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A STATISTICAL STUDY OF THE SEISMIC PROPERTIES IN TAIWAN

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Abstract

Through 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 June 2018, there were 3,257 labelled as well as 10,898 total (labelled 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.

Haulier, a county on the east coast of Taiwan, is the place that has the highest frequency of earthquakes, the shortest time interval between two earthquakes, and releases most energy. The energy released from total earthquakes in Haulier in the period of January 1995 to June 2018 is equivalent to 188.9 atomic bombs, which were dropped over Hiroshima, Japan. 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 114.9 km (intermediate-depth). Maybe it is because the hypocenters of Keelung are in the submerged tectonic plate. In the past 282 months (January 1995 to June 2018) the strongest magnitude (Richter magnitude scale, ML) was 7.3, which happened on September 21, 1999.

This study shows that if the unlabeled earthquakes (usually small in magnitude and impact locally) are neglected, the total energy will be uncounted up to 2.4E+22 ergs. Such an energy lost is equivalent to 37.72 atomic bombs. Therefore, to put all records in the CWB seismic archive in the analysis is strongly recommended to avoid obtaining inaccurate results.

The regression of intensity with independent variables, such as longitude, latitude, magnitude, and depth of hypocenters shows 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 is more than 91%, which shows the independent variable, intensity, is 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 are consistent with the statistical analyses.

Key Words: CWB Seismic Archive, Coefficient of Determination, Hypocenter

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 in this island because it is unavoidable to escape the influence from 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, labelled and unlabeled. The labelled ones have stronger impact on several areas of Taiwan, and unlabeled ones only have records but without numbers given, usually less severe than the labelled ones. Each year, the labelled earthquake always starts from number one. In the CWB archive, the author finds that not until May 2000 did the CWB begin to put unlabeled earthquakes into its record. These unlabeled earthquakes may amend the knowledge one lacks if many aftershocks of a strong earthquake are neglected.

The author is interested in how different the statistical properties of total and labelled earthquakes will be. From January 1995 to June 2018, there were 3,257 labelled and 10,898 total (labelled plus unlabeled) earthquakes occurring in 23.5 years (282 months). The total and labelled number of earthquakes differs more than three times. If their statistical properties were similar, then one can just pay attention to the labelled ones. Much time and cost will be saved. The difference in the number of labelled and total earthquakes will increase with the increase of time.

Number of earthquakes in Taiwan and their statistical properties

There were 10,898 earthquakes occurring from January 1995 to June 2018, but only 3,257 were labelled 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 labelled [1]. The earthquake records from January 1995 to June 2018 covering 282 months or 23.5 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 total earthquakes), Appendix B (for labelled 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.

Number of earthquakes per year in Taiwan

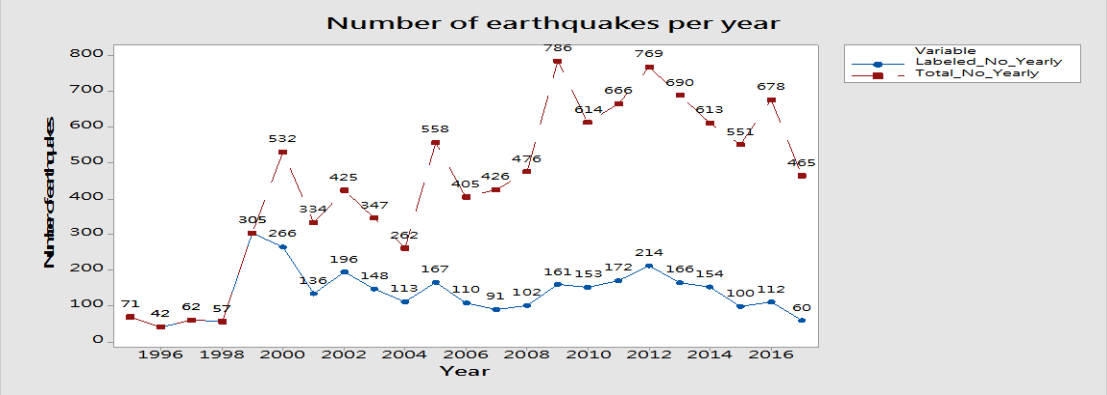

Figure 1: Number of total (labelled and unlabeled) and labelled earthquakes from 1995 to 2017

From the above figure, one finds the total earthquakes (10,898) are about 3.15 times more than the labelled (3,257) 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.

Number of total earthquakes per year in Taiwan

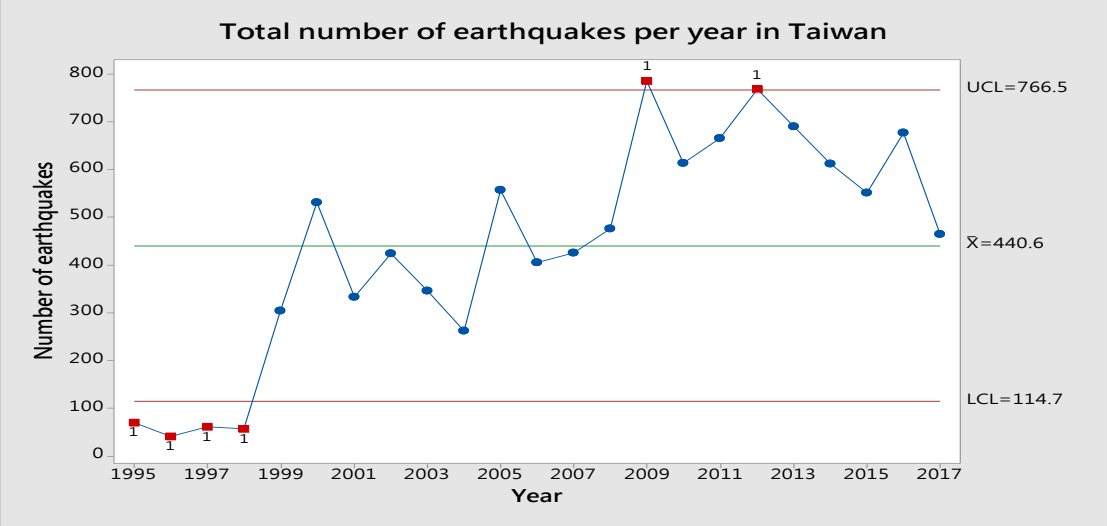

Figure 2: Number of total earthquakes per year from 1995 to 2017 in Taiwan

From the above figure, one finds the average number of total earthquakes per year is 440.6. Year 2009 has 786 records of earthquakes, which is three standard errors above the mean. But from 1995 to 1998, the records are extremely low, the accumulation of energy may contribute tremendously to the 921 earthquake, which is 7.3 magnitude by the Richter scale. From the above figure, one also notice the total number of earthquakes may have an increasing trend.

Number of labelled earthquakes per year in Taiwan

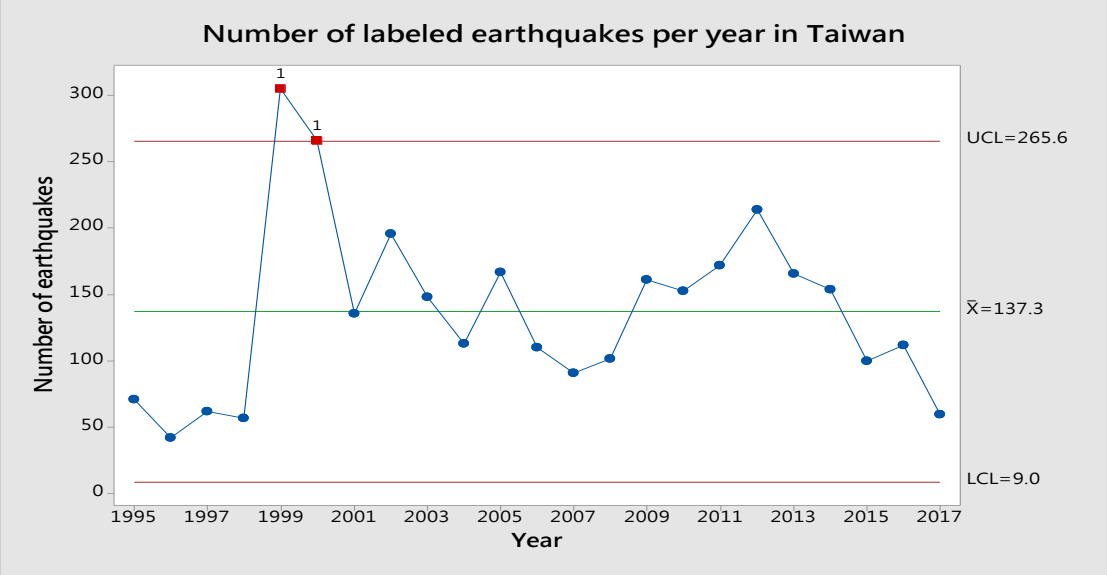

Figure 3: Number of labelled earthquakes per year from 1995 to 2017 in Taiwan

From the above figure, one finds the average number of earthquakes per year is 137.3 times. Year 1999 has extraordinary high number of records due to the horrible 921 earthquake, which registered with a magnitude of 7.3 on the Richter scale. The 921 Manitou 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 is two standard errors below the mean. The energy accumulated during these (and previous) periods seemed to be finally released in year 1999.

