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THE STATISTICAL DESCRIPTIONS OF SEISMIC CHARACTERISTICS OF TAIWAN

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ABSTRACT

Through a statistical study of the seismic archive of the Central Weather Bureau (CWB) of Taiwan to make people understand more the properties of earthquakes in each city and county in Taiwan is the purpose of this paper. From January 1995 to March 2019, there were 3,318 labeled as well as 11,246 total (labeled plus unlabeled) earthquakes recorded in the Central CWB of Taiwan. The statistical seismic properties evaluated in this paper include: yearly numbers, mean times per year, mean times per month, mean depth (km), maximum magnitude (ML), mean interval of time between two earthquakes, energy released ratio, and energy equivalent to the number of atomic bombs in each city and county. These properties are plotted as diagrams to facilitate reading.

Hualien, a county on the east coast of Taiwan, was the place that had the highest frequency of earthquakes, the shortest time interval between two earthquakes, and released most energy. The energy released from total earthquakes in Hualien in the period of January 1995 to March 2019 is equivalent to 191.3 atomic bombs, which were dropped over Hiroshima, Japan. Most of the earthquakes in Taiwan's twenty municipal areas were categorized to be shallow (<70km), except Keelung, which had an average depth of hypocenters at 114.9 km (intermediate-depth). Maybe it is because the hypocenters of Keelung were in the submerged tectonic plate. In the past 291 months (January 1995 to March 2019) the strongest magnitude (Richter magnitude scale, ML) was 7.3, which happened on September 21, 1999.

This study showed that if the unlabeled earthquakes (usually small in magnitude and impact locally) were neglected, the total energy will be uncounted up to 2.5E+22 ergs. Such energy lost was equivalent to 39.7 atomic bombs. Therefore, to put all records in the CWB seismic archive in the analysis was strongly recommended to avoid obtaining inaccurate results.

The regression of intensity with independent variables, such as longitude, latitude, magnitude, and depth of hypocenters showed that the intensity of Taiwan decreases with increasing longitude, increases with increasing latitude, increases with increasing magnitude and decreases with increasing depth. The coefficient of determination was more than 91%, which showed the dependent variable, intensity, was highly explained through the knowledge of the variability in the independent variables. The depth of hypocenters, intensities, and magnitudes of all earthquakes are plotted with three-dimensional diagrams, and the results were consistent with the statistical analyses.

Keywords: CWB Seismic Archive, Coefficient of Determination, Hypocenters

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1. Introduction

Taiwan is on the Circum-Pacific seismic belt; therefore, the earthquakes occur from time to time. How to systematically study the properties of them is important for the people on this island because it is unavoidable to escape the influence of earthquakes as long as they live in Taiwan.

The Central Weather Bureau (CWB) records longitude, latitude, magnitude, depth, occurring time, and intensity of each earthquake. And such a treasured record becomes the source to glimpse the mystery of the movement of plate tectonics. The archive of the Central Weather Bureau (CWB) of Taiwan has two kinds of earthquake records, labeled and unlabeled. The labeled ones have a 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 number one. In the CWB archive, the author found that not until May 2000 did the CWB begin to put unlabeled earthquakes into its record. These properties of unlabeled earthquakes may amend the knowledge of those aftershocks of a strong earthquake.

The author was interested in how different the statistical properties of total and labeled earthquakes will be. From January 1995 to March 2019, there were 3,318 labeled and 11,246 total (labeled plus unlabeled) earthquakes occurring in 24.25 years (291 months). The total and labeled number of earthquakes differ more than three times. If their statistical properties were similar, then one can just pay attention to the labeled ones. Much time and cost will be saved. The difference in the number of labeled and total earthquakes will increase with the increasing of time.

2. Number of earthquakes in Taiwan and their statistical properties

There were 11,246 earthquakes occurring from January 1995 to March 2019, but only 3,318 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 [1]. The earthquake records from January 1995 to March 2019 covering 291 months or 24.25 years are analyzed in this paper. After tedious data manipulation and arrangement, the number of earthquakes in each city and county was summarized in Appendix A (for total earthquakes), Appendix B (for labeled earthquakes), Appendix C (for energy calculation and an equivalent number of atomic bombs), and Appendix D (for hypocenter locations and intensities). In the following subsections, each property of these tables will be presented by graphs to facilitate reading.

2.1 Number of earthquakes per year in Taiwan

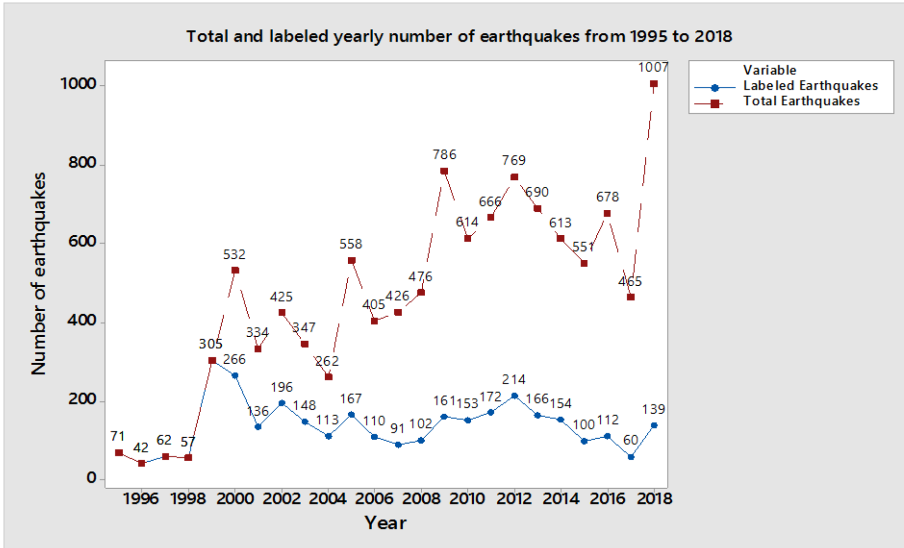

Figure 1: Number of the total (labeled and unlabeled) and labeled earthquakes per year from 1995 to 2018

From the above figure, one finds the total earthquakes (11,246) are about 3.39 times more than the labeled (3,318) ones. After the year 2000, the two records begin to separate because not until May 2000 did the CWB begin to put small-scale earthquakes into the archive.

2.1.1 Number of total earthquakes per year in Taiwan

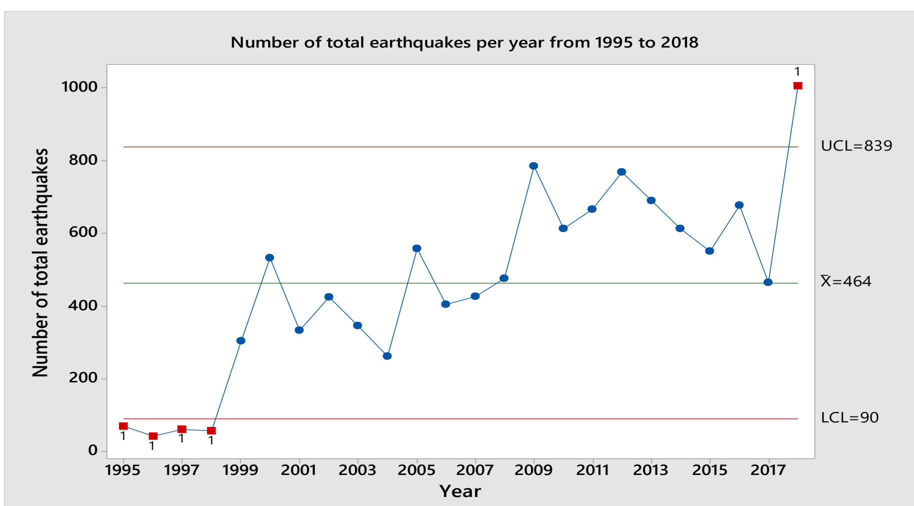

Figure 2: Number of total earthquakes per year from 1995 to 2018 in Taiwan

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From the above figure, one finds the average number of total earthquakes per year was 464. The year 2018 had 1,007 records of earthquakes, which was three standard errors above the mean. On the other hands, from 1995 to 1998, the records were extremely low (three standard errors below the mean), the accumulation of energy may contribute tremendously to the 921 earthquake, which was 7.3 magnitude by the Richter scale. From the above figure, one also noticed the total number of earthquakes may have a trend of increasing.

