International Journal of Advanced Engineering and Management Research
Vol. 2 Issue 4, 2017

www.ijaemr.com ISSN: 2456-3676

SEISMIC PROPERTIES AND REGRESSION ANALYSIS OF EARTHQUAKES IN TAIWAN

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ABSTRACT

Three purposes are set for this study: first, to discover the statistical properties of total (labeled plus unlabeled) earthquakes in Taiwan; second, to find out the regression equations of intensity and relationship to its magnitudes (M_L), depth (km) of hypocenters, and location (longitude and latitude); third, to plot three-dimensional graphs of magnitudes (M_L), depth (km), and intensity (gal) for all 9,871 earthquakes occurring from January 1995 to June 2107. All earthquakes recorded are obtained from 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 (M_L), maximum magnitude, interval of time 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 interval 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. Totally 5.04E+23 ergs of energy are accumulated by all 9,871 earthquakes in Taiwan for the past 22.5 years. Such an energy is equivalent to 800.31atomic bombs. To express an astronomical number of energy with atomic bomb numbers in each city and county substantiates abstract energy into graphical reality.

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, M_L) was 7.3. Although Taitung also recorded the same magnitude, its epicenter is off-island. Therefore, no major damage and injury has been filed.

Three three-dimensional diagrams were plotted of magnitudes (M_L), depth (km) of hypocenters, and intensity (gal) of all 9,871 earthquakes with respect to their longitudes and latitudes. Thus, it may facilitate readers to understand the distribution of these earthquakes.

Key Words: CWB Archive, Little Boy, Hypocenter, Regression Analysis

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, and are usually less severe than the labeled ones. Each year, the labeled earthquake always starts from one. It was not until May 2000 did the CWB archive begin to put unlabeled earthquakes into its record. Maybe the great number of aftershocks of 921-earthquake (Richter magnitude scale 7.3 M_L) influenced the decision of high ranking officials at CWB.

From January 1995 to June 2017, 3,129 labeled and 9,871 total (labeled plus unlabeled) earthquakes occurred in 22.5 years (270 months).The difference in number between labeled and total earthquakes will increase with the extension of time period. To avoid misinterpretation of the properties of earthquakes, in this study, all 9,871 earthquakes are taken into consideration.

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 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). All 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 total labeled and unlabeled earthquakes), Appendix B (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 Total Number of Earthquakes in Each Year

This subsection is used to find the earthquake frequencies of each year from 1995 to 2017 (expected).

