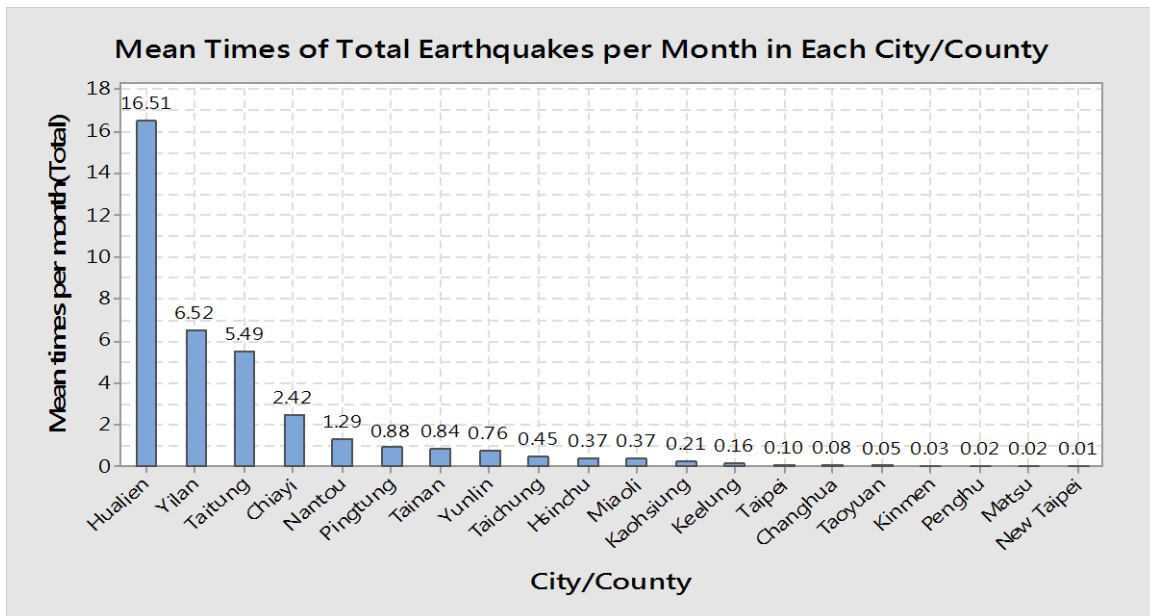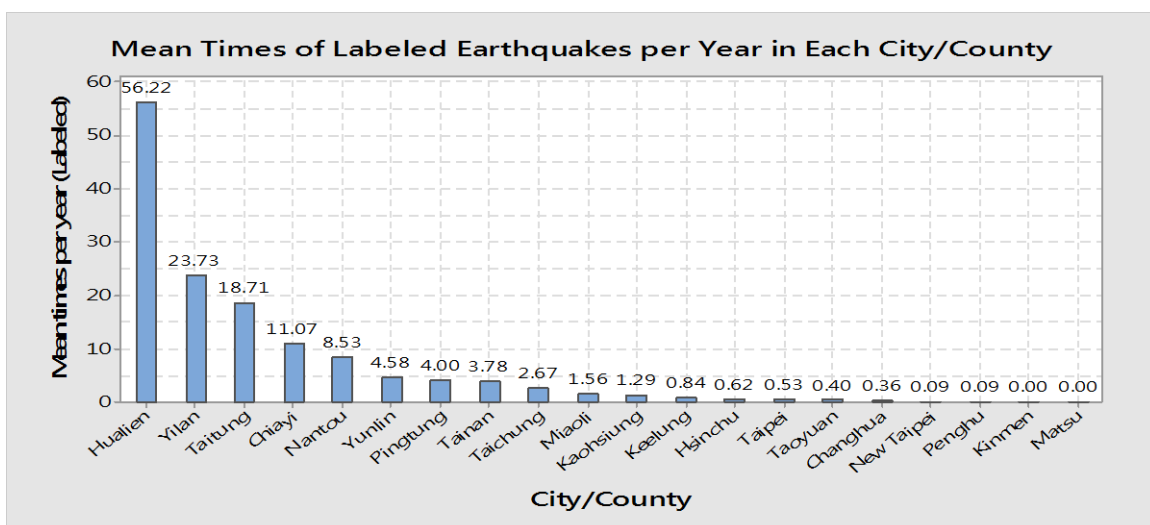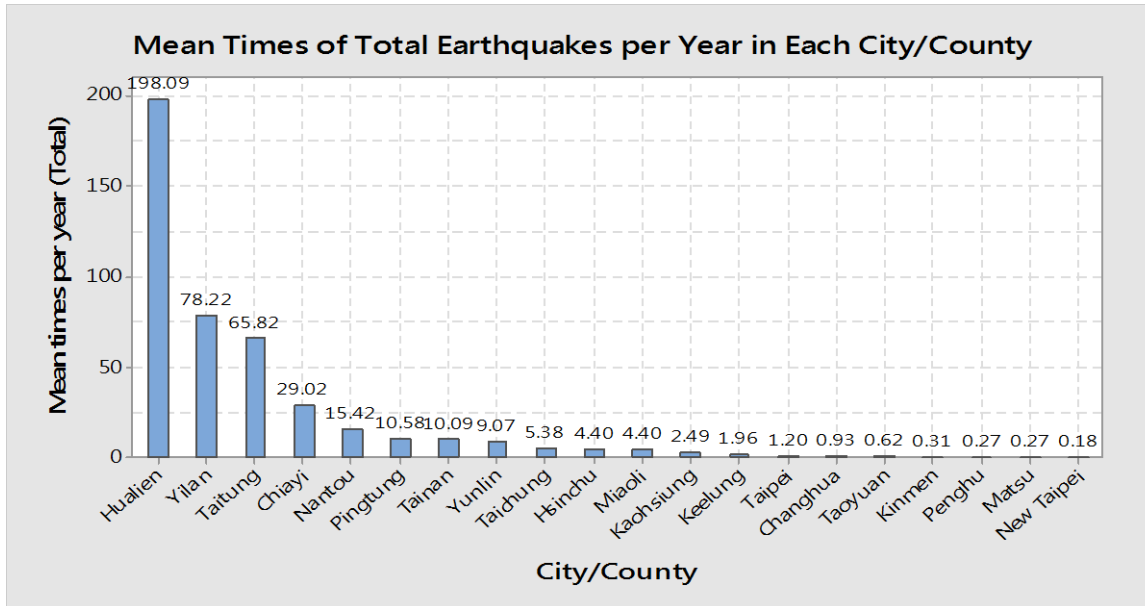

Figure 11: Mean times of total earthquakes per year for each city/county in Taiwan from January 1995 to June 2017

Hualien has the most frequent earthquakes per year with the number of 198.09, then followed by Yilan (78.22), and Taitung (65.82). From the above figure, one finds the unlabeled earthquakes sharply increase the yearly number of each city and county.