2.1.2 Number of labeled earthquakes per year in Taiwan

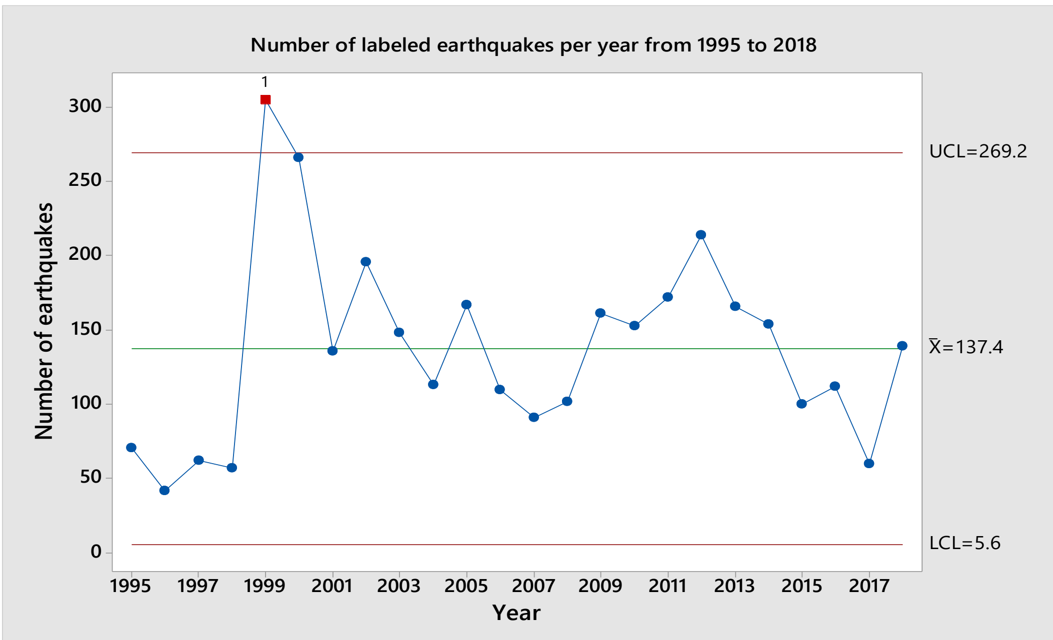

Figure 3: Number of labeled earthquakes per year from 1995 to 2018 in Taiwan

From the above figure, one found the average number of labeled earthquakes per year was 137.4 times. The year 1999 had an extraordinarily high number of records due to the horrible 921 earthquake, which registered with a magnitude of 7.3 on the Richter scale. The 921 Nantou earthquake took away 2,415 lives as well as injured 11,305 people [4]. Note that from 1995 to 1998, the yearly number of earthquakes was two standard errors below the mean. The energy accumulated during these (and previous) periods seems to be finally released in the year 1999.

2.1.3 Number of total (labeled plus unlabeled) earthquakes per month in Taiwan

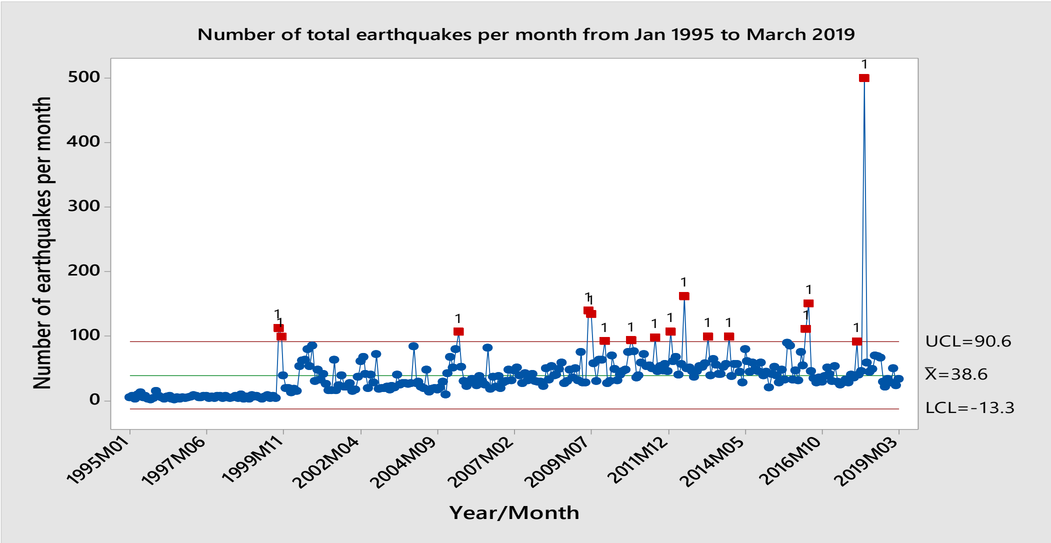

Figure 4: Number of earthquakes per month from January 1995 to March 2019 in Taiwan

The average number of earthquakes occurring in Taiwan from January 1995 to March 2019 was 38.6 times per month. There were sixteen months with numbers above three standard errors of the mean. One extraordinary large point was in February 2018, there were five hundred (500) of earthquakes recorded in that month.

2.1.4 Number of labeled earthquakes per month in Taiwan

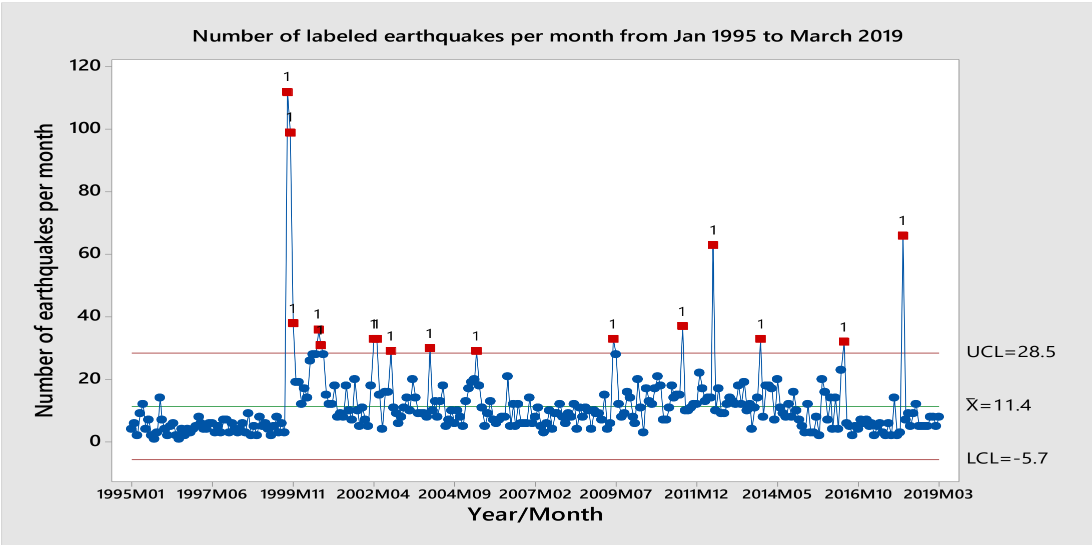

Figure 5: Number of labeled earthquakes per month from January 1995 to March 2019 in Taiwan

The mean value of labeled earthquakes for January 1995 to March 2019 was 11.4 times per month. There were sixteen months with numbers above three standard errors of the mean.

2.2 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 24.25 years (291 months) from January 1995 to March 2019. Both bar and pie charts were used to identify number and percentage (%) of earthquakes in each locality.

2.2.1 Number of total earthquakes in each city and county

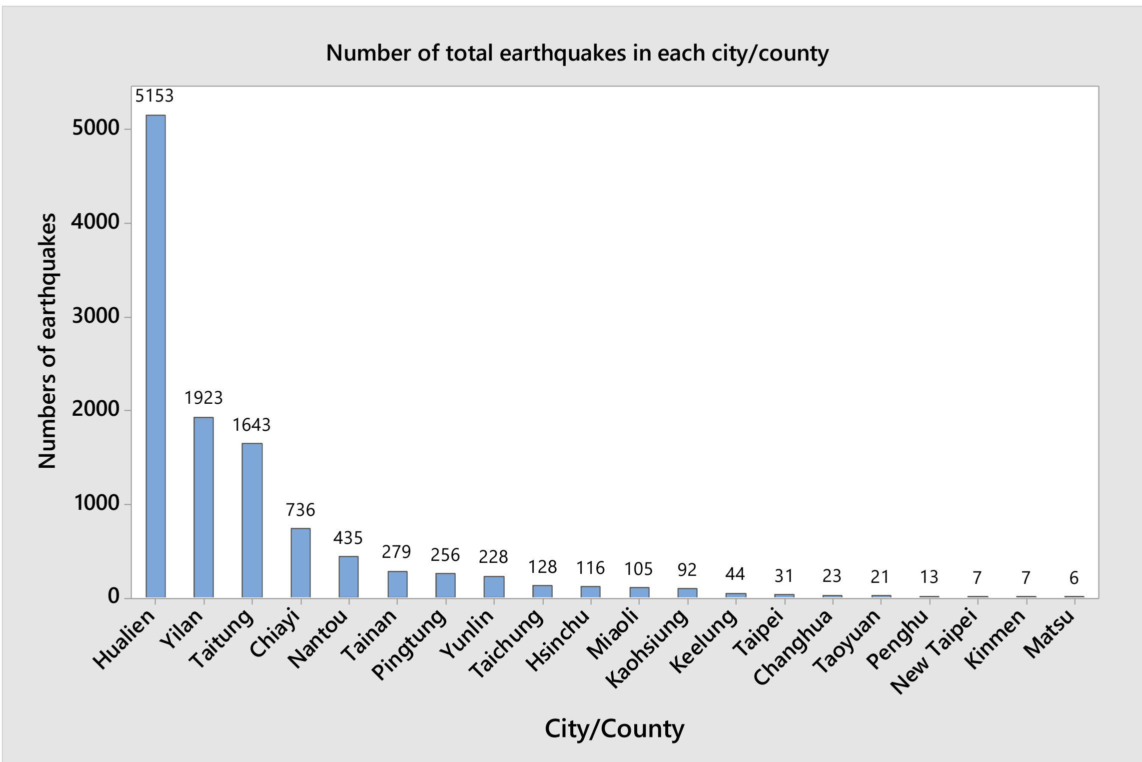

Figure 6: Number of total earthquakes in each city and county from January 1995 to March 2019

From the above figure, one found Hualien was the county with the highest earthquake occurring frequency. There were 5,153 earthquakes in the past 291 months. Yilan and Taitung had the second and third highest frequency with numbers of 1,923 and 1,643 respectively.

2.2.2 Ratio of total earthquakes distribution in each city and county

To express the number of earthquakes in each city and county as the percentage to the total numbers can make readers understand the distribution of earthquakes in the whole of Taiwan.