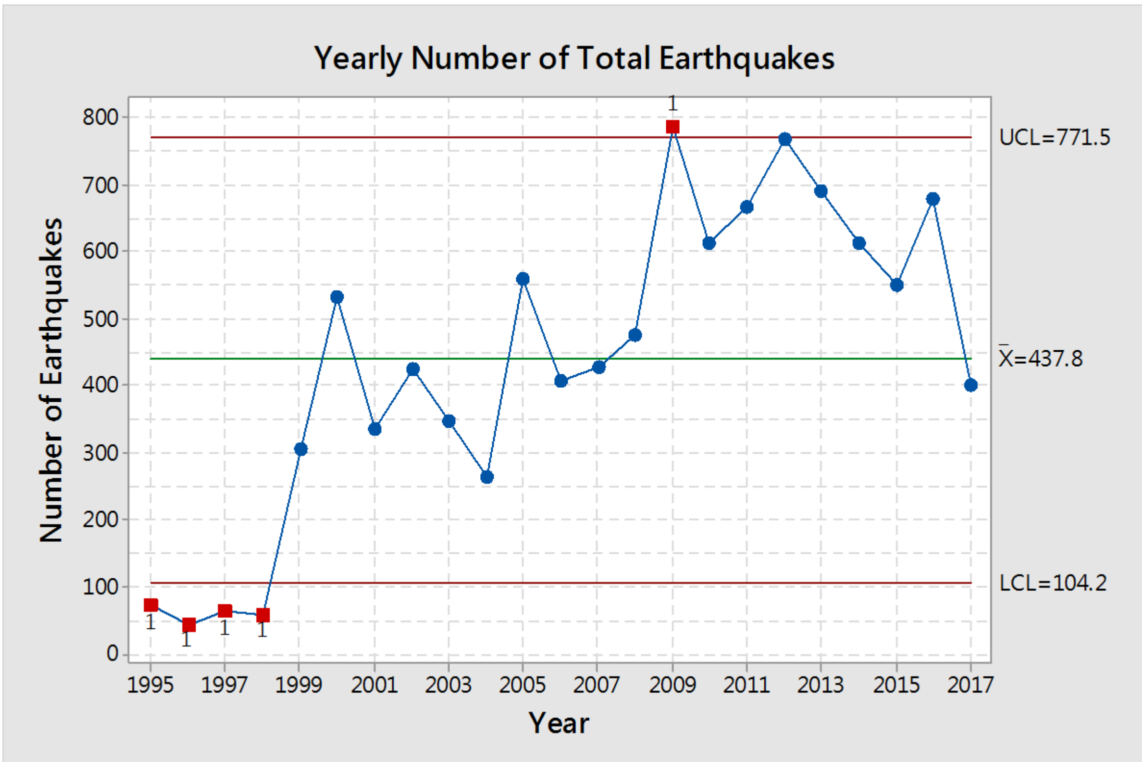

Figure 1: Number of total earthquakes per year from years 1995 to 2017 (expected)

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 has not yet put small-scaled earthquakes in the archive.

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

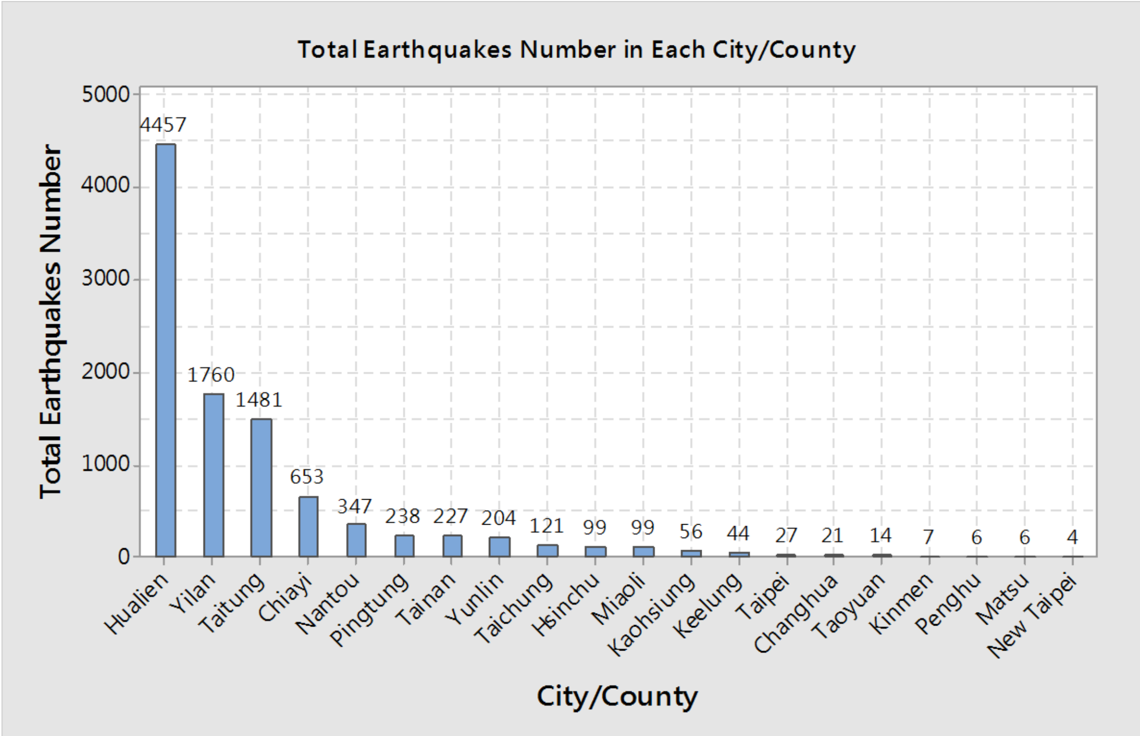

Figure 2: Total number of earthquakes from January 1995 June 2017 for each city/county in Taiwan