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

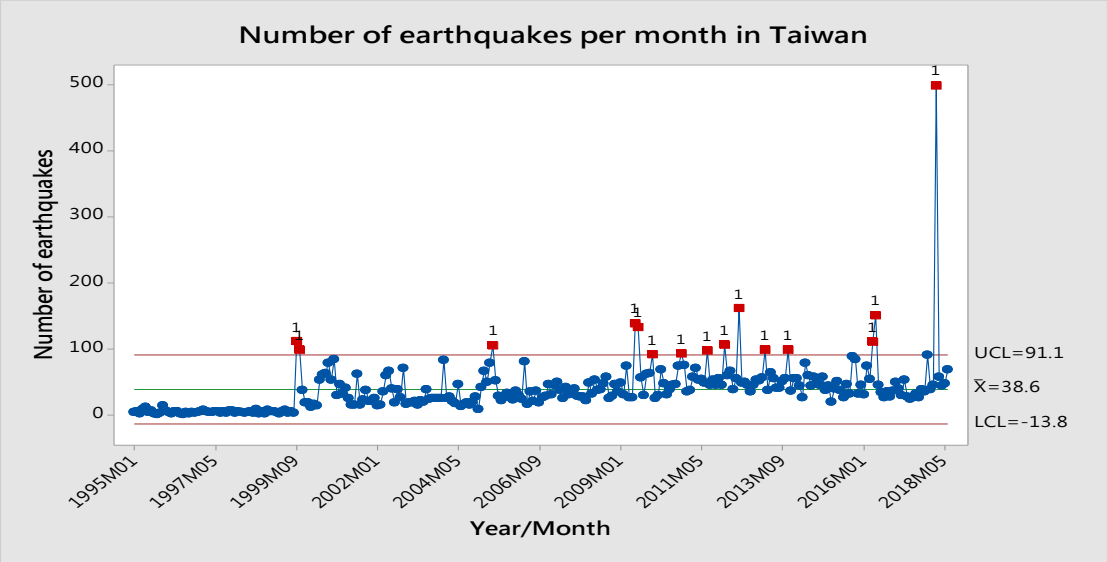

Figure 4: Number of earthquakes per month from January 1995 to June 2018 in Taiwan

The average number of earthquakes occurring in Taiwan from January 1995 to June 2018 is 38.6 times per month. There are fifteen months with numbers above three standard errors of the mean. One extraordinary large point is in February 2018, there were five hundreds of earthquakes recorded in that month.

Number of labelled earthquakes per month in Taiwan

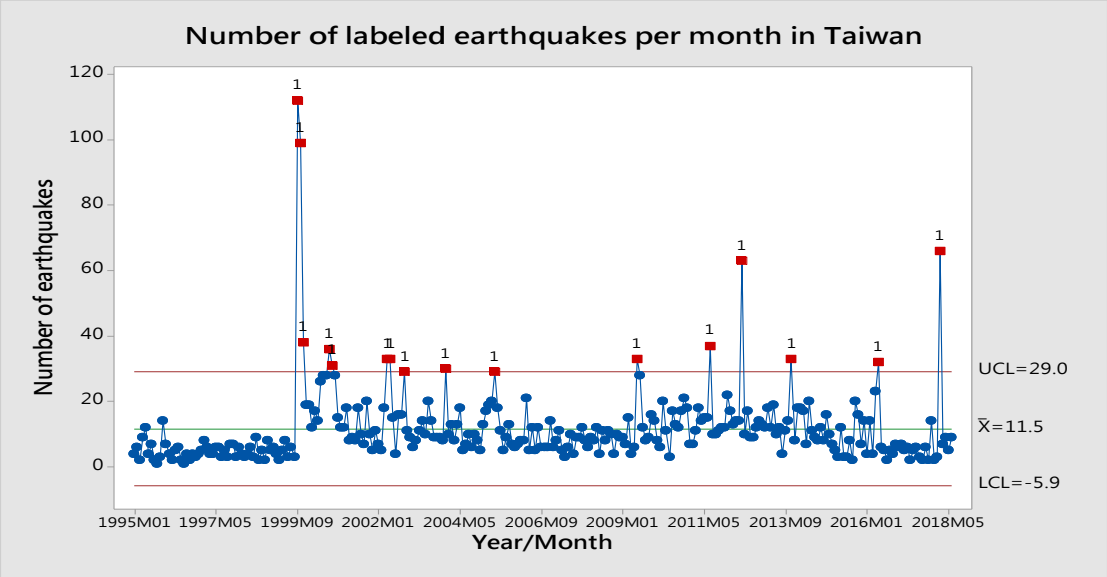

Figure 5: Number of labelled earthquakes per month from January 1995 to June 2018 in Taiwan

The mean value of labelled earthquakes for January 1995 to June 2018 is 11.5 times per month. There are sixteen months with numbers above three standard errors of the mean.

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 23.5 years (282 months) from January 1995 to June 2018. Both bar and pie charts are used to identify number and percentage (%) of earthquakes in each locality.

Number of total earthquakes in each city and county

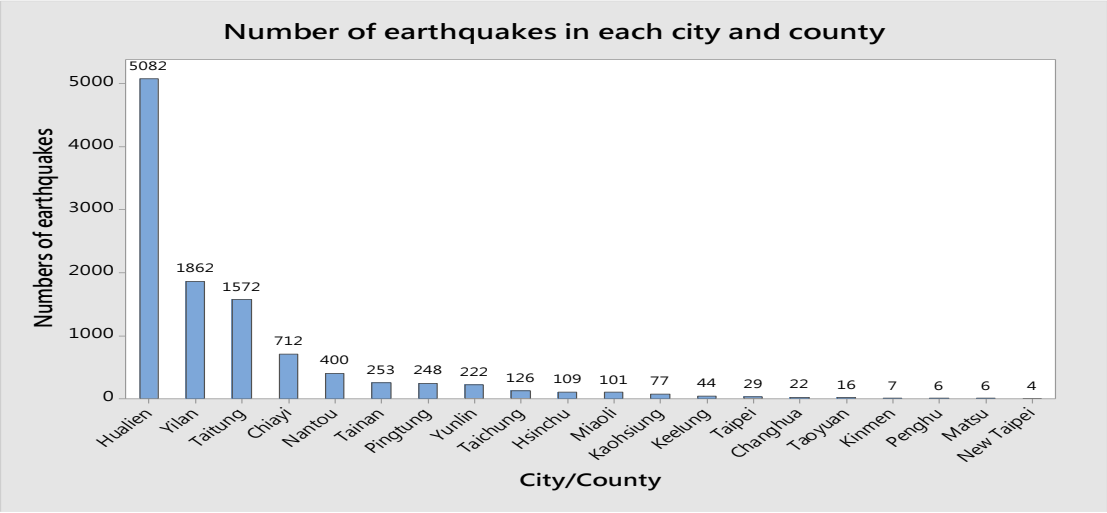

Figure 6: Number of earthquakes in each city and county from January 1995 to June 2018 from the above figure, one finds Haulier is the county with the highest earthquake occurring frequency. There are 5,082 earthquakes in the past 282 months. Milan and Tantung have the second and third highest frequency with numbers of 1,862 and 1,572 respectively.

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.