2.4 Mean Depth (km)

The average depth of each earthquake measured in the unity of kilometer (km) in each city and county is also studied in this paper. The shallower hypocenter may have stronger intensity of each locality due to the attenuation effect.

2.4.1 Mean Depth (km) of Labeled Earthquakes in Each City/County

Figure 12: Mean depth (km) of labeled earthquakes for each city/county from January 1995 to June 2017

Almost all the mean depth of hypocenters of labeled earthquakes in Taiwan are shallow (<70 km), except Keelung (103.6km), which is classified as intermediate-depth. Maybe it is because earthquakes in Keelung occur on the submerged tectonic plate.
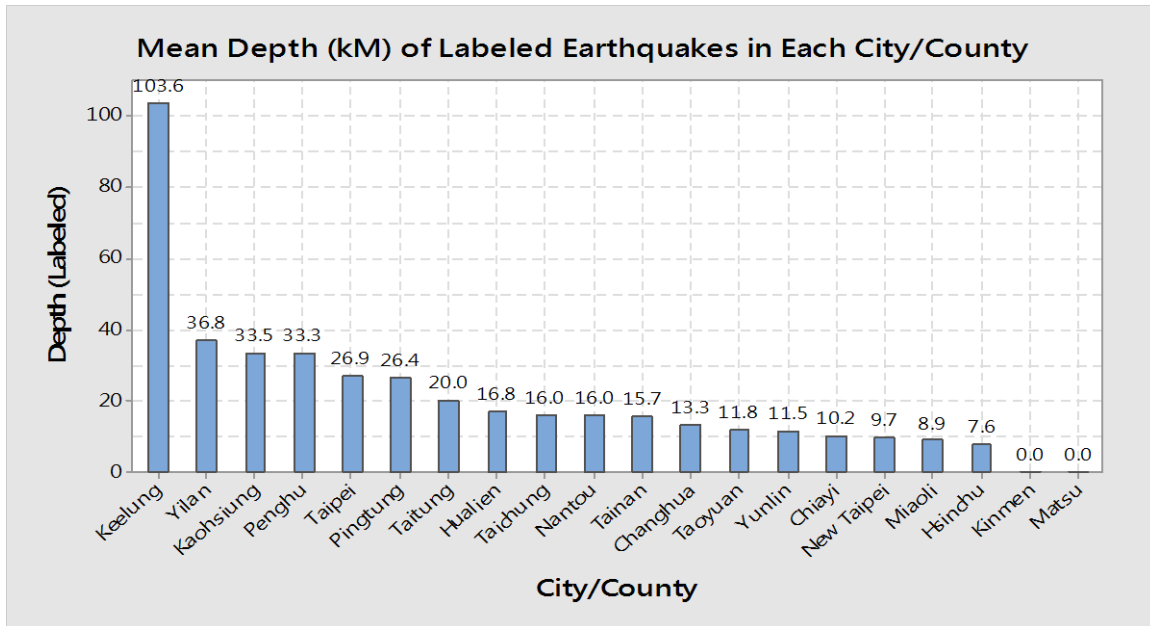
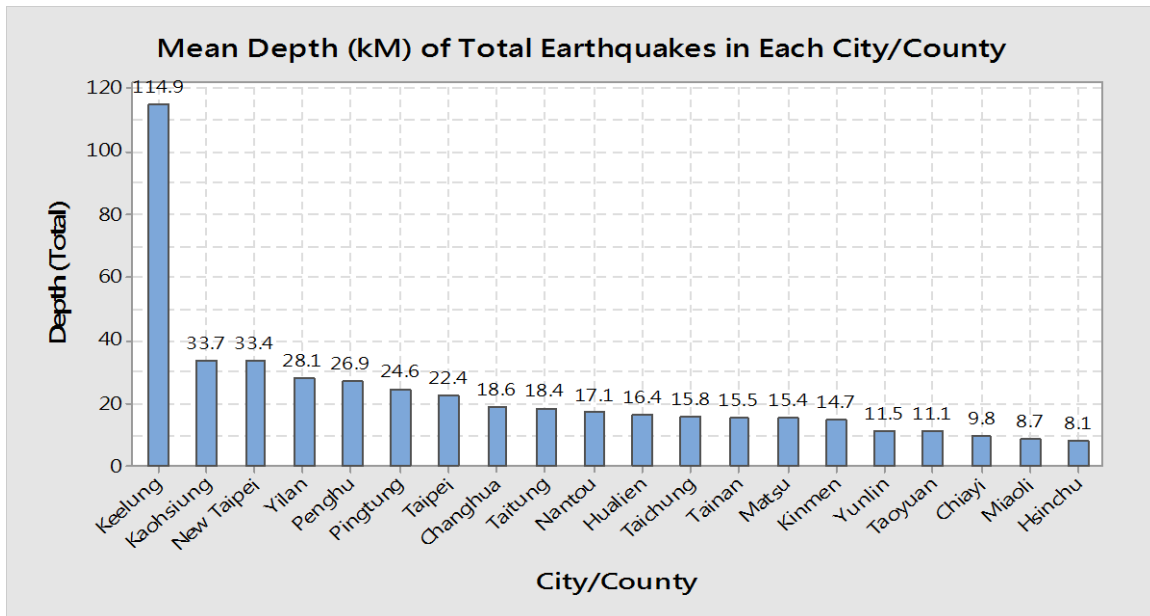## 2.4.1 Mean Depth (km) of Total Earthquakes in Each City/County

Figure 13: Mean depth (km) of total earthquakes for each city/county from January 1995 to June 2017

Same as the labeled ones, almost all the mean depth of hypocenters of total earthquakes in Taiwan are shallow (<70 km), except Keelung (114.9km), which is classified as intermediate-depth. The shallowest average hypocenter depth is located in Hsinchu (8.1 km).

2.5 Mean Magnitude (Richter magnitude scale, M_L)

Magnitude is the energy released from an earthquake. It is often estimated from the equation suggested by Gutenberg and Richter (Kramer 1996) as $\log E = 11.8 + 1.5 Ms$ with unit of ergs. This value is a fixed value and it will not be changed by the distance from the epicenter of an earthquake.