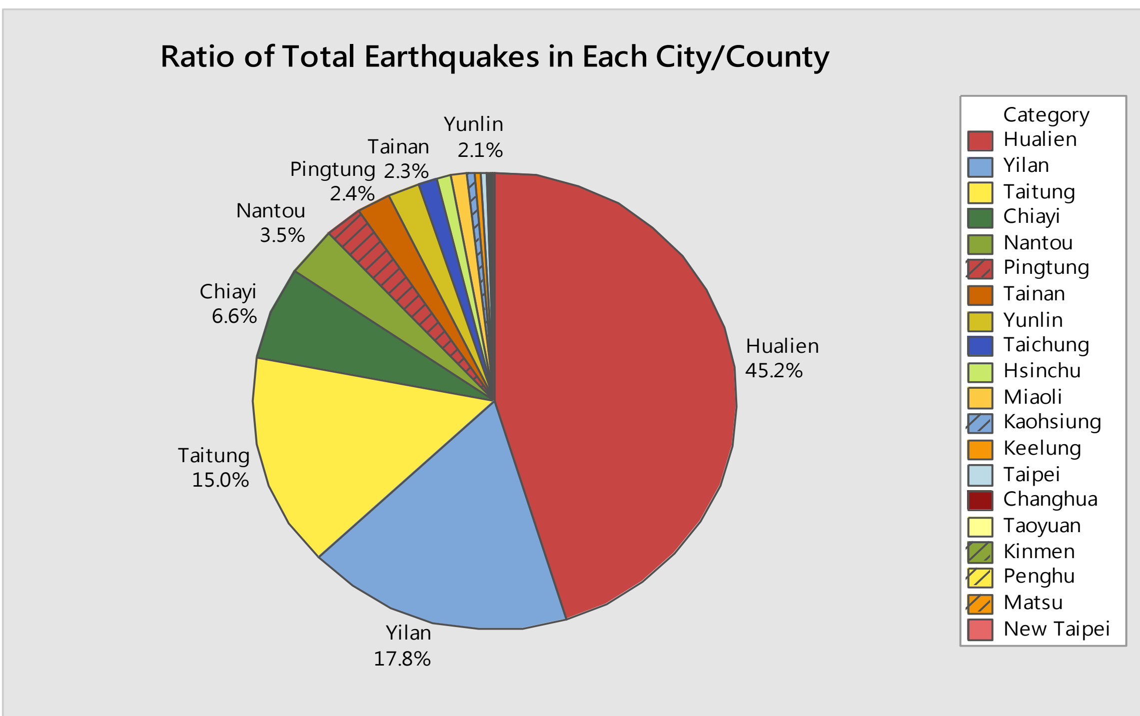

Figure 3: Percentage (%) of frequency of total earthquakes of each city/county from January 1995 to June 2017

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.