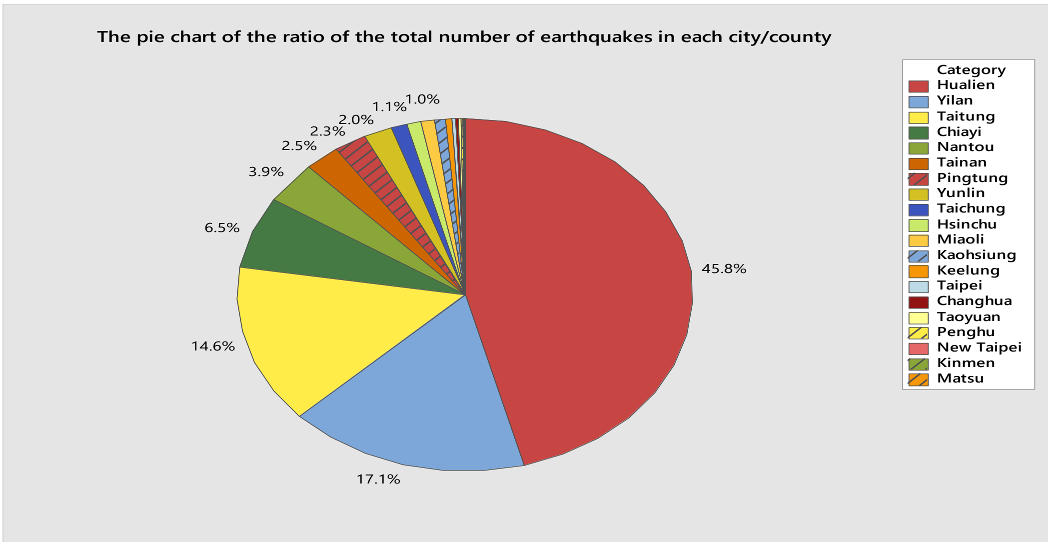

Figure 7: Percentage (%) distribution of total earthquakes in each city and county

From the above pie chart, there are 45.8% of earthquakes occurring in Hualien, 17.1% in Yilan, and 14.6% in Taitung. These three counties are all on the eastern coast of Taiwan. By adding these three numbers together, one may say that in the past 24.25 years, 77.5% of total earthquakes in Taiwan occurred there.

2.2.3 Number of labeled earthquakes in each city and county

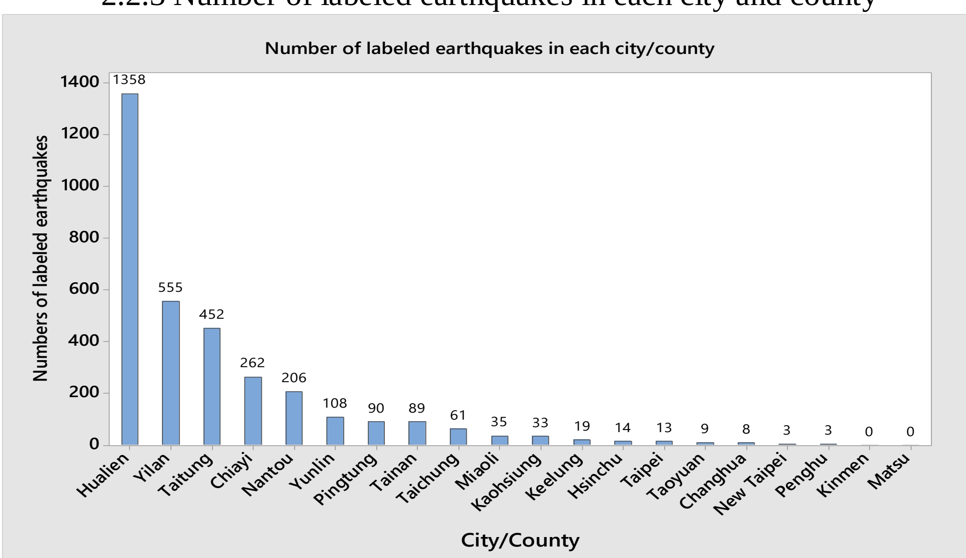

Figure 8: Number of labeled earthquakes in each city and county from January 1995 to March 2019

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From the above figure, one finds there were 1,358 labeled earthquakes occurring in Hualien in the past 291 months. Yilan and Taitung had the second and third highest frequency with numbers 555 and 452 respectively. Comparing figures 6 and 8, the total earthquakes were more than three times than the labeled ones.

2.2.4 Ratio of labeled earthquakes distribution in each city and county

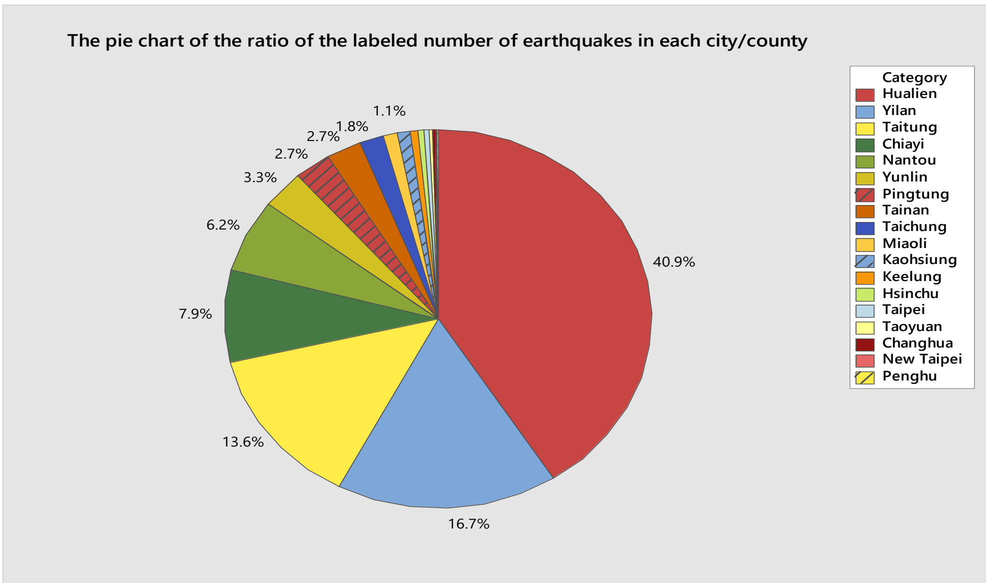

Figure 9: Percentage (%) distribution of labeled earthquakes in each city and county

From the above pie chart, there were 40.9% of labeled earthquakes occurring in Hualien, 16.7% in Yilan, and 13.6% in Taitung.

2.3 Maximum magnitude in each city and county

The magnitude of an earthquake represents its energy released. The energy measurement equation was proposed by Gutenberg and Richter [2] with formula as:

$$\log E = 11.8 + 1.5 M_s \qquad (1)$$

Where E is energy with unit ergs, and M_s is the shear-wave magnitude.

2.3.1 Maximum magnitude of total earthquakes in each city and county

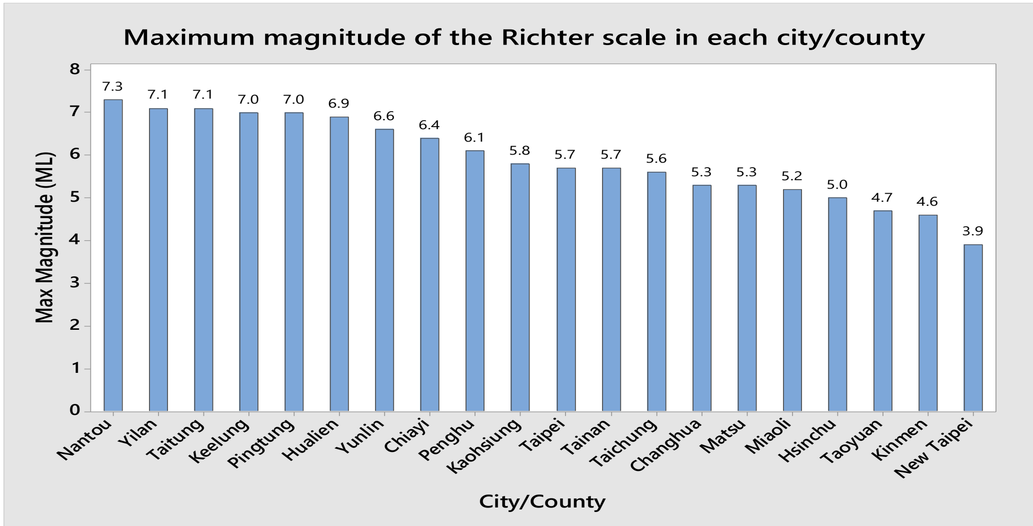

Figure 10: Maximum magnitude of total earthquakes in each city and county

The maximum magnitude earthquake in the past 24.25 years was 7.3, which occurred in Nantou on September 21, 1999. Totally 2,415 people died and 11,305 were injured in that earthquake [4]. Although the maximum magnitude of Yilan, Taitung, Keelung, and Pingtung were 7.0 or above, the epicenters of them were off Taiwan, hence much less damage was observed.