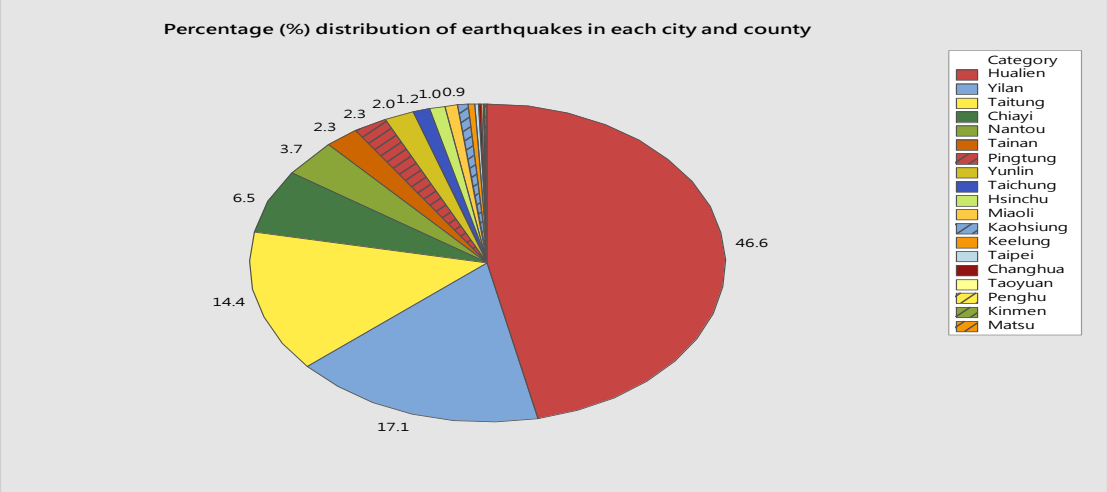

Figure 7: Percentage (%) distribution of earthquakes in each city and county

From the above pie chart, there are 46.6% of earthquakes occurring in Haulier, 17.1% in Milan, and 14.4% in Tantung.

Number of labelled earthquakes in each city and county

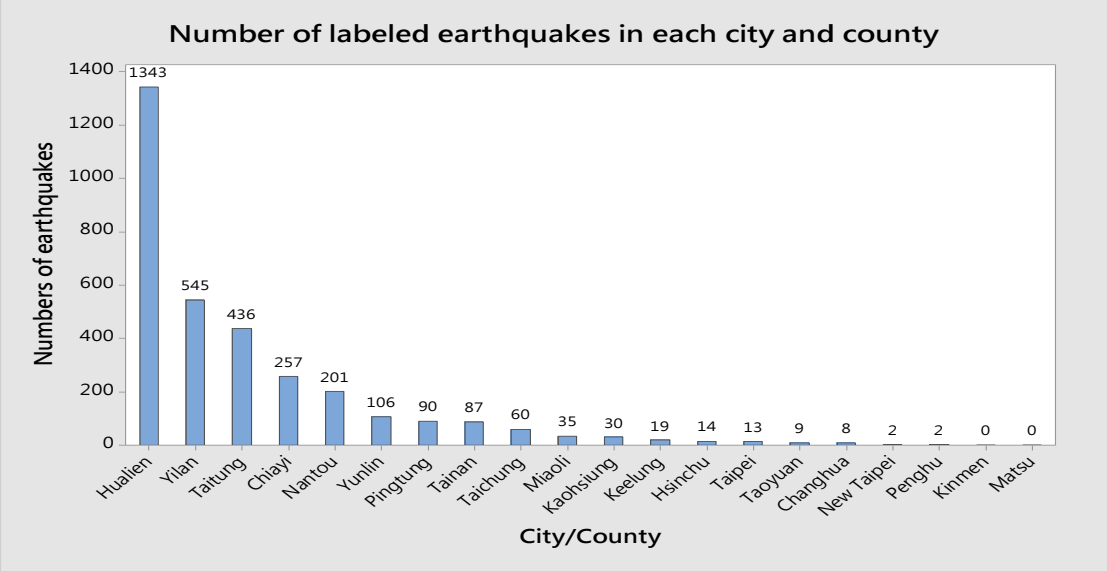

Figure 8: Number of labelled earthquakes in each city and county from January 1995 to June 2018

From the above figure, on finds there are 1,343 labelled earthquakes occurring in Haulier in the past 282 months. Milan and Tantung have the second and third highest frequency with numbers 545 and 436 respectively. Comparing figures 6 and 8, the total earthquakes are more than three times than the labelled ones.

Ratio of labelled earthquakes distribution in each city and county

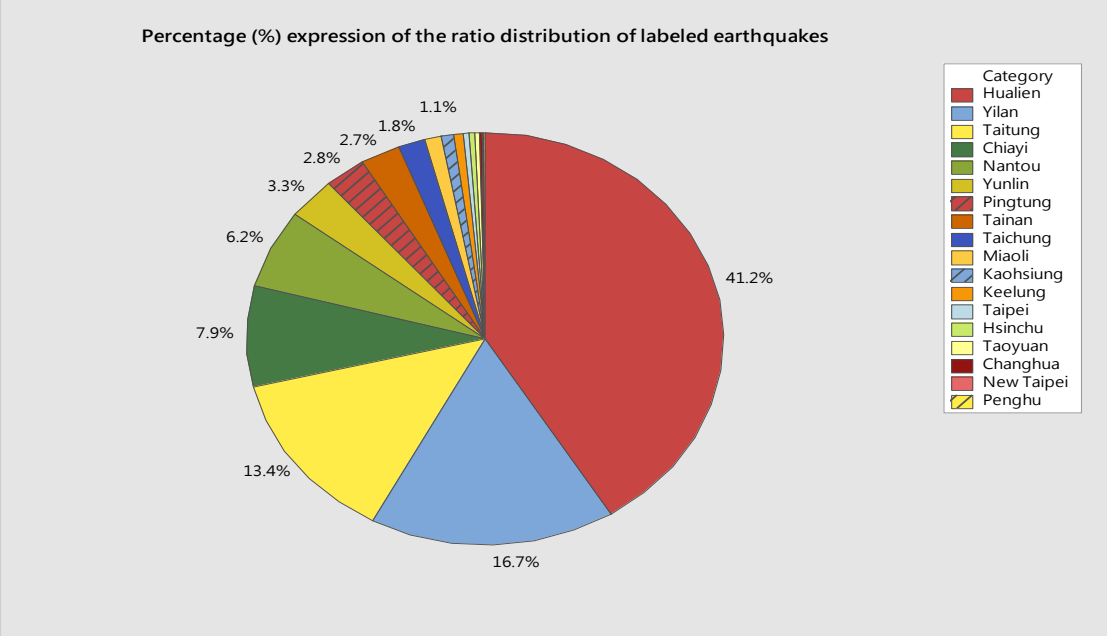

Figure 9: Percentage (%) distribution of labelled earthquakes in each city and county

From the above pie chart, there are 41.2% of labelled earthquakes occurring in Haulier, 16.7% in Milan, and 13.4% in Tantung.

Maximum magnitude in each city and county

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

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

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

Maximum magnitude of total earthquakes in each city and county

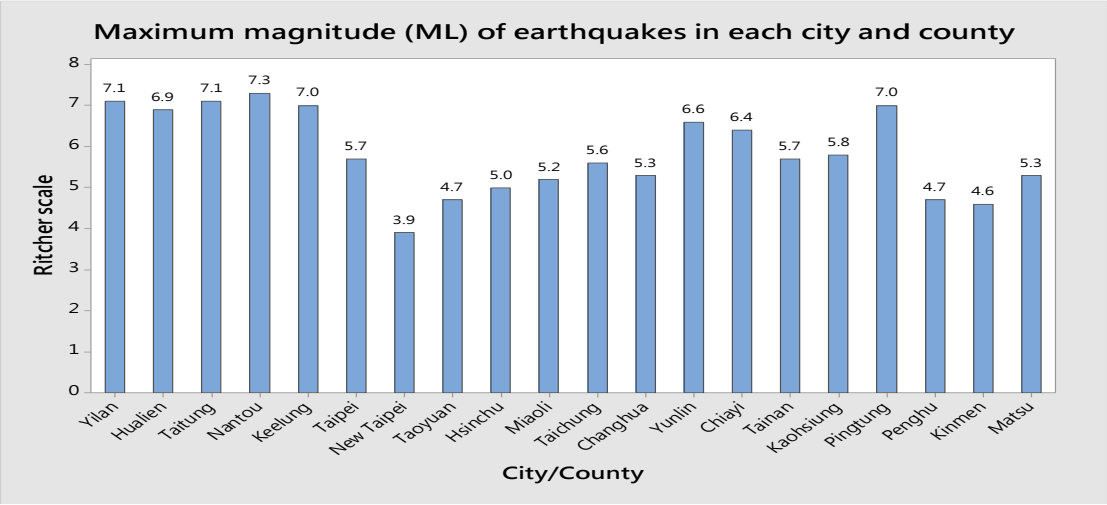

Figure 10: Maximum magnitude of earthquakes in each city and county

The maximum magnitude earthquake in the past 23.5 years is 7.3, which occurred in Manitou on September 21, 1999. Totally 2,415 people died and 11,305 were injured in that earthquake [4]. Although the maximum magnitude of Milan, Tantung, Keelung and Panting is 7.0 or above, the epicentres of them are off Taiwan, hence much less damage was observed.