2.3 Mean Times per Month in Each City/County

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

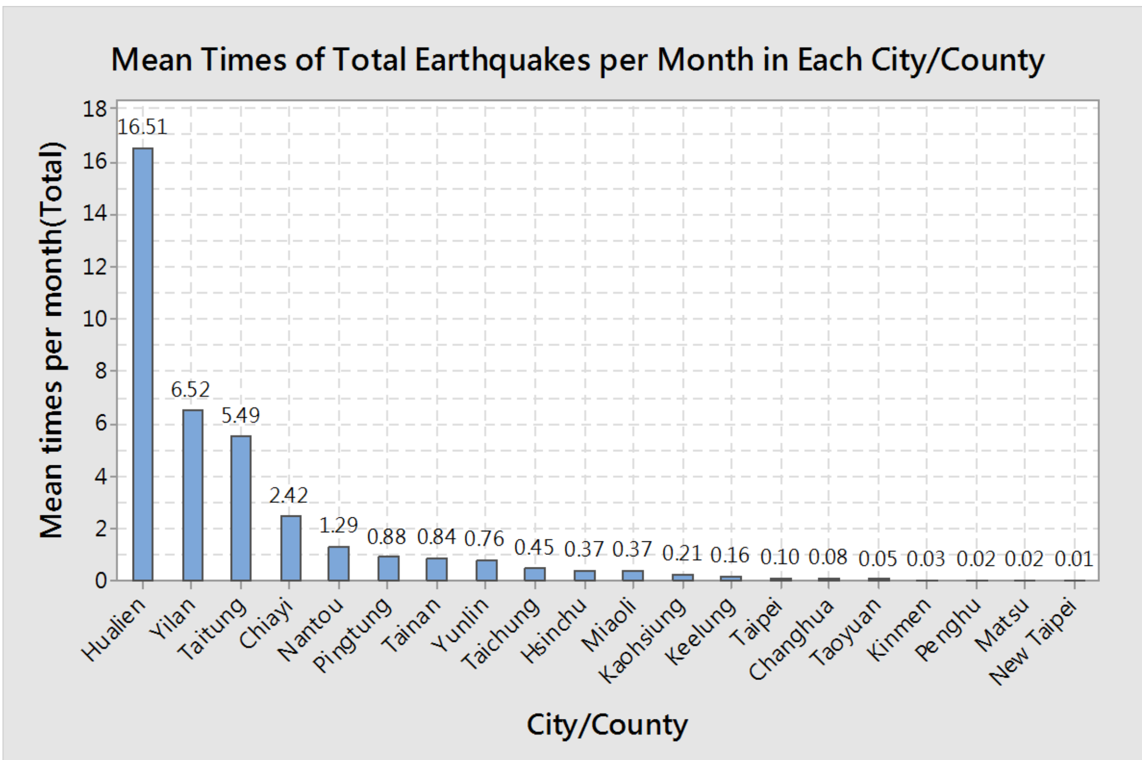

Figure 4: Mean times of total earthquakes per month for each city/county in Taiwan from January1995 to June 2017

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.