2.3.2 Mean magnitude of total earthquakes in each city and county

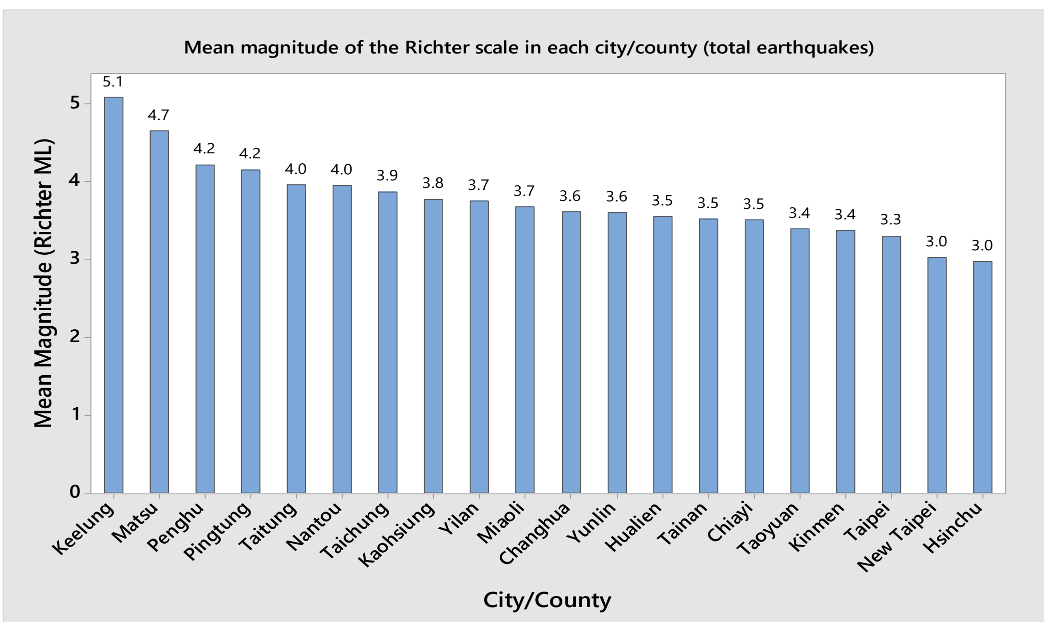

Figure 11: The mean magnitude of total earthquakes in each city and county

The largest mean value of earthquakes in the past 24.25 years was 5.1 on Keelung. The serious damage of earthquakes was rarely observed in that area because the depth of hypocenters was deeper than any locality in Taiwan. The wave of earthquakes dissipated its energy when reaching the surface, so did its power of damage.

2.3.3 Mean magnitude of labeled earthquakes in each city and county

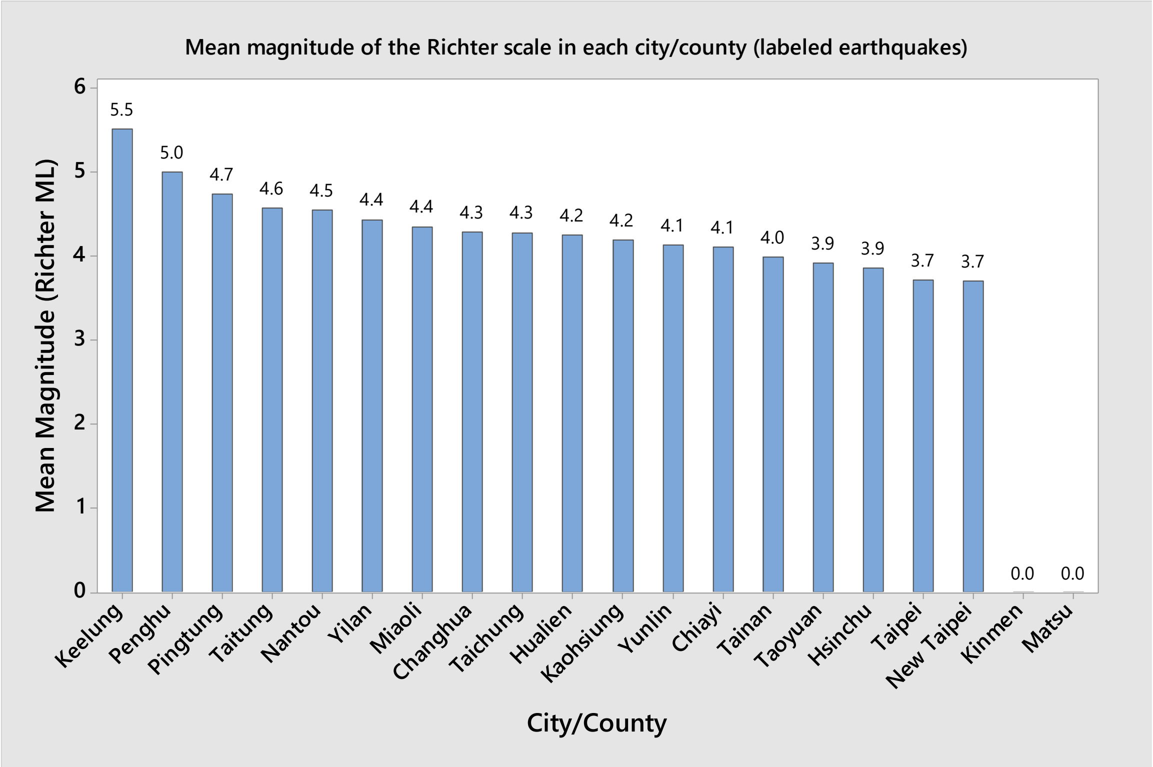

Figure 12: The mean magnitude of labeled earthquakes in each city and county

The largest mean value of labeled earthquakes in the past 24.25 years was 5.5 in Keelung. Two islets Kinmen and Matsu did not have any record of labeled data.

2.4 Energy distribution of earthquakes

The energy released by earthquakes is huge and difficult to manipulate with computer programs. In this study, the author "normalized" the energy accumulated in the past 24.25 years in each city and county by means of the energy generated by the atomic bomb detonated over Hiroshima, Japan. The energy produced by the atomic bomb with code-name Little Boy was 6.3E+20 ergs [5].

2.4.1 Energy distribution of total earthquakes in each city and county

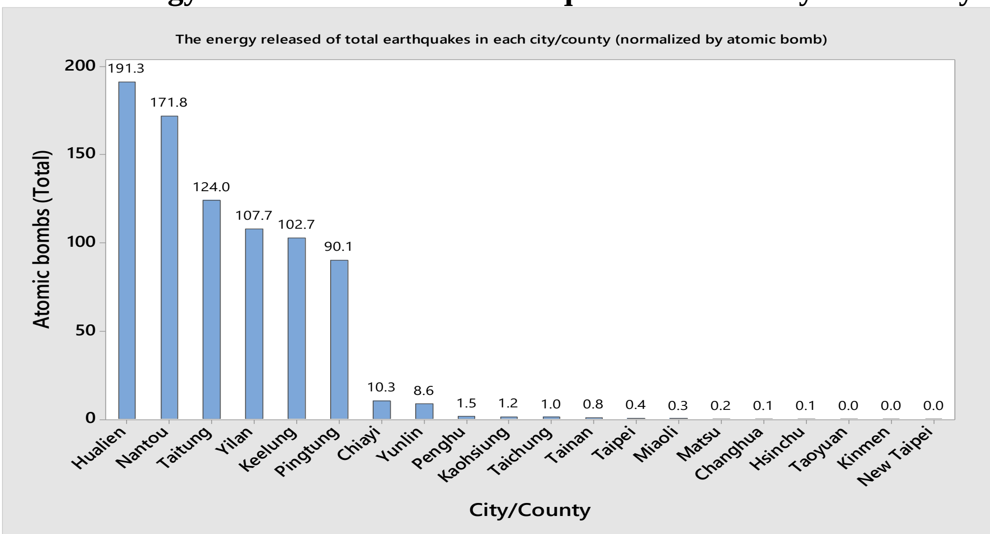

Figure 13: Energy released by earthquakes and expressed by the equivalent atomic bomb numbers from January 1995 to March 2019

In the past 24.25 years, the earthquakes in Hualien generated energy equivalent to 191.3 atomic bombs. Nantou was the second highest, with the number of 171.8 bombs, and the third was Taitung, with 124.0 atomic bombs.

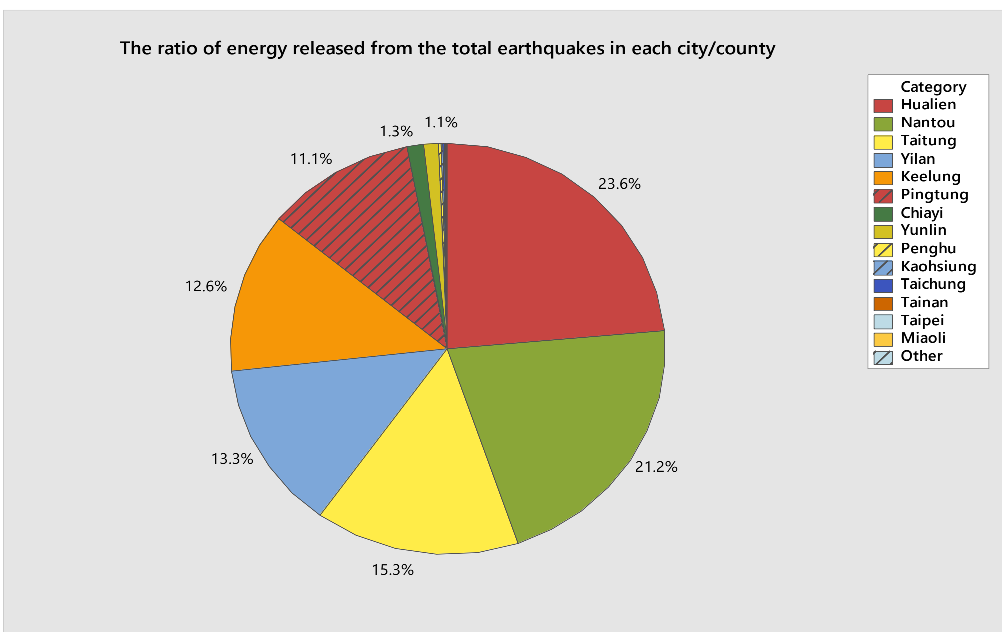

Figure 14: The percentage (%) distribution of energy issued by total earthquakes

In the past 291 months, Hualien accounted for up to 23.6% of the total energy generated by all the earthquakes occurring in Taiwan. Nantou and Taitung shared 21.2% and 15.3% respectively.