2.5.1 Mean Magnitude (Richter magnitude scale, ML) of Labeled Earthquakes in Each City/County
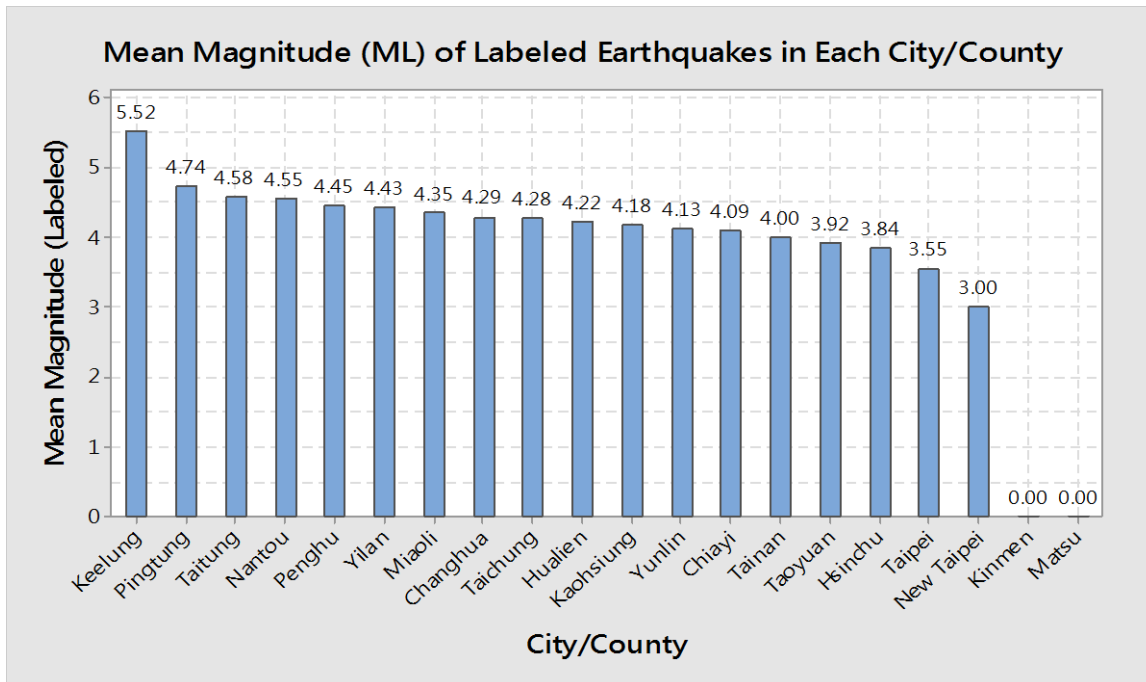
Figure 14: Mean magnitude of labeled earthquakes of each city/county from January 1995 to June 2017

Surprisingly, the highest mean magnitude (Richter, M_L) for Taiwan is in Keelung (5.52). The mean value of magnitude of labeled earthquakes from January 1995 to June 2017 is 4.23 (M_L). Catastrophic earthquake has rarely occurred in Keelung, although the mean magnitude there is higher than any other places. It is probably the hypocenters of earthquakes are deep in that area so the waves attenuated to the surface are less harmful.

2.5.2 Mean Magnitude (Richter magnitude scale, ML) of Total Earthquakes in Each City/County
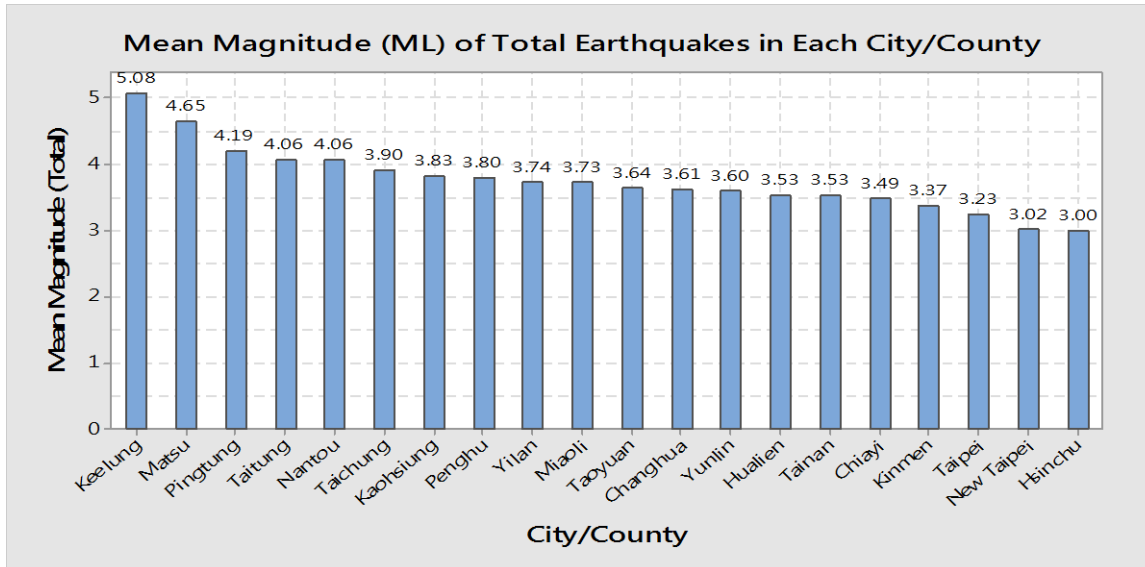
Figure 15: Mean magnitude of total earthquakes of each city/county from January 1995 to June 2017

The highest mean magnitude (Richter, M_L) for Taiwan is in Keelung (5.08). The mean value of magnitude of labeled earthquakes from January 1995 to June 2017 is 3.75 (M_L).

2.6 Maximum Magnitude of Earthquakes for Each City/County in Taiwan

The maximum magnitude of earthquakes in each municipal area may implicitly express the potential hazard of a city/county. Since the maximum values of labeled and total earthquakes are similar, only total earthquakes' results are plotted.