2.4 Mean Times per Year of Total Earthquakes in Each City/County

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

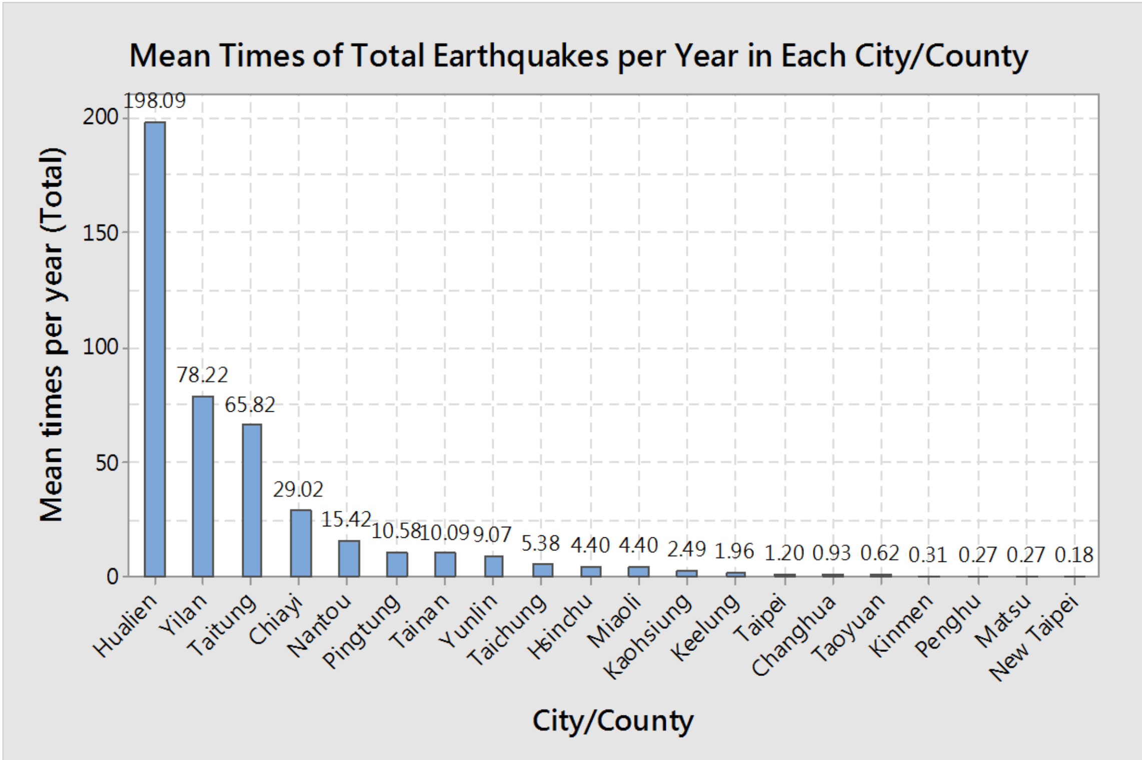

Figure 5: Mean times of total earthquakes per year for each city/county in Taiwan from January 1995 to June 2017

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 numbers of each city and county.

2.5 Mean Depth (km) of Total Earthquakes in Each City/County

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 induce stronger intensity of each locality due to the attenuation effect.