2.4.2 Energy distribution of labeled earthquakes in each city and county

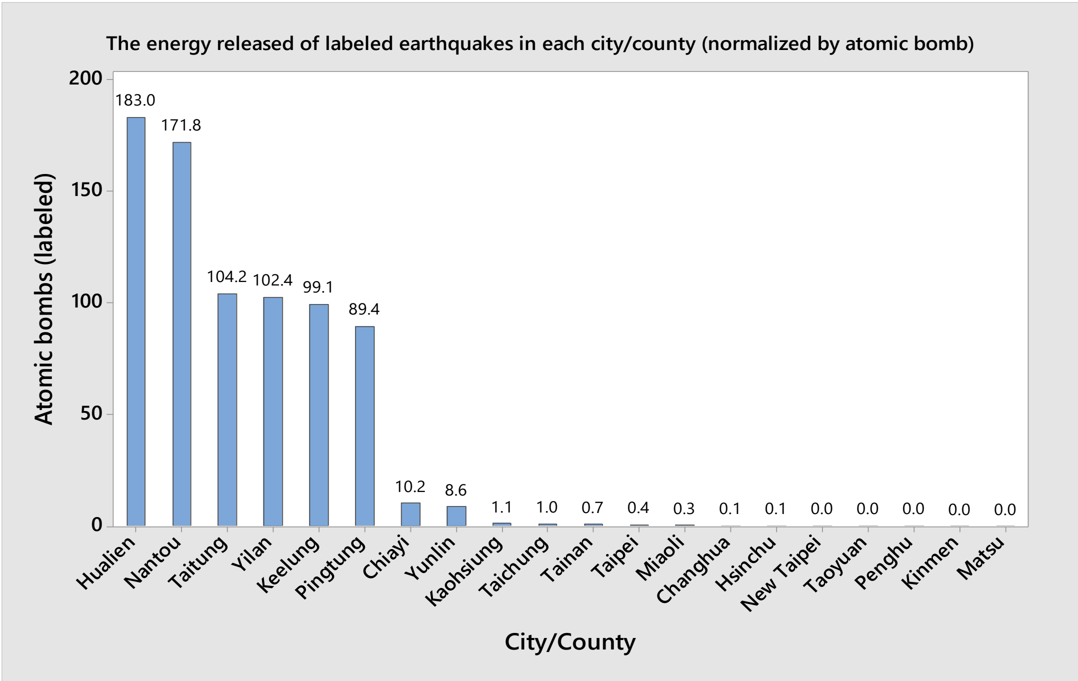

Figure 15: Energy released by labeled earthquakes and expressed by the equivalent number of atomic bombs from January 1995 to March 2019

In the past 24.25 years, the labeled earthquakes in Hualien generated energy equivalent to 183.0 atomic bombs. Nantou was the second highest, with the number of 171.8 bombs, and the third was Taitung, with 104.2 atomic bombs.

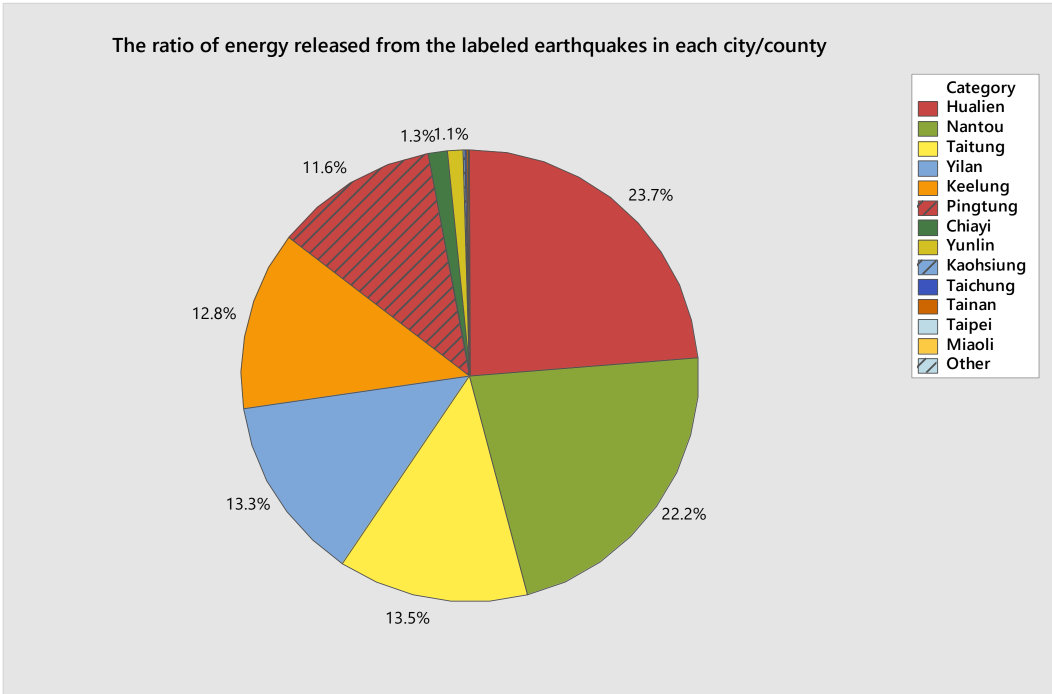

Figure 16: The percentage (%) distribution of energy issued by labeled earthquakes

In the past 291 months, Hualien accounted for up to 23.7 % of the energy generated by the labeled earthquakes occurring in Taiwan. Nantou and Taitung shared 22.2% and 13.5% respectively.

2.5 Average depth (km) of hypocenters of earthquakes

The average depth of earthquakes in each locality was checked in this subsection. At the same Richter magnitude of an earthquake, the shallower one has stronger intensity on the ground surface.

2.5.1 Average depth (km) of hypocenters of total earthquakes in each city and county

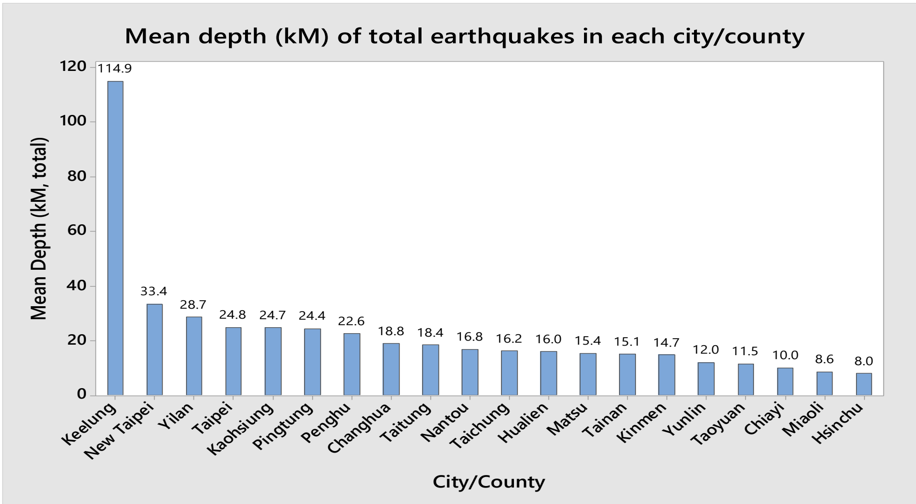

Figure 17: The average depth (km) of total earthquakes in each city and county

The average depth of earthquakes in Keelung was 114.9 km (intermediate-depth), which was the deepest for all areas in Taiwan. The depths of earthquakes in other places were below 70km and were categorized as “shallow” [1]. The average depth of earthquakes in Hsinchu was 8.0 km, and it was the shallowest in Taiwan.

2.5.2 Average depth (km) of hypocenters of labeled earthquakes in each city and county

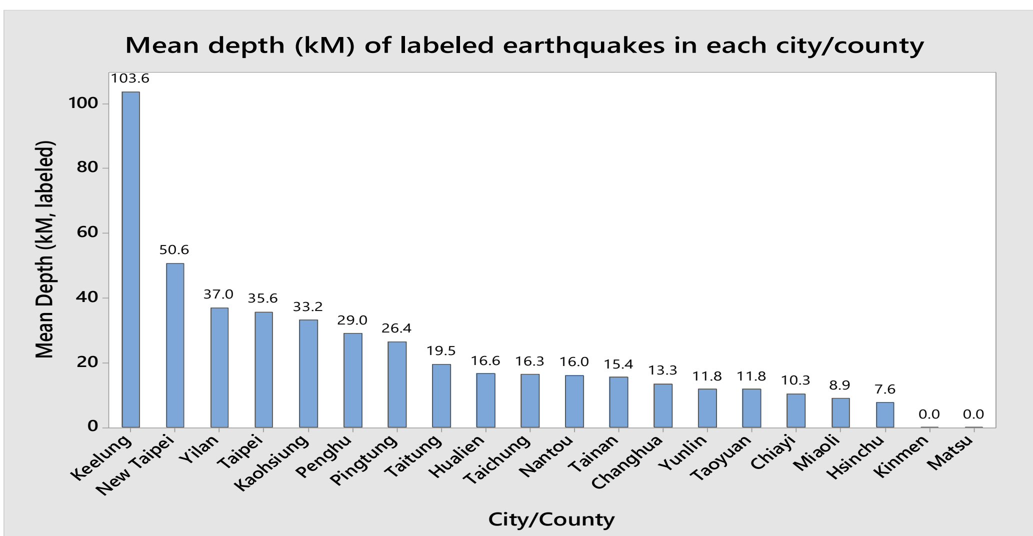

Figure 18: The average depth (km) of labeled earthquakes in each city and county

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The average depth of labeled earthquakes in Keelung was 103.6 km (intermediate-depth), which was the deepest for all areas in Taiwan. Hsinchu had the shallowest average depth of hypocenters, 7.6 km. Kinmen and Matsu had no labeled earthquakes ever recorded.