2.6.1 Maximum Magnitude of Total Earthquakes in Each City/County
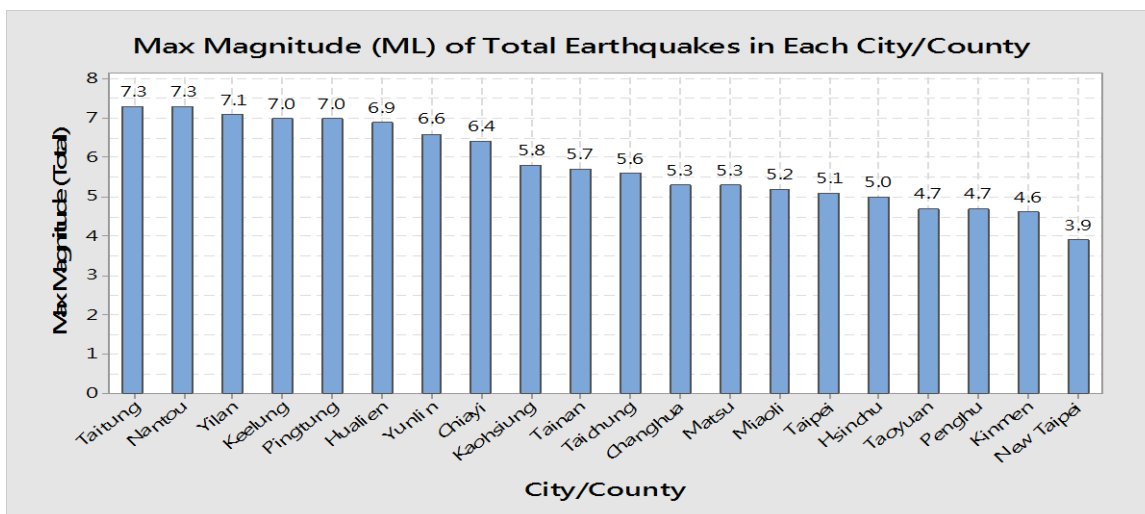
Figure 16: Maximum magnitude (M_L) of each city/county in Taiwan

The maximum magnitude of earthquakes in Taiwan for the past 22.5years is 7.3 (Richter magnitude scale M_L) in Nantou on September 21, 1999. Totally 2,415 people died and 11,305 were injured in that earthquake (wiki/921_earthquake). Although the magnitude of Taitung is 7.3 and those of Yilan, Keelung, and Pingtung are 7.0 or above, the epicenters of them are out of Taiwan, hence much less damage was done to the Formosa Island.

2.7 Mean Time (d Time in days) Between Two Earthquakes in Each City/County

The time between two earthquakes in each area is discussed in this subsection to measure the possible period of earthquake appearing

2.7.1 Mean Time (dTime in days) Between Two Labeled Earthquakes in Each City/County
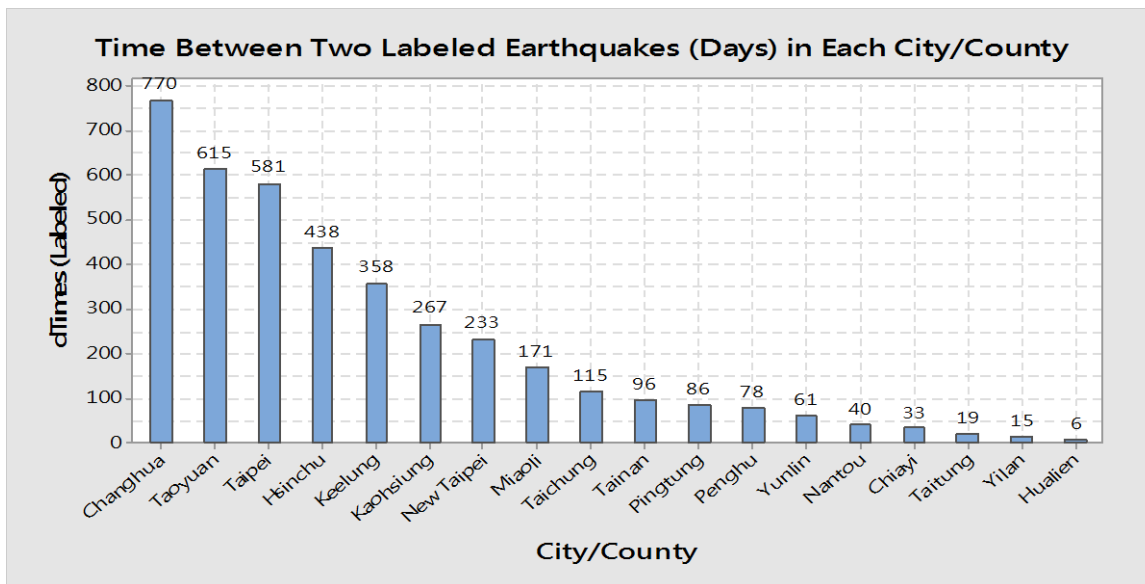
Figure 17: Mean interval of time (days) between two labeled earthquakes for each city/county from January 1995 to June 2017

Mean interval of time between two earthquakes for each city/county is defined as dTime (days). In Hualien, people might experience a tremor of ground every 6 days while for Changhua the interval of two earthquakes takes 770 days. Two counties Kinmen and Matsu are excluded from this analysis because no labeled earthquake record was found.

2.7.2 Mean Time (d Time in days) Between Two Total Earthquakes in Each City/County
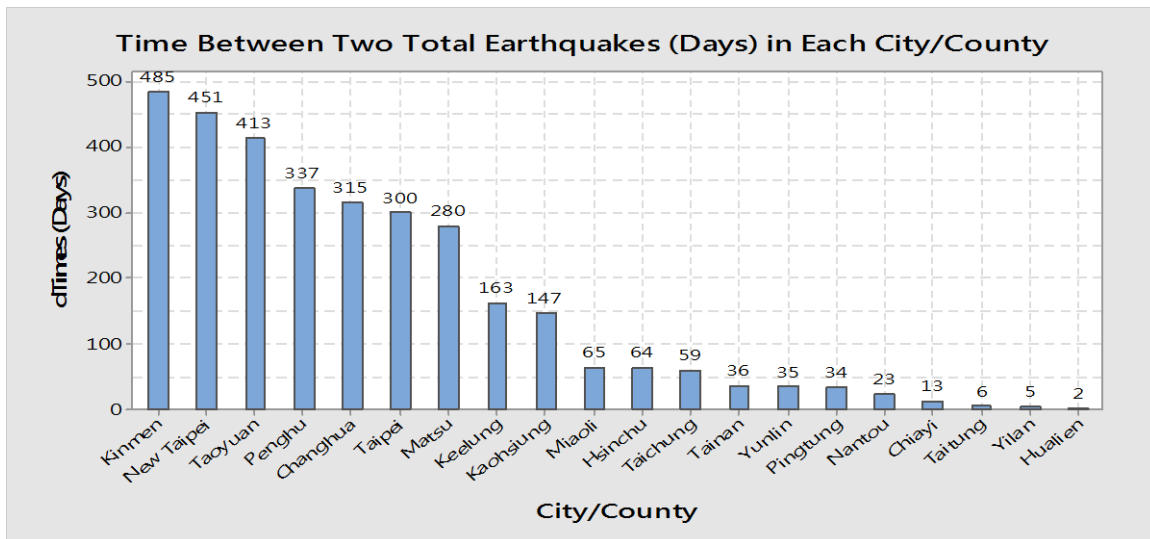
Figure 18: Mean interval of time (days) between two total earthquakes for each city/county from January 1995 to June 2017

In Hualien, the period of time between two earthquakes is as short as two days. Kinmen is on the other extremely end. The interval of two earthquakes is 485 days. Two counties Kinmen and Matsu are included in the analysis because there are still a few minor earthquakes occurring there.