Mean magnitude of total earthquakes in each city and county

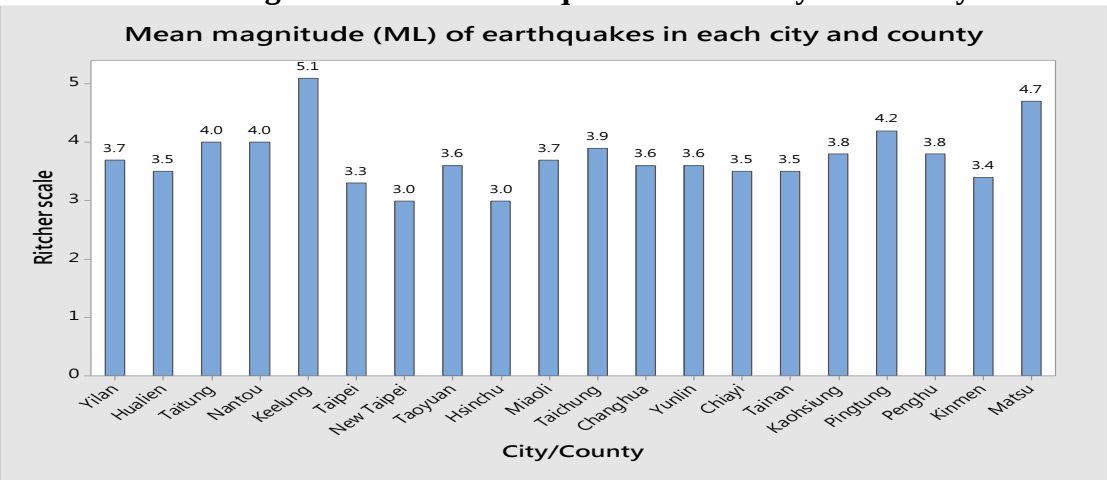

Figure 11: The mean magnitude of earthquakes in each city and county

The largest mean value of earthquakes in the past 23.5 year is 5.1 on Keelung. The serious damage of earthquakes was rarely observed in that area because the depth of hypocenters is deeper than any locality in Taiwan. The wave of earthquakes dissipates its energy when reaching surface, so does its power of damage.

Mean magnitude of labelled earthquakes in each city and county

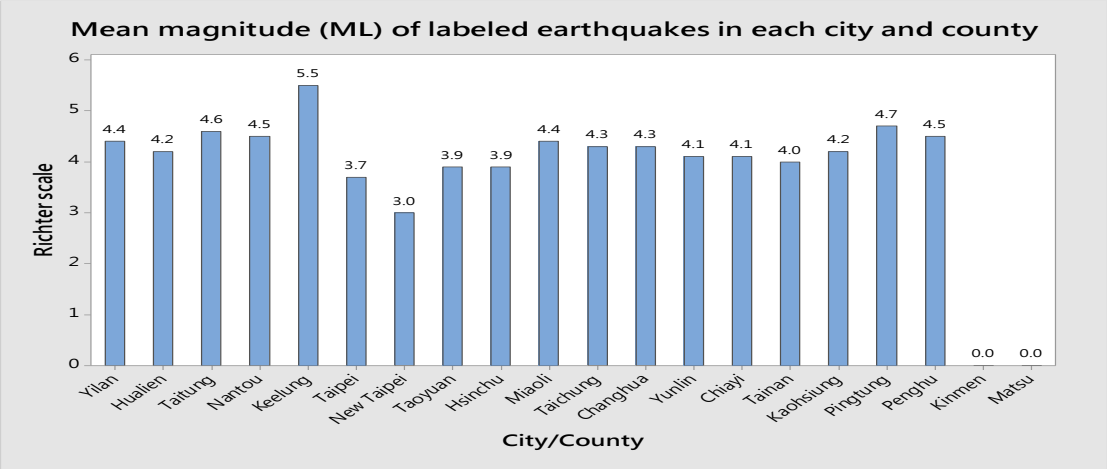

Figure 12: The mean magnitude of labelled earthquakes in each city and county

The largest mean value of labelled earthquakes in the past 23.5 year is 5.5 on Keelung. Two islets Kinsmen and Matsu do not have any record of labelled data.

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 23.5 years energy 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].

Energy distribution of total earthquakes in each city and county

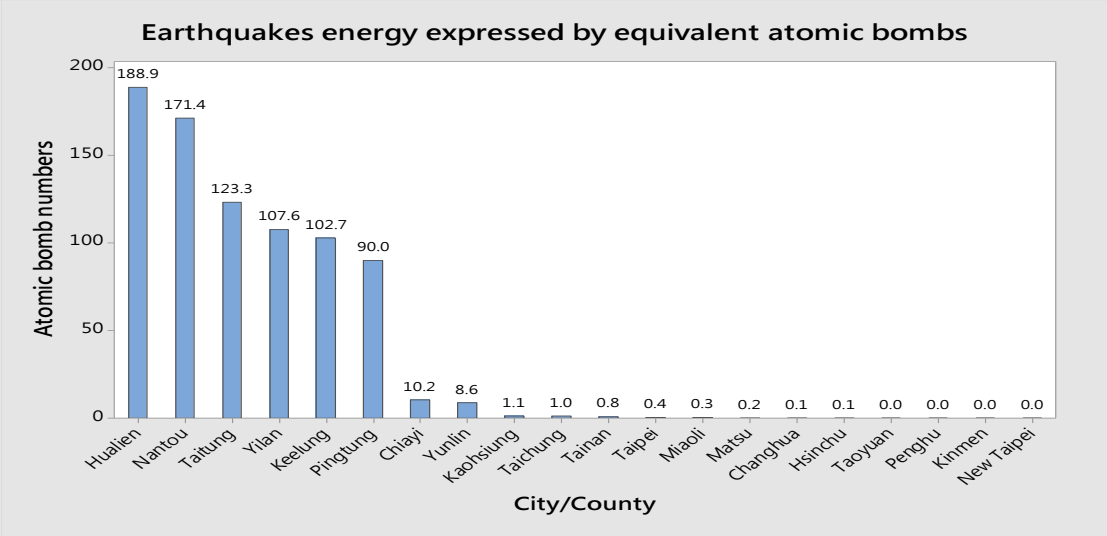

Figure 13: Energy released by earthquakes and expressed by the equivalent atomic bomb numbers from January 1995 to June 2018

In the past 23.5 years, the earthquakes in Haulier generated energy equivalent to 188.9 atomic bombs. Manitou is the second highest, with the number of 171.4 bombs, and the third is Tantung, with 123.3 atomic bombs.

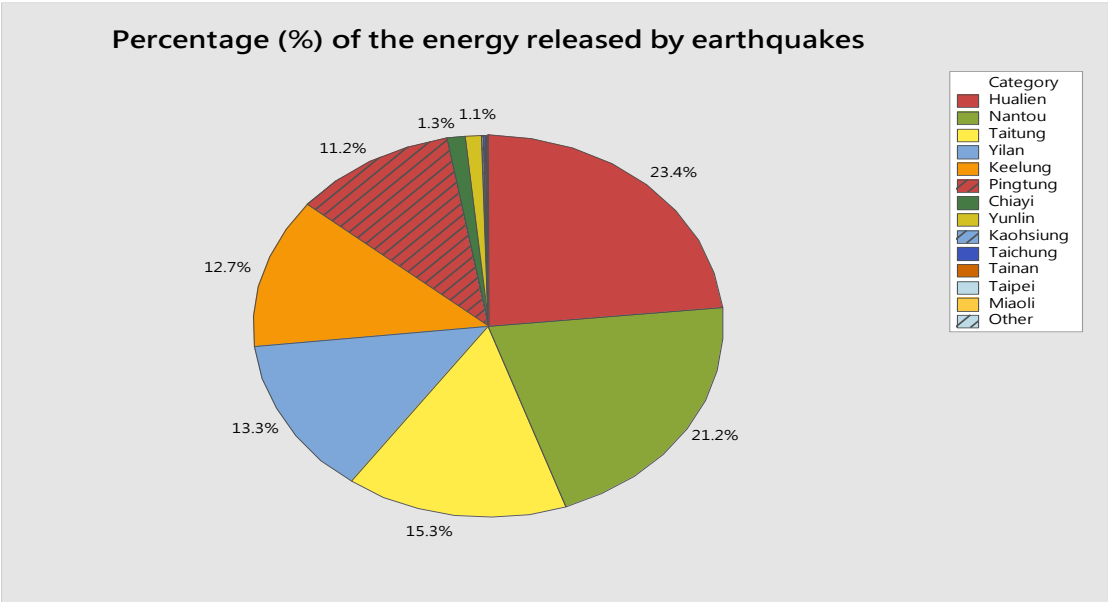

Figure 14: The percentage (%) distribution of energy issued by earthquakes

In the past 282 months, Haulier accounts for up to 23.4% of total energy generated by all the earthquakes occurring in Taiwan. Manitou and Tantung share 21.2% and 15.3% respectively.