2.6 Average days between two earthquakes

The average days between two earthquakes were calculated in this subsection. The shorter the interval, the more the number of earthquakes will be observed.

2.6.1 Average days between two earthquakes in each city and county (total earthquakes)

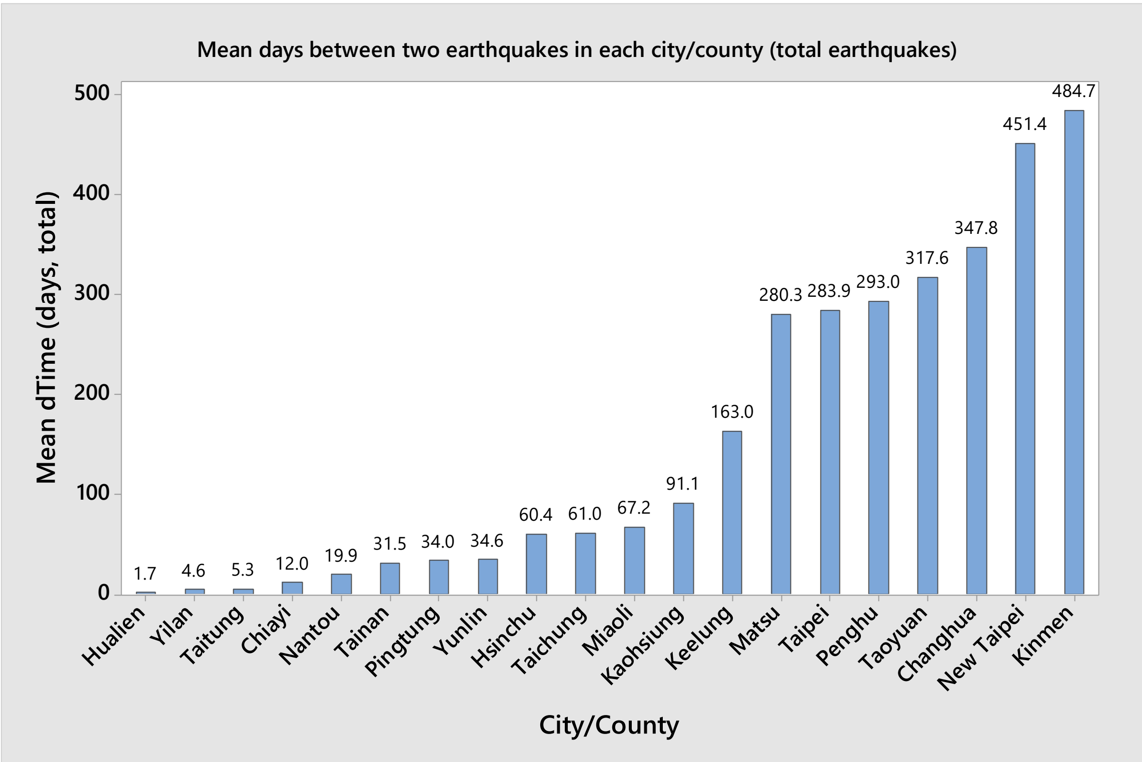

Figure 19: The average time (days) between two earthquakes (total earthquakes)

Hualien had the most frequent earthquakes and the shortest gap time (days) between two earthquakes. Averagely speaking, for every 1.7 days, Hualien will have an earthquake. Kinmen, on the extreme end, the gap between two earthquakes extend to 484.7 days.

2.6.2 Average days between two labeled earthquakes in each city and county

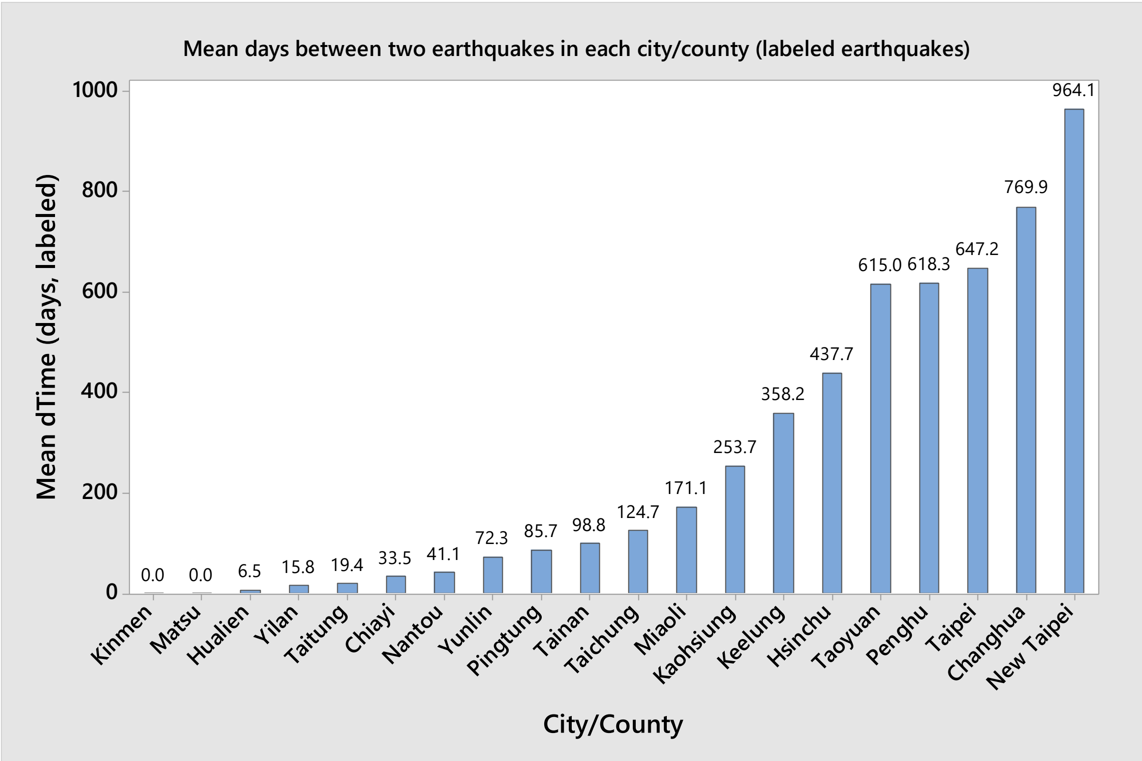

Figure 20: The average time (days) between two labeled earthquakes

Averagely speaking, for every 6.5 days, Hualien will have a labeled earthquake. New Taipei, on the extreme end, the gap between two labeled earthquakes extend to 964.1 days. Kinmen and Matsu had no labeled earthquake ever recorded.

3. Regression analysis and three-dimensional diagrams

The purpose of this section was to try to use an equation to represent the intensity on the surface of the ground and its relationship with longitude, latitude, magnitude, and hypotheses depth (km) of earthquakes. Three-dimensional diagrams of longitude, latitude, and intensity, depth and magnitude are also plotted to facilitate reading.

3.1 Regression between intensity, longitude, latitude, magnitude, and depth (km) of earthquakes

All the earthquakes from January 1995 to March 2019, totally 11,246 records were used in the regression analysis. As long as variables such as longitude, latitude, magnitude, and depth of an earthquake were observed, and substituted into the regression equation, the intensity on the surface of the ground can be obtained. The regression equation of the relationship between intensity and the four aforementioned variables was:

$$Intensity = -0.03696\ Longitude + 0.2065\ Latitude + 0.7118\ M_L - 0.019466\ Depth \quad (2)$$

(t-value) (-14.07) (15.96) (62.90) (-44.89)

And $R^2_{(adj)} = 91.85\%$

The interesting observation of the above equation was that the intensity of an earthquake decreases with the increasing longitude, increases with the increasing latitude increases with the increasing magnitude, and decreases with the increasing depth of hypocenter. The *t-value* of each parameter was big, which means the corresponding *p-value* is smaller than the 5% level of significance. In other words, the hypothesis H_0*: parameter =0* was rejected, and each parameter in the above equation was not zero. The adjusted coefficient of determination $R^2_{(adj)}$ was as high as 91.85%, which means that the dependent variable (intensity) can be highly explained by the independent variables on the right-hand side of the regression equation [6, 7].

3.2 Regression between intensity, magnitude, and depth of earthquakes

If the longitude and latitude are not considered in the regression, then the following equation can be obtained:

$$Intensity = 0.8259\ M_L - 0.01995\ Depth \quad (3)$$

(t-value) (267.85) (-46.32)

$R^2_{(adj)} = 91.52\%$

The *t-value* of the regression equation is big, and its *p-value* is smaller than the 5% level of significance. The high coefficient of determination $R^2_{(adj)} = 91.52\%$, which means that the dependent variable (intensity) can be highly explained by the independent variables on the right-hand side of the regression equation [6, 7].