2.8 Ratio of Energy (ergs)

Since the energy released from an earthquake is usually large, and it is not easy to make comparison. To express released energy in percentage ratio will be easier to read, and to compare it with the atomic bomb dropped in Hiroshima (Little Boy) is graphically understandable.

2.8.1 Ratio of Energy Released from Labeled Earthquakes in Each City/County
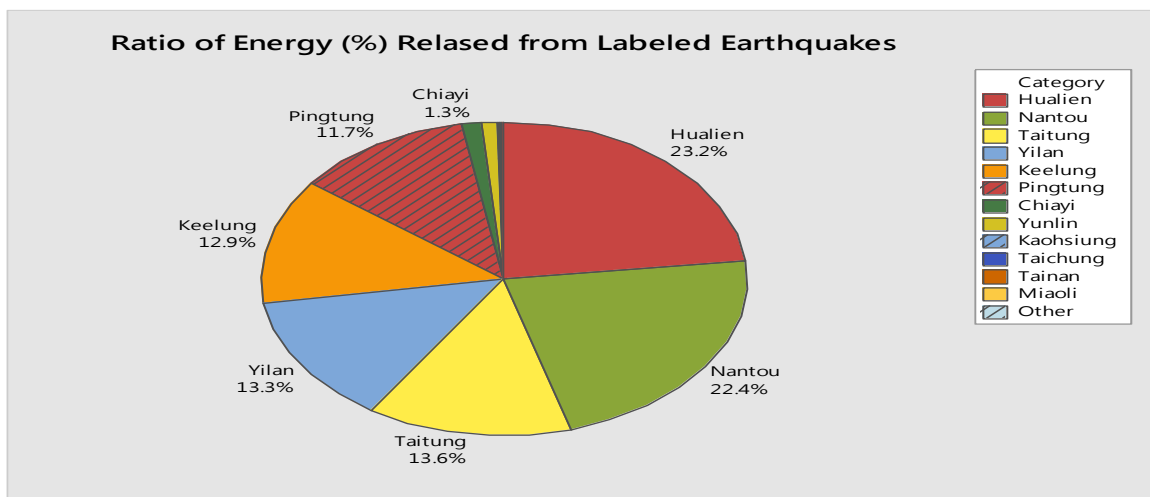
Figure 19: The ratio (%) of energy released in each city/county to total energy released by labeled earthquakes in Taiwan from January 1995 to June 2017

The energy calculation for each earthquake is based on the equation given by Gutenberg and Richter (Kramer, 1996). The energy released from all labeled earthquakes is calculated by equation $\log_{10}E=11.8+1.5M_S$ (ergs). The ratio of energy released by total labeled earthquakes of each area to that of total labeled earthquakes in Taiwan from January 1995 to June 2017 is expressed in percentage. As expected, Hualien grabs number one (23.2%), followed by Nantou (22.4%) and Taitung (13.6%).Note that because the energy released by those unlabeled earthquakes is not counted, the above results are just for reference only.

2.8.2 Ratio of Energy Released from Total Earthquakes in Each City/County
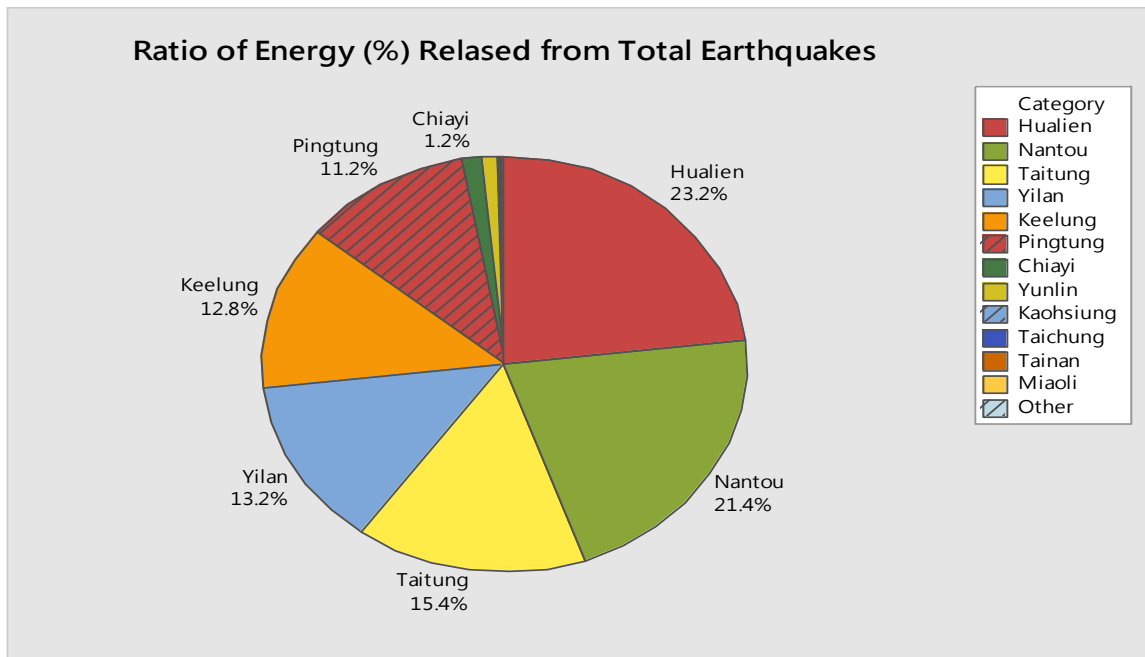
Figure 20: The ratio (%) of energy released in each city/county to total energy released by total earthquakes in Taiwan from January 1995 to June 2017

The ratio of released energy by earthquakes in each area to that by total earthquakes in Taiwan from January 1995 to June 2017 is expressed in percentage. As expected, Hualien grabs number one (23.2%), followed by Nantou (21.4%) and Taitung (15.4%).Note that because the released energy is counted by total earthquakes, the above results are more accurate.