Energy distribution of labelled earthquakes in each city and county

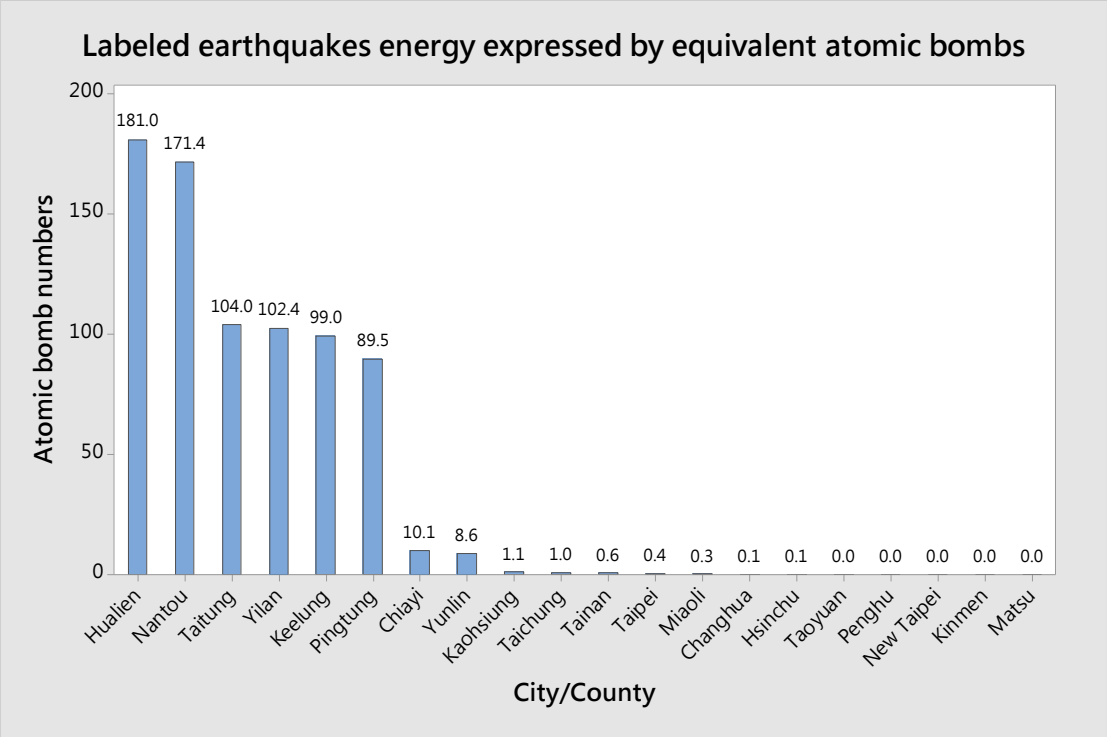

Figure 15: Energy released by labelled earthquakes and expressed by the equivalent number of atomic bombs from January 1995 to June 2018

In the past 23.5 years, the labelled earthquakes in Haulier generated energy equivalent to 181.0 atomic bombs. Manitou is the second highest, with the number of 171.4 bombs 171.4, and the third is Tantung, with 104.0 atomic bombs.

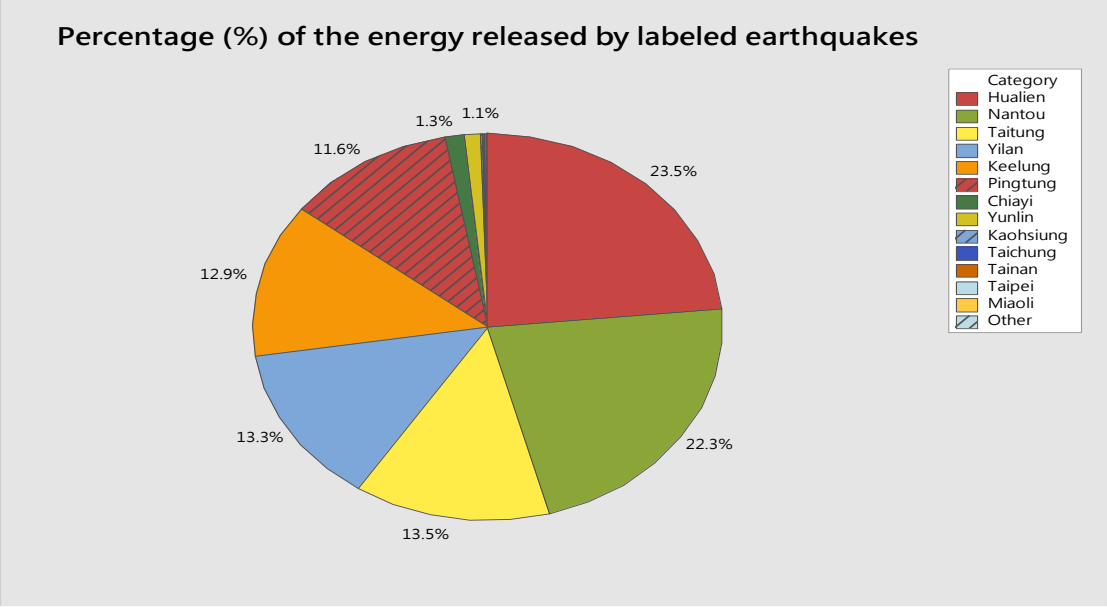

Figure 16: The percentage (%) distribution of energy issued by labelled earthquakes

In the past 282 months, Haulier account for up to 23.5% of total energy generated by the labelled earthquakes occurring in Taiwan. Manitou and Tantung share 22.3% and 13.5% respectively.