Table 1: The intensity regression equation of earthquakes in Taiwan

Regression equation	Coefficient of determination $R^2_{(adj)}$
Intensity = -0.03852 Longitude + 0.2143 Latitude + 0.7125 M_L *- 0.019580 Depth*	*91.85%*
Intensity = 0.8259 ML - 0.01995 Depth	*91.52%*

3.3 Three-dimensional diagrams

3.3.1 Longitude, latitude, and depth (km)

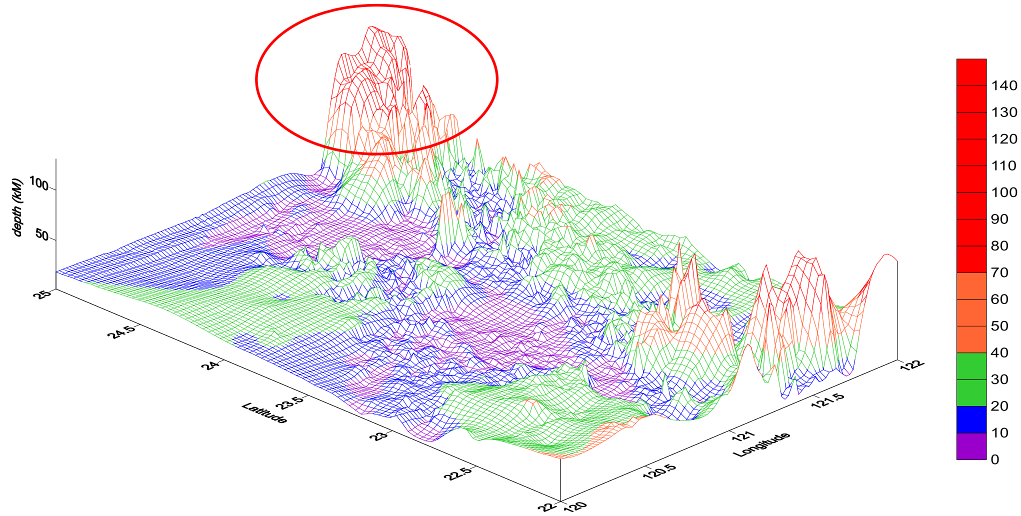

Figure 21: Depths (km) of hypocenters of earthquakes from January 1995 to March 2019 in Taiwan

From the above figure, one observed that most of the depths of hypocenters of earthquakes in Keelung were deeper than 70 km. The distinctive zone, which was on the northern tip of Taiwan, was the location of Keelung.

3.3.2 Longitude, latitude, and intensity

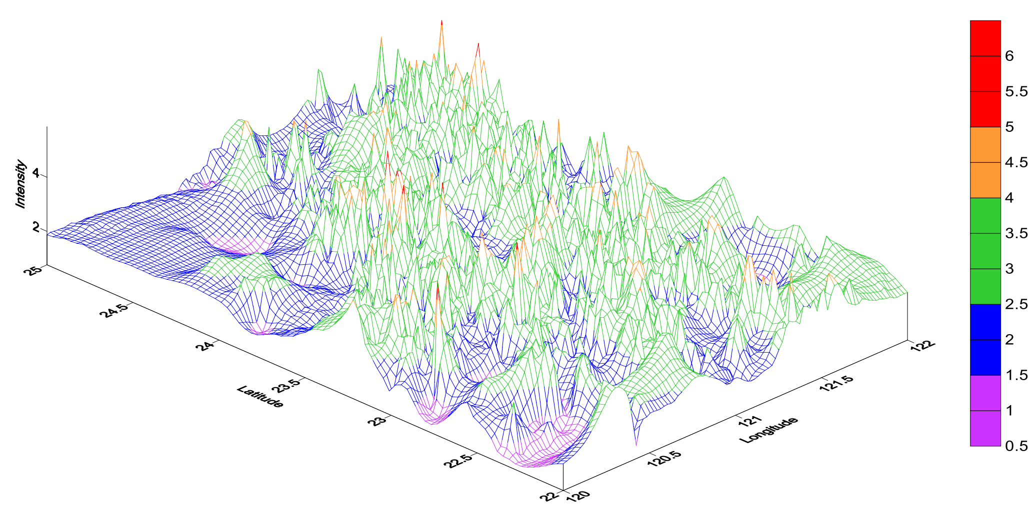

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Figure 22: Intensity of earthquakes from January 1995 to March 2019 in Taiwan

From the above figure, one found the intensities of most earthquakes were smaller than 5.0. And if the intensity was higher than that value, serious damage may occur.

3.3.3 Longitude, latitude and magnitude (M_L)

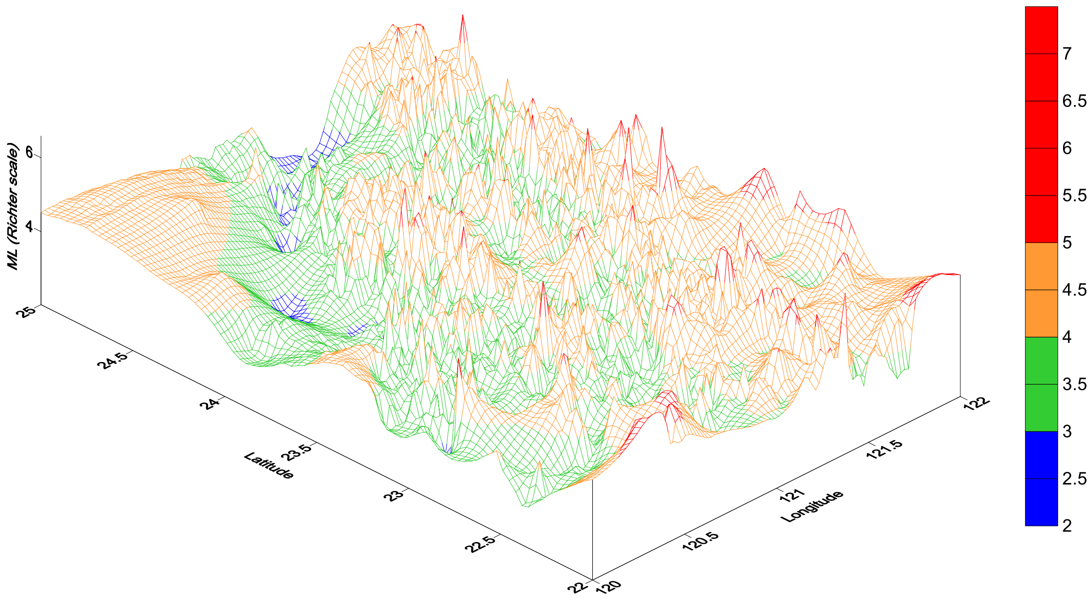

Figure 23: Magnitude (M_L) of earthquakes from January 1995 to March 2019 in Taiwan

From the above figure, one found that the magnitude of most of the earthquakes in Taiwan was between 3 to 5 on the Richter scale.

4. Conclusions

After analyzing seismic data in Taiwan from January 1995 to March 2019 and scrutinizing the major characters of earthquakes in all twenty municipal areas in Taiwan, the following statistical conclusions can be summarized concisely as follows:

4.1 For Total (both labeled and unlabeled) Earthquakes

(1) Hualien was the most active place for earthquakes in Taiwan. There were 5,153 earthquakes in Hualien out of totally 11,246 earthquakes in Taiwan, and the frequency ratio was 45.8%. Yilan took the second place, occurring 1,923 times with the ratio of 17.1%. Taitung with 1,643 times in the third, with the ratio of 14.6%.

(2) In each year, averagely, there were 464 earthquakes occurring in Taiwan.

(3) Almost all the mean depths of hypocenters of earthquakes in Taiwan were shallow (<70 km), except Keelung (114.9 km), which was classified as intermediate-depth. Maybe it is because earthquakes in Keelung were in the submerged tectonic plate. The shallowest depth of earthquakes was in Hsinchu, 8.0 km.

(4) The maximum magnitude of earthquakes in Taiwan for the past 24.25 years was 7.3 (Richter magnitude scale, ML) in Nantou on September 21, 1999.

(5) In Hualien, the average interval of the two earthquakes was 1.7 days. In Kinmen, the interval between the two earthquakes takes 484.7 days, which was the longest in Taiwan.

(6) The total energy released from all earthquakes in the past 24.25 years was 5.1E+23 ergs. Hualien was accounted for up to 23.6% of it and was the place where earthquakes released the most energy.

(7) From January 1995 to March 2019 there was energy equivalent to 812.1 atomic bombs generated in Taiwan. No doubt, Hualien was the most intense area with an equivalent of 191.3 bombs. Nantou (171.8 bombs) was the second, followed by Taitung (124.0 bombs).

(8) The regression equation between intensity, longitude, latitude, magnitude, and depth (km) has been obtained. The determination of coefficient $R^2_{(adj)}$ was 91.85%, which means that the dependent variable can be highly explained through the knowledge of variability in the independent variables.

4.2 For Labeled Earthquakes

(1) Hualien was the most active place for earthquakes in Taiwan. There were 1,358 earthquakes in Hualien out of totally 3,318 earthquakes in Taiwan, and the frequency ratio was 40.9%. Yilan took the second place, occurring 555 times with the ratio of 16.7%. Taitung with 452 times in the third, with the ratio of 13.6%.

(2) In each year, averagely, there were 137.4 labeled earthquakes occurring in Taiwan.

(3) Almost all the mean depth of hypocenters of earthquakes in Taiwan was shallow (<70 km), except Keelung (103.6 km), which was classified as intermediate-depth. The shallowest depth of labeled earthquakes was in Hsinchu, 7.6 km.

(4) In Hualien, the average period of two labeled earthquakes was 6.5 days, while in New Taipei, the interval between two labeled earthquakes took 964.1 days, which was the longest in Taiwan.

(5) The total energy released from labeled earthquakes in the past 24.25 years was 4.9E+23 ergs. Hualien was accounted for up to 23.7% and also was the place released most energy.

(6) From January 1995 to March 2019 the labeled earthquakes generated energy equivalent to 772.4 atomic bombs in Taiwan. No doubt, Hualien was the most intense area, 183.0 bombs. Nantou 171.8 was the second, followed by Taitung, 104.2 bombs. There is 39.7 bombs difference between the atomic bomb numbers of total earthquakes (812.1 bombs) and labeled ones (772.4 bombs). Hence, the negligence of those unlabeled earthquakes will deviate the accuracy of statistical results.