2.8.3 Energy Released from Labeled Earthquakes Expressed in the Number of Atomic Bombs
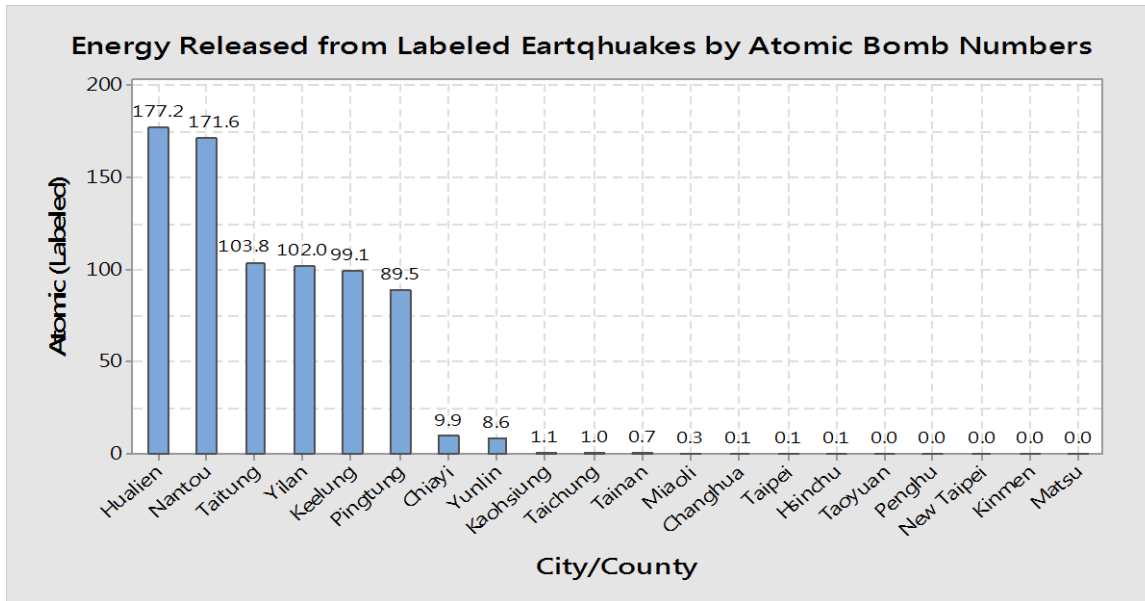
Figure 21: Energy released from labeled earthquakes in each city/county by atomic bomb numbers

The energy released from the atomic bomb dropped in Hiroshima by the end of WWII is about 63TJ (Little Boy). To transfer abstract energy of earthquake to atomic bomb numbers may impress readers. The energy released from labeled earthquakes accumulate to 4.82E+23 ergs, which is equivalent to 764.95 atomic bombs. In each year the energy released from labeled earthquakes is 30.0 atomic bombs.

2.8.4 Energy Released from Total Earthquakes Expressed in Number of Atomic Bombs
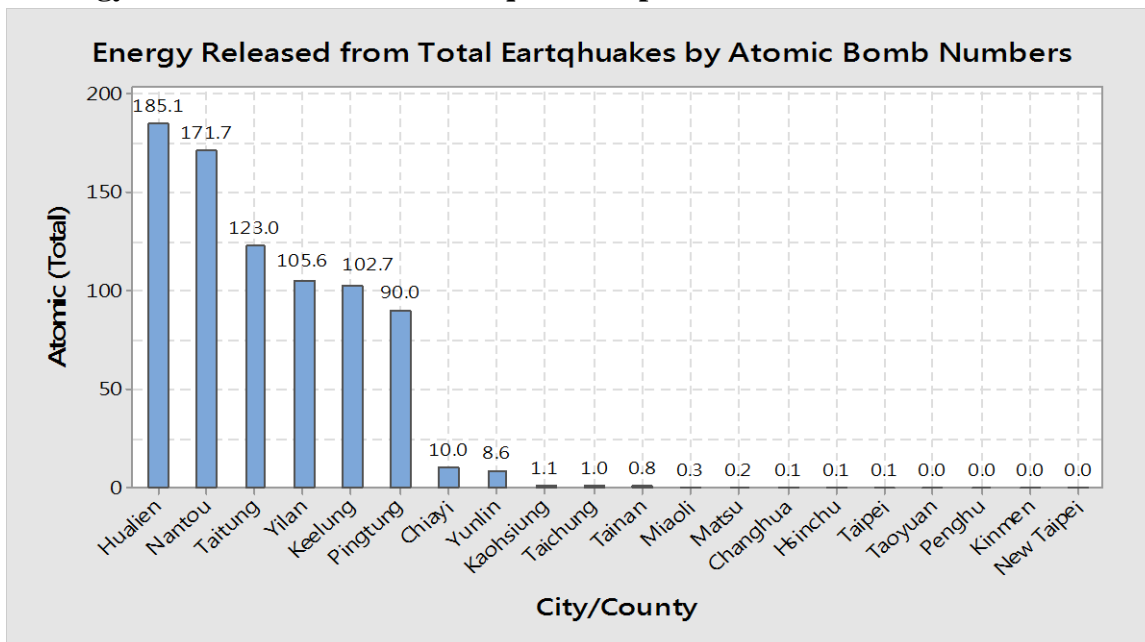
Figure 22: Energy released from total earthquakes in each city/county by atomic bomb numbers

The energy released from total earthquakes accumulates to 5.04E+23 ergs, which is equivalent to 800.31 atomic bombs. In each year the energy released from total earthquakes is equivalent to 35.57 atomic bombs.

By comparing 800.31 and 764.95, there is 35.36 atomic bombs difference if unlabeled earthquakes are neglected. Such a gap may increase by the increasing of time, and should be treated with extreme care.

The other observation is that in Nantou, the atomic bomb numbers both in labeled and total earthquakes are almost identical. It shows the labeled earthquakes occurring at Nantou dominates almost all released energy.

3. Conclusions

After analyzing earthquake data in Taiwan from January 1995 to June 2017and scrutinizing the major characters of labeled and total earthquakes in all twenty municipal areas in Taiwan, the following statistical conclusions can be summarized concisely as follows.