Average depth (km) of hypocenters of earthquakes

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

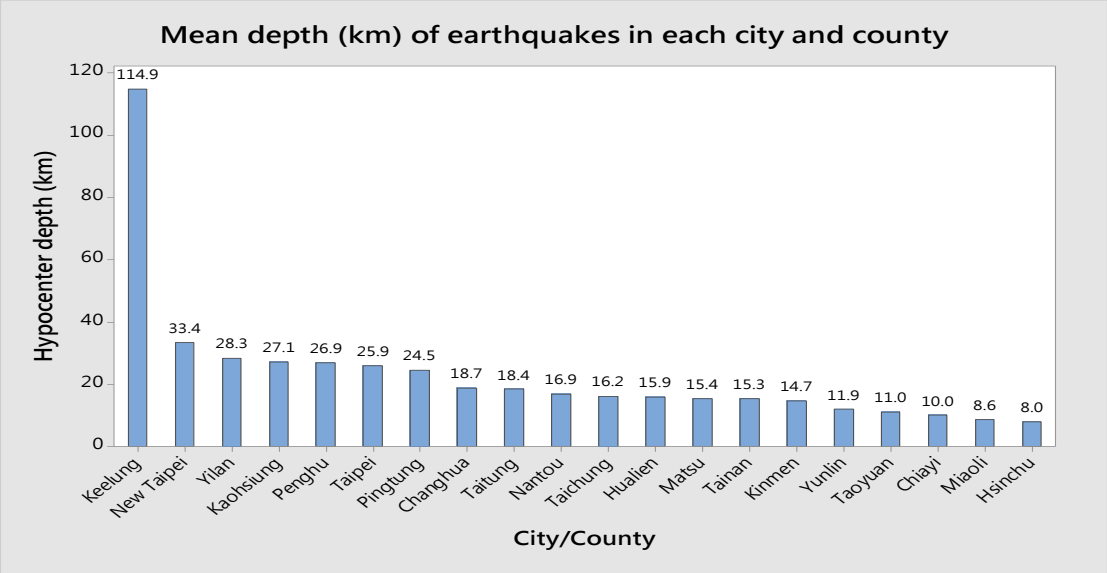

Figure 17: The average depth (km) of earthquakes in each city and county

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

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

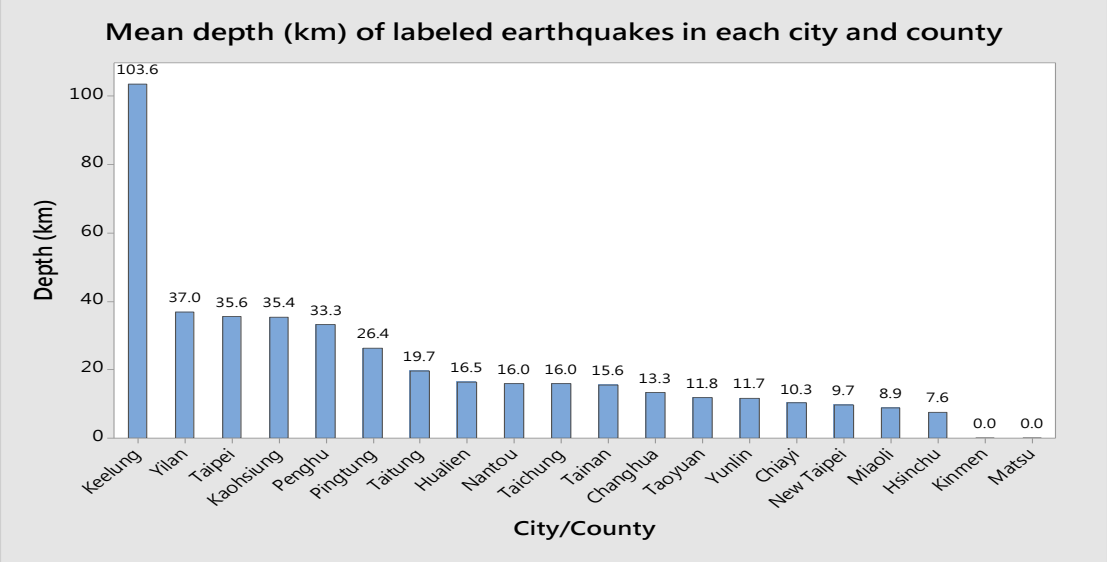

Figure 18: The average depth (km) of labelled earthquakes in each city and county

The average depth of labelled earthquakes in Keelung is 103.6 km (intermediate-depth), which is the deepest for all areas in Taiwan. Hinchey has the shallowest average depth of hypocenters -7.6 km.

Average days between two earthquakes

Average days between two earthquakes in each city and county

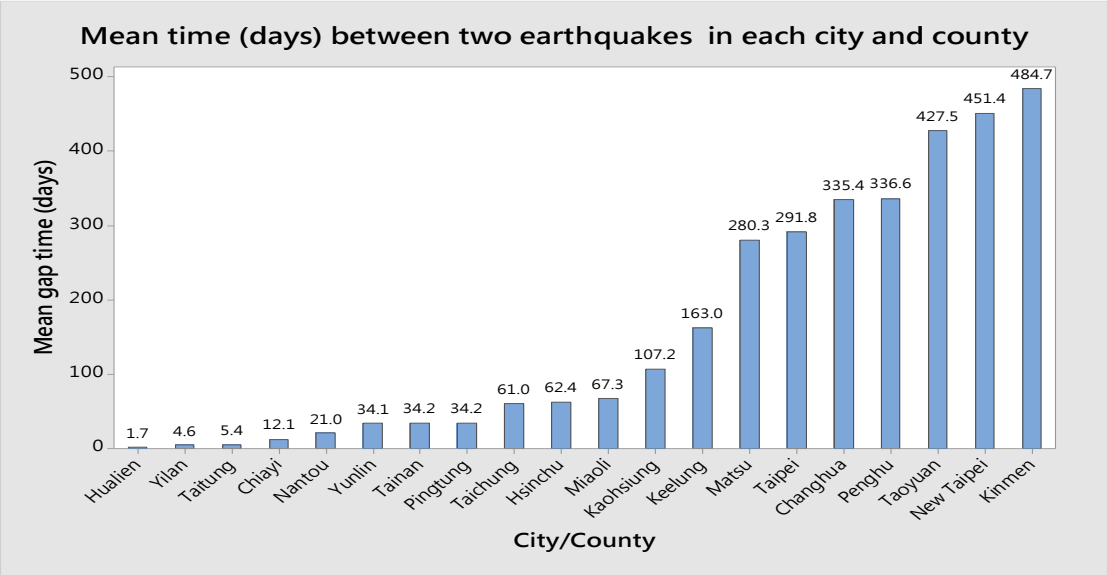

Figure 19: The average time (days) between two earthquakes

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

Average days between two labelled earthquakes in each city and county

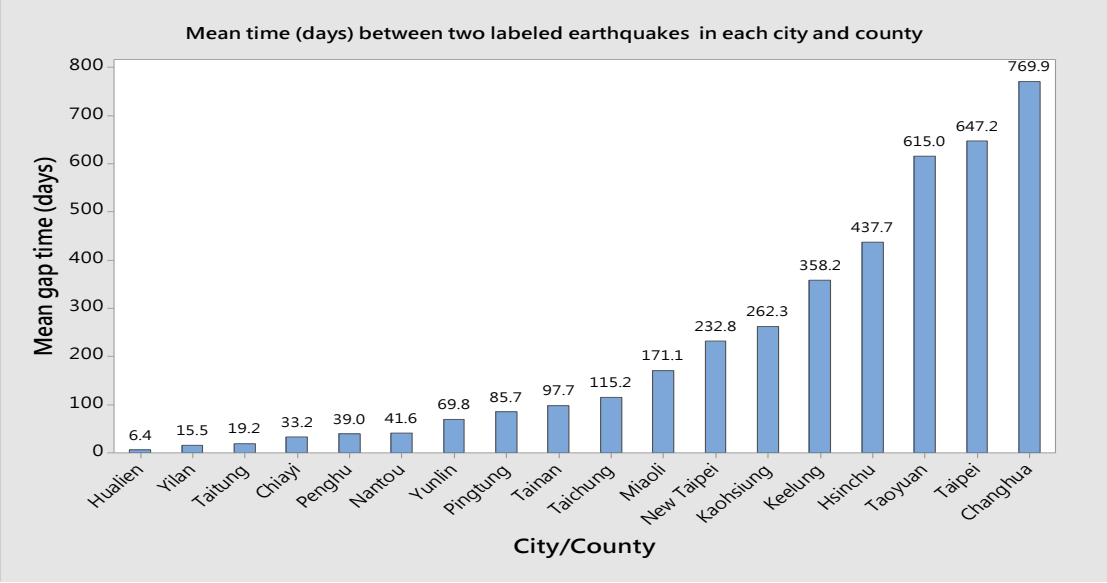

Figure 20: The average time (days) between two labelled earthquakes

Averagely speaking, for every 6.4 days, Haulier will have earthquakes. Changsha, on the extreme end, the gap between two labelled earthquakes extends to 769.9 days. Kinsmen and Matsu have no labelled earthquake data, hence, are not plotted in the figure.

Regression analysis and three-dimensional diagrams

The purpose of this section is to try to use an equation to represent the intensity on the surface of 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.

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

All the earthquakes from January 1995 to June 2018, totally 10,898 records are used in the regression analysis. As long as variables such as longitude, latitude, magnitude, and depth of an earthquake are observed, and substituted into the regression equation, the intensity on the surface of ground can be obtained. The regression equation of the relationship between intensity and four aforementioned variables is:

$$Intensity = -0.03852\ Longitude + 0.2143\ Latitude + 0.7125\ M_L - 0.019580\ Depth \quad (2)$$

(t-value) *(-14.37)* *(16.25)* *(62.24)* *(-44.19)*

And $R^2_{(adj)} = 91.93\%$

The interesting observation of the above equation is 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 is big, which means the corresponding *p-value* is smaller than 5% level of significance. In other words, the hypothesis *H_0: parameter =0* is rejected, and each parameter in the above equation is not zero. The adjusted coefficient of determination $R^2_{(adj)}$ is as high as 91.93%, 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].