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6 Appendices:

There are four appendices with data of total (labeled plus unlabeled) earthquakes (Appendix A), labeled earthquakes (Appendix B), the energy released from earthquakes (Appendix C), and location and intensity of each earthquake (Appendix D). These four tables provide the backbone for this paper.

6.1 Appendix A:

Table A1: The total earthquake data for each city and county in Taiwan (From January 1995 to March 2019)

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)		Total Energy Released (ergs)	Mean dTime (days)
						Mean	Max		
Yilan	1923	4.9	79.3	17.1	28.7	3.7	7.1	6.8E+22	4.6

Hualien	5153	13.2	212.5	45.8	16.0	3.5	6.9	1.2E+23	1.7
Taitung	1643	4.2	67.8	14.6	18.4	4.0	7.1	7.8E+22	5.3
Nantou	435	1.1	17.9	3.9	16.8	4.0	7.3	1.1E+23	19.9
Keelung	44	0.1	1.8	0.4	114.9	5.1	7	6.5E+22	163.0
Taipei	31	0.1	1.3	0.3	24.8	3.3	5.7	2.6E+20	283.9
New Taipei	7	0.0	0.3	0.1	33.4	3.0	3.9	5.1E+17	451.4
Taoyuan	21	0.1	0.9	0.2	11.5	3.4	4.7	1.6E+19	317.6
Hsinchu	116	0.3	4.8	1.0	8.0	3.0	5	4.2E+19	60.4
Miaoli	105	0.3	4.3	0.9	8.6	3.7	5.2	2.1E+20	67.2
Taichung	128	0.3	5.3	1.1	16.2	3.9	5.6	6.4E+20	61.0
Changhua	23	0.1	0.9	0.2	18.8	3.6	5.3	7.8E+19	347.8
Yunlin	228	0.6	9.4	2.0	12.0	3.6	6.6	5.4E+21	34.6
Chiayi	736	1.9	30.4	6.5	10.0	3.5	6.4	6.5E+21	12.0
Tainan	279	0.7	11.5	2.5	15.1	3.5	5.7	5.2E+20	31.5
Kaohsiung	92	0.2	3.8	0.8	24.7	3.8	5.8	7.4E+20	91.1
Pingtung	256	0.7	10.6	2.3	24.4	4.2	7	5.7E+22	34.0
Penghu	13	0.0	0.5	0.1	22.6	4.2	6.1	9.3E+20	293.0
Kinmen	7	0.0	0.3	0.1	14.7	3.4	4.6	6.5E+18	484.7
Matsu	6	0.0	0.2	0.1	15.4	4.7	5.3	1.0E+20	280.3
Total	11,246	1.4	23.2	100.0	22.8	3.7	7.3	5.1E+23	152.2
Energy (ergs)	$\log_{10}E=11.8+1.5M_S$								
Average dTime (days)	The average days between two earthquakes.								

6.2 Appendix B:

Table B1: The labeled earthquake data for each city and county in Taiwan (From January 1995 to March 2019)

City/County	Numbers of earthquakes	Mean times per	Mean times per year	Earthquake percentage (%)	Depth (km)	Magnitude (Richter M_L)	Total Energy Released (ergs)	Average dTime

		month				Mean	Max		(days)
Yilan	555	1.4	22.9	16.7	37.0	4.4	7.1	6.5E+22	15.8
Hualien	1358	3.5	56.0	40.9	16.6	4.2	6.9	1.2E+23	6.5
Taitung	452	1.2	18.6	13.6	19.5	4.6	7.1	6.6E+22	19.4
Nantou	206	0.5	8.5	6.2	16.0	4.5	7.3	1.1E+23	41.1
Keelung	19	0.0	0.8	0.6	103.6	5.5	7	6.2E+22	358.2
Taipei	13	0.0	0.5	0.4	35.6	3.7	5.7	2.6E+20	647.2
New Taipei	3	0.0	0.1	0.1	50.6	3.7	3.9	2.8E+19	964.1
Taoyuan	9	0.0	0.4	0.3	11.8	3.9	4.7	1.5E+19	615.0
Hsinchu	14	0.0	0.6	0.4	7.6	3.9	5	3.7E+19	437.7
Miaoli	35	0.1	1.4	1.1	8.9	4.4	5.2	2.0E+20	171.1
Taichung	61	0.2	2.5	1.8	16.3	4.3	5.6	6.2E+20	124.7
Changhua	8	0.0	0.3	0.2	13.3	4.3	5.3	7.4E+19	769.9
Yunlin	108	0.3	4.5	3.3	11.8	4.1	6.6	5.4E+21	72.3
Chiayi	262	0.7	10.8	7.9	10.3	4.1	6.4	6.4E+21	33.5
Tainan	89	0.2	3.7	2.7	15.4	4.0	5.7	4.1E+20	98.8
Kaohsiung	33	0.1	1.4	1.0	33.2	4.2	5.8	7.2E+20	253.7
Pingtung	90	0.2	3.7	2.7	26.4	4.7	7	5.6E+22	85.7
Penghu	3	0.0	0.1	0.1	29.0	5.0	6.1	8.3E+18	618.3
Kinmen	0	0.0	0.0	0.0	N.A.	N.A.	N.A.	0.0E+00	N.A.
Matsu	0	0.0	0.0	0.0	N.A.	N.A.	N.A.	0.0E+00	N.A.
Total	3,318	0.4	6.8	100.0	25.7	4.3	7.3	4.9E+23	296.3
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 [2]. 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 [3]. In this study, the author does not distinguish these two magnitudes. During the energy calculation, M_S was substituted by M_L.

6.3 Appendix C:

Table C1: Released energy of earthquakes from January 1995 to March 2019 in Taiwan

City/County	The energy released of labeled earthquakes and equivalent to atomic bomb numbers			The energy released of total earthquakes and equivalent to atomic bomb numbers		
	The energy released (ergs)	Energy ratio (%)	Equivalent atomic bomb numbers	The energy released (ergs)	Energy ratio (%)	Equivalent atomic bomb numbers
Yilan	6.5E+22	13.3	102.4	6.8E+22	13.3	107.7
Hualien	1.2E+23	23.7	183.0	1.2E+23	23.6	191.3
Taitung	6.6E+22	13.5	104.2	7.8E+22	15.3	124.0
Nantou	1.1E+23	22.2	171.8	1.1E+23	21.2	171.8
Keelung	6.2E+22	12.8	99.1	6.5E+22	12.6	102.7
Taipei	2.6E+20	0.1	0.4	2.6E+20	0.1	0.4
New Taipei	2.8E+19	0.0	0.0	5.1E+17	0.0	0.0
Taoyuan	1.5E+19	0.0	0.0	1.6E+19	0.0	0.0
Hsinchu	3.7E+19	0.0	0.1	4.2E+19	0.0	0.1
Miaoli	2.0E+20	0.0	0.3	2.1E+20	0.0	0.3
Taichung	6.2E+20	0.1	1.0	6.4E+20	0.1	1.0
Changhua	7.4E+19	0.0	0.1	7.8E+19	0.0	0.1
Yunlin	5.4E+21	1.1	8.6	5.4E+21	1.1	8.6
Chiayi	6.4E+21	1.3	10.2	6.5E+21	1.3	10.3
Tainan	4.1E+20	0.1	0.7	5.2E+20	0.1	0.8
Kaohsiung	7.2E+20	0.1	1.1	7.4E+20	0.1	1.2
Pingtung	5.6E+22	11.6	89.4	5.7E+22	11.1	90.1
Penghu	8.3E+18	0.0	0.0	9.3E+20	0.2	1.5
Kinmen	0.0E+00	0.0	0.0	6.5E+18	0.0	0.0

Matsu	0.0E+00	0.0	0.0	1.0E+20	0.0	0.2
Total	4.9E+23	100.0	772.4	5.1E+23	100.0	812.1

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 found that the negligence of unlabeled earthquakes may under-estimate the released energy up to 2.5E+22 ergs, or more graphically speaking, equivalent to 39.7 atomic bombs dropped in Hiroshima, Japan during WWII.

6.4 Appendix D:

Table D1: Location of hypocenters, magnitudes, and intensities from January 1995 to March 2019 (only shown partially)

Number	Longitude	Latitude	ML	Depth (kM)	Intensity
1	121.70	24.96	4.50	91.50	2.00
2	121.43	23.68	5.10	3.80	6.00
3	120.76	23.30	4.50	14.30	3.00
4	120.19	23.05	4.20	16.00	4.00
5	121.92	23.76	5.20	24.60	3.00
6	121.74	24.03	4.70	27.00	3.00
7	121.69	24.20	5.80	21.70	5.00
8	121.70	24.26	4.40	25.70	3.00
9	120.23	23.06	4.00	12.10	4.00
10	121.46	23.06	4.90	16.50	4.00
11	121.52	23.78	4.80	17.90	3.00
12	121.86	24.64	5.60	76.00	4.00
13	122.43	23.94	5.90	14.60	3.00
14	121.02	21.83	5.00	29.80	3.00
15	121.45	23.76	4.30	17.70	5.00
….	….	….	….	….	….
11238	121.94	24.75	4.7	83.1	3.00

11239	120.7	23.03	3.4	7.9	1.00
11240	122.41	24.48	4.7	88.9	2.00
11241	120.72	23.62	3.5	11.8	2.00
11242	122.44	24.7	4.6	106	2.00
11243	121.74	23.51	4.1	16.7	2.00
11244	121.53	24.04	3	19.1	3.00
11245	120.6	23.89	3.2	21.7	2.00
11246	121.59	24.54	3.8	64.6	1.00