3.1 For Labeled Earthquakes

(1) Hualien is the most active place for earthquakes in Taiwan. There are 1,265earthquakes in Hualien out of totally 3,129 earthquakes in Taiwan, and the frequent ratio is 40.4%. Yilan takes the second place, occurring 534 times with the ratio of 17.1%. Taitung with 421 times is the third, with the ratio of 13.5%.

(2) In each month, 4.69 times of labeled earthquakes happen in Hualien, 1.98 times in Yilan, and 1.56 times in Taitung respectively.

(3) The highest frequency of earthquakes per year is in Hualien with a number of 56.22, and followed by Yilan (23.73), and Taitung (18.71).

(4) Almost all the mean depth of hypocenters of earthquakes in Taiwan is shallow (<70 km), except Keelung (103.63km), which is classified as intermediate-depth. Maybe it is because earthquakes in Keelung are in the submerged tectonic plate.

(5) The highest mean magnitude (Richter magnitude scale, M_L) for Taiwan is in Keelung (5.52). The mean value of magnitude of labeled earthquakes from January 1995 to June2017 is 4.23.

(6) The maximum magnitude of earthquakes in Taiwan for the past 22.5 years is 7.3 (Richter magnitude scale, M_L) in Nantou on September 21, 1999.

(7) In Hualien, the average period of two labeled earthquakes is 6.48 days, while in Changhua the interval between two labeled earthquakes takes 769.8 days, which is the longest in Taiwan.

(8) The total energy released from labeled earthquakes in the past 22.5 years is 4.82E+23 ergs. Hualien accounts for 23.2% of it, and is the place where the labeled earthquakes release most energy.

(9) The "Little Boy" atomic bomb, which was dropped in Hiroshima and released 63 TJ (6.3E+20 ergs) of energy, is used to express the abstract quantity into real number. From January 1995 to June 2017 there were 764.95 atomic bombs burst in Taiwan. No doubt Hualien was the most intense area, 177.2 bombs. Nantou 171.6 is the second, and followed by Taitung, 103.8 bombs.

3.2 For Total (both labeled and unlabeled) Earthquakes

(1) Hualien is the most active place for earthquakes in Taiwan. There are 4,457 earthquakes in Hualien out of totally 9,871 earthquakes in Taiwan, and the frequent ratio is 45.2%. Yilan takes the second place, occurring 1,760 times with the ratio of 17.8%. Taitung with 1,481 times is the third, with the ratio of 15.0%.

(2) In each month, 16.51 times of labeled earthquakes happen in Hualien, 6.52 times in Yilan, and 5.79 times in Taitung respectively.

(3) The highest frequency of earthquakes per year is in Hualien with a number of 198.09, and followed by Yilan (78.22), and Taitung (65.82).

(4) Almost all the mean depth of hypocenters of earthquakes in Taiwan is shallow (<70 km), except Keelung (114.92 km), which is classified as intermediate-depth. Maybe itis because earthquakes in Keelung are in the submerged tectonic plate.

(5) The highest mean magnitude (Richter magnitude scale, ML) for Taiwan is in Keelung (5.08). The mean value of magnitude of all earthquakes from January1995 to June 2017 is 3.75.

(6) The maximum magnitude of earthquakes in Taiwan for the past 22.5 years is 7.3 (Richter magnitude scale, ML) in Nantou on September 21, 1999. Although the maximum magnitude in Taitung is also 7.3, its epicenter is off-island. Therefore, no severe damage was recorded.

(7) In Hualien, the average interval of two labeled earthquakes is 1.84 days, and in Kinmen the interval between two labeled earthquakes takes 484.7 days, which is the longest in Taiwan.

(8)The total energy released from all earthquakes in the past 22.5 years is 5.03E+23 ergs. Hualien accounts for 23.2% of it, and is the place where earthquakes released the most energy.

(9) From January 1995 to June 2017 there were 800.31 atomic bombs burst in Taiwan. No doubt Hualien was the most intense area with and equivalent of 185.1 bombs burst. Nantou (171.7bombs) is the second, and followed by Taitung (120.3 bombs).There are 35.36 bombs difference between the atomic bomb numbers of total earthquakes (800.31bombs) and labeled ones (764.95 bombs). The energy gap will increase with time if only labeled earthquakes are considered in the analysis. It is obviously inappropriate for the analysis of unlabeled earthquakes to be neglected from the calculation.

4.References

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Appendices:

There are three appendices with data of labeled earthquakes (Appendix A), total earthquakes (labeled plus unlabeled, Appendix B), and energy released from earthquakes (Appendix C). These three tables provide the back bone in this paper.

Appendix A:

Table A1: The labeled earthquake data for each city and county in Taiwan (From January 1995 to June 2017)

City/County	Numbers of earthquakes	Mean times per month	Mean times per year	Earthquake percentage (%)	Depth (km)	Magnitude (Richter M_L)		Total Energy Released (ergs)	Average dTime (days)
						Mean	Max		
Yilan	534	1.98	23.7	17.07	36.76	4.43	7.1	6.43E+2	15.22

			3					2	
Hualien	1,265	4.69	56.22	40.43	16.78	4.22	6.9	1.12E+23	6.48
Taitung	421	1.56	18.71	13.45	19.98	4.58	7.1	6.54E+22	19.24
Nantou	192	0.71	8.53	6.14	15.97	4.55	7.3	1.08E+23	39.64
Keelung	19	0.07	0.84	0.61	103.63	5.52	7.0	6.24E+22	358.23
Taipei	12	0.04	0.53	0.38	26.91	3.55	5.1	3.48E+19	581.49
New Taipei	2	0.01	0.09	0.06	9.7	3.0	3.3	6.33E+16	232.76
Taoyuan	9	0.03	0.40	0.29	11.77	3.92	4.7	1.54E+19	614.97
Hsinchu	14	0.05	0.62	0.45	7.63	3.84	5.0	3.70E+19	437.67
Miaoli	35	0.13	1.56	1.12	8.92	4.35	5.2	1.96E+20	171.12
Taichung	60	0.22	2.67	1.92	16.02	4.28	5.6	6.14E+20	115.15
Changhua	8	0.03	0.36	0.26	13.34	4.29	5.3	7.44E+19	769.86
Yunlin	103	0.38	4.58	3.29	11.49	4.13	6.6	5.43E+21	61.13
Chiayi	249	0.92	11.07	7.96	10.21	4.09	6.4	6.23E+21	32.78
Tainan	85	0.31	3.78	2.72	15.65	4.00	5.6	4.07E+20	96.29
Kaohsiung	29	0.11	1.29	0.98	33.45	4.18	5.8	6.99E+20	266.78