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:

$$Intensity = 0.82633\ M_L - 0.020041\ Depth \quad (3)$$

(t-value) *(264.17)* *(-45.51)*

$R^2_{(adj)} = 91.58\%$

The *t-value* of the regression equation is big, and its *p-value* is smaller than 5% level of significance. The high coefficient of determination $R^2_{(adj)} = 91.58\%$, 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	*91.93%*
Intensity = 0.82633 M_L - 0.020041 Depth	*91.58%*

Three-dimensional diagrams

Longitude, latitude, and depth (km)

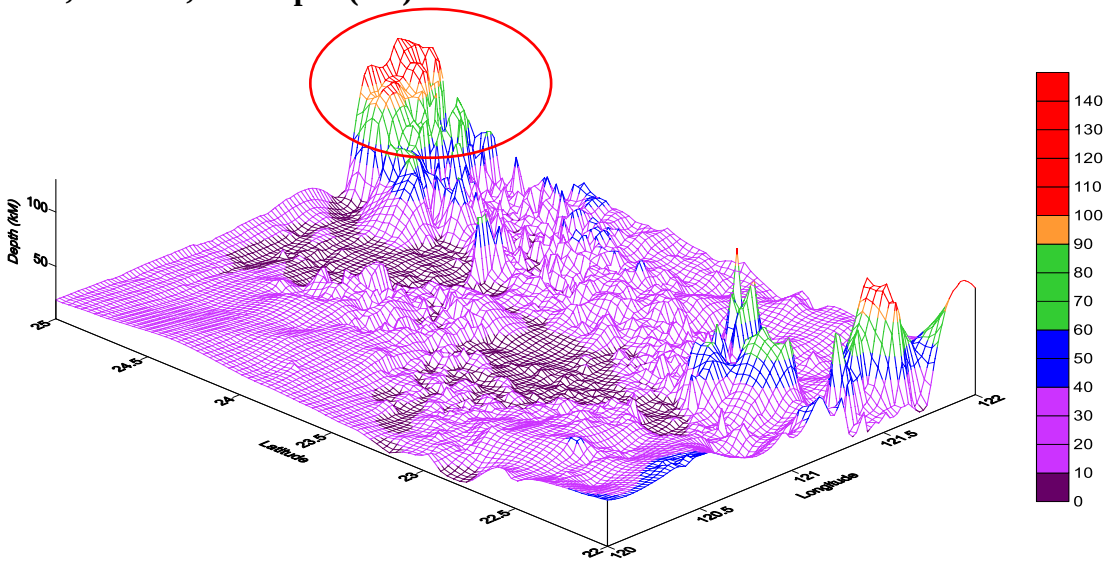

Figure 21: Depths (km) of hypocenters of earthquakes from January 1995 to June 2018 in Taiwan

From the above figure, one can observe that the depths of hypocenters of earthquakes in Keelung, which is on the northern top of Taiwan, are distinct.

Longitude, latitude, and intensity

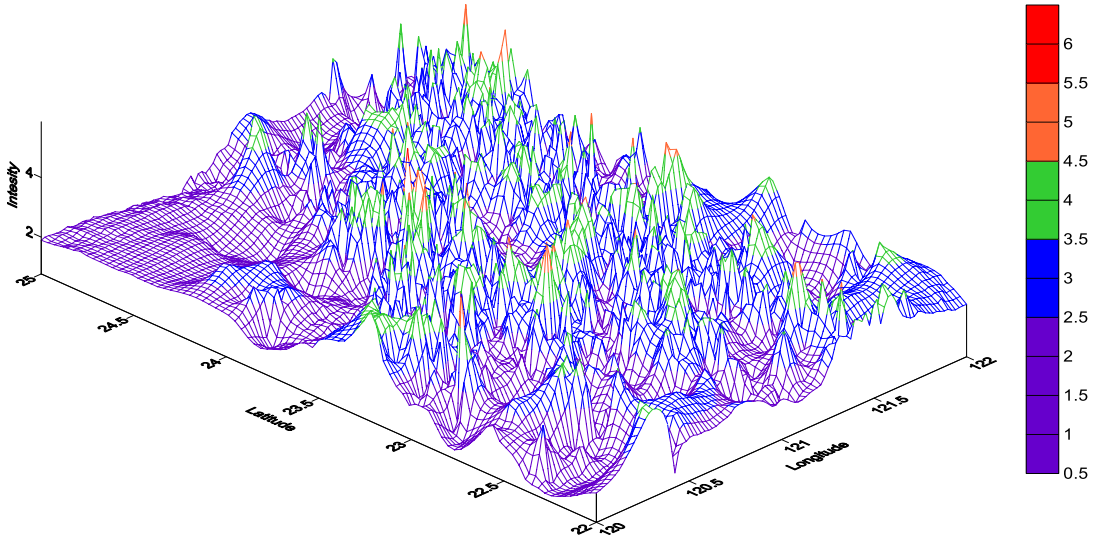

Figure 22: Intensity of earthquakes from January 1995 to June 2018 in Taiwan

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

Longitude, latitude and magnitude (M_L)

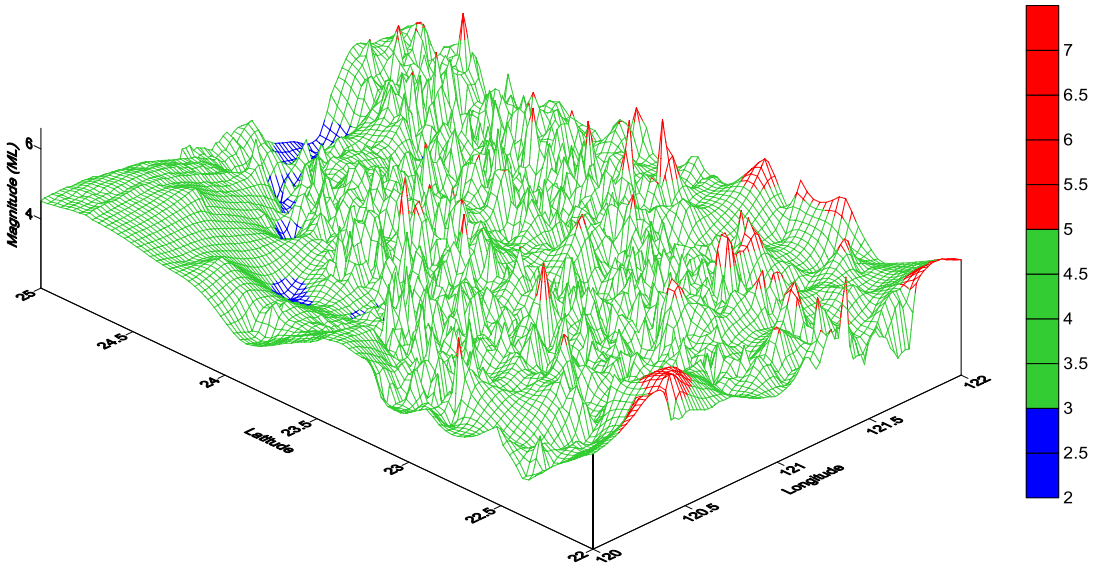

Figure 23: Magnitude (ML) of earthquakes from January 1995 to June 2018 in Taiwan

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

Conclusions

After analyzing seismic data in Taiwan from January 1995 to June 2018 and scrutinizing the major characters of earthquakes in all twenty municipal areas in Taiwan, the following statistical conclusions can be summarized concisely as follows:

For Total (both labelled and unlabeled) Earthquakes

(1) Haulier is the most active place for earthquakes in Taiwan. There are 5,082 earthquakes in Haulier out of totally 10,898 earthquakes in Taiwan, and the frequency ratio is 46.6%. Milan takes the second place, occurring 1,862 times with the ratio of 17.1%. Tantung with 1,572 times is the third, with the ratio of 14.4%.

(2) In each year, averagely, there are 38.6 earthquakes occurring in Taiwan.

(3) Almost all the mean depths of hypocenters of earthquakes in Taiwan are shallow (<70 km), except Keelung (114.92 km), which is classified as intermediate-depth. Maybe its because earthquakes in Keelung are in the submerged tectonic plate. The shallowest depth of earthquakes is in Hinchey, 8.0 km.

(4) The maximum magnitude of earthquakes in Taiwan for the past 23.5 years is 7.3 (Richter magnitude scale, ML) in Manitou on September 21, 1999.

(5) In Haulier, the average interval of two earthquakes is 1.7 days. Indiamen, the interval between two earthquakes takes 484.7 days, which is the longest in Taiwan.

(6)The total energy released from all earthquakes in the past 23.5 years is 5.09E+23 ergs. Haulier accounts for up to 23.4% of it, and is the place where earthquakes released the most energy.

(7) From January 1995 to June 2018 there was energy equivalent to 807.4 atomic bombs generated in Taiwan. No doubt, Haulier was the most intense area with an equivalent of 188.9 bombs. Manitou (171.8bombs) was the second, followed by Tantung (123.4 bombs).

(8) The regression equation between intensity, longitude, latitude, magnitude, and depth (km) has been obtained. The determination of coefficient $R^2_{(adj)}$ is 91.93%, which means that the dependent variable can be highly explained through the knowledge of variability in the independent variables.

For Labelled Earthquakes

(1) Haulier is the most active place for earthquakes in Taiwan. There are 1,343earthquakes in Haulier out of totally 3,257earthquakes in Taiwan, and the frequency ratio is 41.2%. Milan takes the second place, occurring 545 times with the ratio of 16.7%. Tantung with 436 times is the third, with the ratio of 13.4%.

(2) In each year, averagely, there are 11.5 labelled earthquakes occurring in Taiwan.

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

(4) In Haulier, the average period of two labelled earthquakes is 6.4 days, while in Changsha; the interval between two labelled earthquakes takes 769.7 days, which is the longest in Taiwan.

(5) The total energy released from labelled earthquakes in the past 23.5 years is 4.85E+23 ergs. Haulier accounts for up to 23.5%, and also is the place released most energy.

(6) From January 1995 to June 2018the labelled earthquakes generated energy equivalent to 769.7 atomic bombs in Taiwan. No doubt, Haulier was the most intense area, 180.8 bombs. Manitou 171.7 was the second, followed by Tantung, 103.9 bombs. There are 37.7 bombs difference between the atomic bomb numbers of total earthquakes (807.4 bombs) and labelled ones (769.7 bombs). Hence, the negligence of those unlabeled earthquakes will deviate the accuracy of statistical results.

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Appendices

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

Appendix A:

Table A1: The total earthquake data for each city and county in Taiwan (From January 1995 to June 2018)

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)	MeandTime (days)
						Mean	Max		
Yilan	1,862	6.6	79.2	17.1	28.3	3.7	7.1	6.78E+22	4.6
Hualien	5,082	18.1	216.3	46.6	15.9	3.5	6.9	1.19E+23	1.7
Taitung	1,572	5.6	66.9	14.4	18.4	4.0	7.1	7.77E+22	5.4
Nantou	400	1.4	17.0	3.7	16.9	4.0	7.3	1.08E+23	21.0
Keelung	44	0.2	1.9	0.4	114.9	5.1	7	6.47E+22	163.0
Taipei	29	0.1	1.2	0.3	25.9	3.3	5.7	2.61E+20	291.8
New Taipei	4	0.0	0.2	0.0	33.4	3.0	3.9	5.11E+17	451.4
Taoyuan	16	0.1	0.7	0.1	11.0	3.6	4.7	1.60E+19	427.5
Hsinchu	109	0.4	4.6	1.0	8.0	3.0	5	4.20E+	62.4

								19	
Miaoli	101	0.4	4.3	0.9	8.6	3.7	5.2	2.13E+20	67.3
Taichung	126	0.4	5.4	1.2	16.2	3.9	5.6	6.34E+20	61.0
Changhua	22	0.1	0.9	0.2	18.7	3.6	5.3	7.76E+19	335.4
Yunlin	222	0.8	9.4	2.0	11.9	3.6	6.6	5.44E+21	34.1
Chiayi	712	2.5	30.3	6.5	10.0	3.5	6.4	6.44E+21	12.1
Tainan	253	0.9	10.8	2.3	15.3	3.5	5.7	5.10E+20	34.2
Kaohsiung	77	0.3	3.3	0.7	27.1	3.8	5.8	7.04E+20	107.2
Pingtung	248	0.9	10.6	2.3	24.5	4.2	7	5.67E+22	34.2
Penghu	6	0.0	0.3	0.1	26.9	3.8	4.7	8.91E+18	336.6
Kinmen	7	0.0	0.3	0.1	14.7	3.4	4.6	6.48E+18	484.7
Matsu	6	0.0	0.3	0.1	15.4	4.7	5.3	1.01E+20	280.3
Total	10,898	1.9	23.2	100	23.1	3.7	5.8	5.09E+23	160.8
Energy (ergs)	$\log_{10}E=11.8+1.5M_S$								
AveragedTime (days)	The average days between two earthquakes.								

Appendix B:

Table B1: The labelled earthquake data for each city and county in Taiwan (From January 1995 to June 2018)

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)	Averaged Time (days)
						Mean	Max		
Yilan	545	1.9	23.2	16.7	37.0	4.4	7.1	6.45E+22	15.5
Hualien	1,343	4.8	57.1	41.2	16.5	4.2	6.9	1.14E+23	6.4
Taitung	436	1.5	18.6	13.4	19.7	4.6	7.1	6.55E+22	19.2
Nantou	201	0.7	8.6	6.2	16.0	4.5	7.3	1.08E+23	41.6
Keelung	19	0.1	0.8	0.6	103.6	5.5	7	6.24E+22	358.2
Taipei	13	0.0	0.6	0.4	35.6	3.7	5.7	2.59E+20	647.2
New Taipei	2	0.0	0.1	0.1	9.7	3.0	3.3	6.33E+16	232.8
Taoyuan	9	0.0	0.4	0.3	11.8	3.9	4.7	1.54E+19	615.0
Hsinchu	14	0.0	0.6	0.4	7.6	3.9	5	3.70E+19	437.7
Miaoli	35	0.1	1.5	1.1	8.9	4.4	5.2	1.96E+20	171.1
Taichung	60	0.2	2.6	1.8	16.0	4.3	5.6	6.14E+20	115.2
Changhua	8	0.0	0.3	0.2	13.3	4.3	5.3	7.44E+19	769.9
Yunlin	106	0.4	4.5	3.3	11.7	4.1	6.6	5.44E+21	69.8
Chiayi	257	0.9	10.9	7.9	10.3	4.1	6.4	6.39E+21	33.2
Tainan	87	0.3	3.7	2.7	15.6	4.0	5.6	4.08E+2	97.7

								0	
Kaohsiung	30	0.1	1.3	0.9	35.4	4.2	5.8	7.00E+20	262.3
Pingtung	90	0.3	3.8	2.8	26.4	4.7	7	5.64E+22	85.7
Penghu	2	0.0	0.1	0.1	33.3	4.5	4.7	8.34E+18	39.0
Kinmen	0	0.0	0.0	0.0	N.A.	N.A.	N.A.	0	N.A.
Matsu	0	0.0	0.0	0.0	N.A.	N.A.	N.A.	0	N.A.
Total	3,257	N.A.	N.A.	100	N.A.	N.A.	N.A.	4.85E+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 [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.

Appendix C:

Table C1: Released Energy of Earthquakes from January 1995 to June 2018 in Taiwan

City/County	Energy releasedof labeled earthquakes and equivalent to atomic bomb numbers		Energy releasedof total earthquakes and equivalent to atomic bomb numbers	
	Energy released (ergs)	Equivalent atomic bomb numbers	Energy released (ergs)	Equivalent atomic bomb numbers
Yilan	6.45E+22	102.31	6.78E+22	107.54

Hualien	1.14E+23	180.80	1.19E+23	188.9.
Taitung	6.55E+22	103.94	7.77E+22	123.38
Nantou	1.08E+23	171.69	1.08E+23	171.77
Keelung	6.24E+22	99.07	6.47E+22	102.64
Taipei	2.59E+20	0.41	2.61E+20	0.41
New Taipei	6.33E+16	0.00	5.11E+17	0.00
Taoyuan	1.54E+19	0.02	1.60E+19	0.03
Hsinchu	3.70E+19	0.06	4.20E+19	0.07
Miaoli	1.96E+20	0.31	2.13E+20	0.34
Taichung	6.14E+20	0.97	6.34E+20	1.01
Changhua	7.44E+19	0.12	7.76E+19	0.12
Yunlin	5.44E+21	8.64	5.44E+21	8.64
Chiayi	6.39E+21	10.14	6.44E+21	10.23
Tainan	4.08E+20	0.65	5.10E+20	0.81
Kaohsiung	7.00E+20	1.11	7.04E+20	1.12
Pingtung	5.64E+22	89.45	5.67E+22	90.05
Penghu	8.34E+18	0.01	8.91E+18	0.01
Kinmen	0	0.00	6.48E+18	0.01
Matsu	0	0.00	1.01E+20	0.16
Total	4.85E+23	769.72	5.09E+23	807.44

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 2.4E+22 ergs, or more graphically speaking, equivalent to 37.72 atomic bombs dropped in Hiroshima, Japan during WWII.