City/County	Numbers of earthquakes	Mean times per month	Mean times per year	Number of Earthquakes/Total Earthquakes (%)	Mean Depth (km)	Magnitude (Richter M_L) Mean	Max	Total Energy Released (ergs)	Mean dTime (days)
Pingtung	90	0.33	4.00	2.88	26.43	4.74	7.00	5.64E+22	85.70
Penghu	2	0.01	0.09	0.06	33.25	4.45	4.7	8.34E+18	78.08
Kinmen	0	0.00	0.00	0.00	N.A.	N.A.	N.A.	0.0	N.A.
Matsu	0	0.00	0.00	0.00	N.A.	N.A.	N.A.	0.0	N.A.
Total	3,129	N.A.	N.A.	100	N.A.	N.A.	N.A.	4.82E+23	N.A.
Energy (ergs)	$\log_{10}E=11.8+1.5M_S$								
Average dTime (days)	The average days between two earthquakes.								

In the above table, the released energy of earthquakes is based on the equation, $\log_{10}E=11.8+1.5M_S$, given by Gutenberg and Richter (Kramer, 1996). Many variations of M_S (shear-wave magnitude) formulas take into account the effects of specific geographic regions so that the final computed magnitude is reasonably consistent with Richter's original definition of M_L (Pidwirny, 2011). In this study, the author does not distinguish these two magnitudes. During the energy calculation, M_S was substituted by M_L.

Appendix B:

Table B1: The total earthquake data for each city and county in Taiwan (From January 1995 to June 2017)

City/County	Numbers of earthquakes	Mean times per month	Mean times per year	Number of Earthquakes/Total Earthquakes (%)	Mean Depth (km)	Magnitude (Richter M_L) Mean	Max	Total Energy Released (ergs)	Mean dTime (days)

Yilan	1760	6.52	78.22	17.83	28.11	3.74	7.1	6.65E+22	4.62
Hualien	4457	16.51	198.09	45.15	16.41	3.53	6.9	1.17E+23	1.84
Taitung	1481	5.49	65.82	15.0	18.39	4.06	7.3	7.75E+22	5.51
Nantou	347	1.29	15.42	3.52	17.09	4.06	7.3	1.08E+23	23.14
Keelung	44	0.16	1.96	0.45	114.92	5.08	7.0	6.47E+22	163.00
Taipei	27	0.10	1.20	0.27	22.39	3.23	5.1	3.69E+19	299.57
New Taipei	4	0.01	0.18	0.04	33.4	3.02	3.9	5.11E+17	451.43
Taoyuan	14	0.05	0.62	0.14	11.12	3.64	4.7	1.59E+19	412.89
Hsinchu	99	0.37	4.40	1.0	8.08	3.00	5.0	4.16E+19	63.98
Miaoli	99	0.37	4.40	1.0	8.67	3.73	5.2	2.12E+20	65.02
Taichung	121	0.45	5.38	1.23	15.82	3.90	5.6	6.33E+20	59.14
Changhua	21	0.08	0.93	0.21	18.64	3.61	5.3	7.70E+19	314.6
Yunlin	204	0.76	9.07	2.07	11.46	3.60	6.6	5.43E+21	35.3
Chiayi	653	2.42	29.02	6.62	9.75	3.49	6.4	6.28E+21	12.5
Tainan	227	0.84	10.09	2.30	15.48	3.53	5.7	4.99E+20	36.1
Kaohsiun	56	0.21	2.49	0.57	33.7	3.83	5.	6.99E+	146.5

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Pingtung	238	0.88	10.58	2.4	24.57	4.19	7	5.67E+22	34.1
Penghu	6	0.02	0.27	0.06	26.87	3.80	4.7	8.91E+18	336.6
Kinmen	7	0.03	0.31	0.07	14.73	3.37	4.6	6.48E+18	484.7
Matsu	6	0.02	0.27	0.06	15.38	4.65	5.3	1.0E+20	280.3
Total	9,871	1.83.	21.94	100	23.25	3.75	5.8	5.04E+23	164.5
Energy (ergs)	$\log_{10}E = 11.8 + 1.5M_S$								
Average dTime (days)	The average days between two earthquakes.								

Appendix C:

Table C1: Released Energy of Earthquakes from January 1995 to June 2017 in Taiwan

City/County	Energy released of labeled earthquakes and equivalent to atomic bomb numbers		Energy released of total earthquakes and equivalent to atomic bomb numbers	
	Energy released (ergs)	Equivalent atomic bomb numbers	Energy released (ergs)	Equivalent atomic bomb numbers
Yilan	6.43E+22	101.99	6.65E+22	105.63
Hualien	1.12E+23	177.22	1.17E+23	185.12
Taitung	6.54E+22	103.79	7.75E+22	122.95

Nantou	1.08E+23	171.62	1.08E+23	171.68
Keelung	6.24E+22	99.07	6.47E+22	102.65
Taipei	3.48E+19	0.06	3.69E+19	0.06
New Taipei	6.33E+16	0.00	5.11E+17	0.00
Taoyuan	1.54E+19	0.02	1.59E+19	0.03
Hsinchu	3.70E+19	0.06	4.16E+19	0.07
Miaoli	1.96E+20	0.31	2.12E+20	0.34
Taichung	6.14E+20	0.97	6.33E+20	1.00
Changhua	7.44E+19	0.12	7.70E+19	0.12
Yunlin	5.43E+21	8.62	5.43E+21	8.62
Chiayi	6.23E+21	9.88	6.28E+21	9.96
Tainan	4.07E+20	0.65	4.99E+20	0.79
Kaohsiung	6.99E+20	1.11	6.99E+20	1.11
Pingtung	5.64E+22	89.45	5.67E+22	90.0
Penghu	8.34E+18	0.01	8.91E+18	0.01
Kinmen	0	0.00	6.48E+18	0.01
Matsu	0	0.00	1.0E+20	0.16
Total	4.82E+23	764.95	5.04E+23	800.31

 Note: The released energy of an atomic bomb is about 63TJ or equivalent to 6.30E+20 ergs (Little Boy)

From the above table, one finds that the negligence of unlabeled earthquakes may under-estimate the released energy up to 2.2E+22 ergs, or more graphically speaking, equivalent to 35.36 atomic bombs dropped in Hiroshima, Japan during WWII.