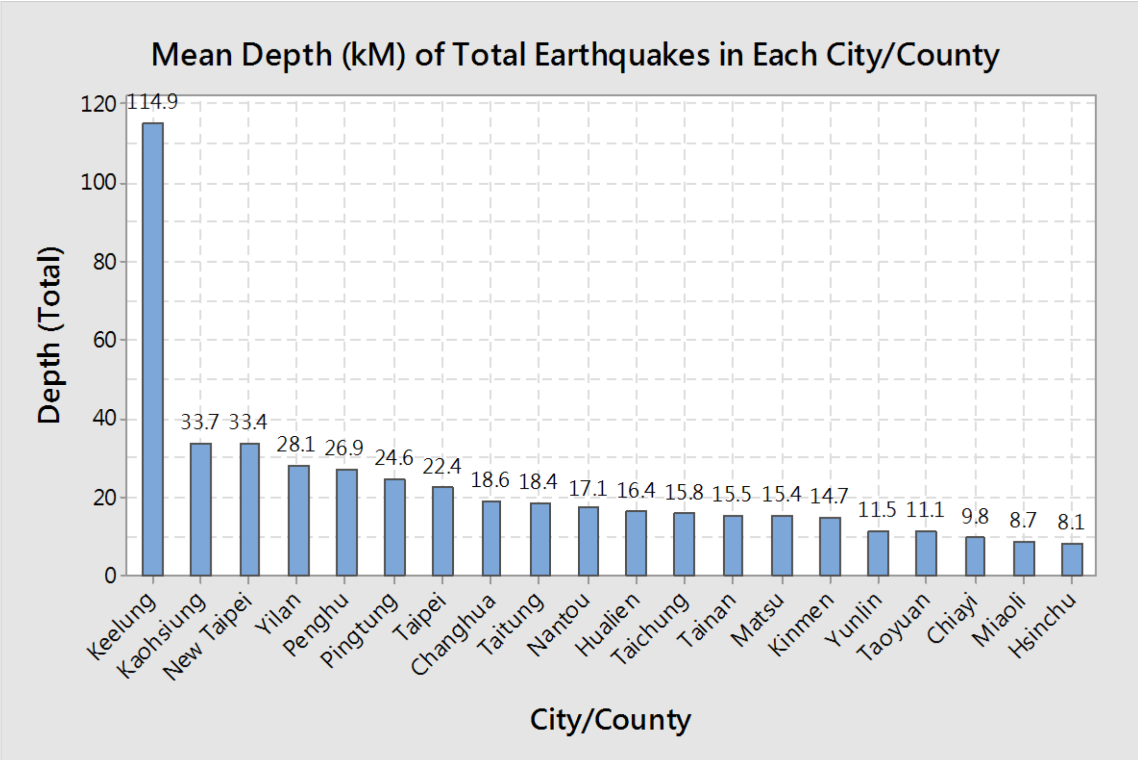

Figure 6: Mean depth (km) of total earthquakes for each city/county from January 1995 to June 2017

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).

2.6 Mean Magnitude (Richter magnitude scale, M_L) of Total Earthquakes in Each City/County

Magnitude is the energy released from an earthquake. It is often estimated from the equation suggested by Gutenberg and Richter (Kramer 1996) as $\log E = 11.8 + 1.5Ms$ 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.

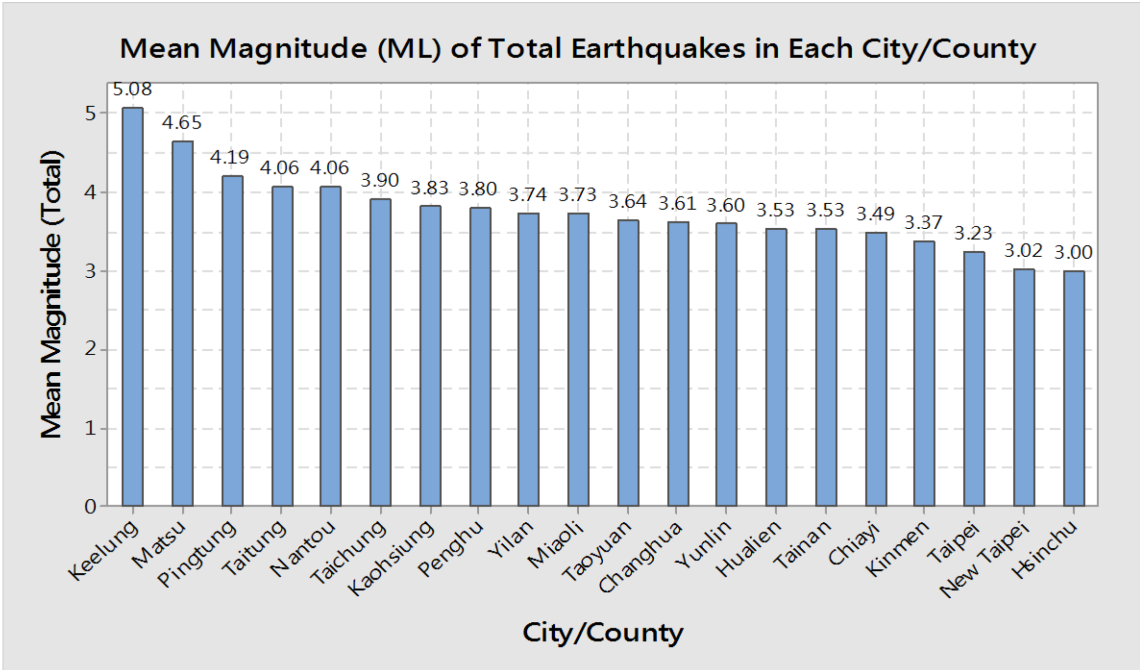

Figure 7: Mean magnitude of total earthquakes of each city/county from January 1995 to June 2017

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

2.7 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. The maximum magnitude of each city and county is plotted in Figure 8.

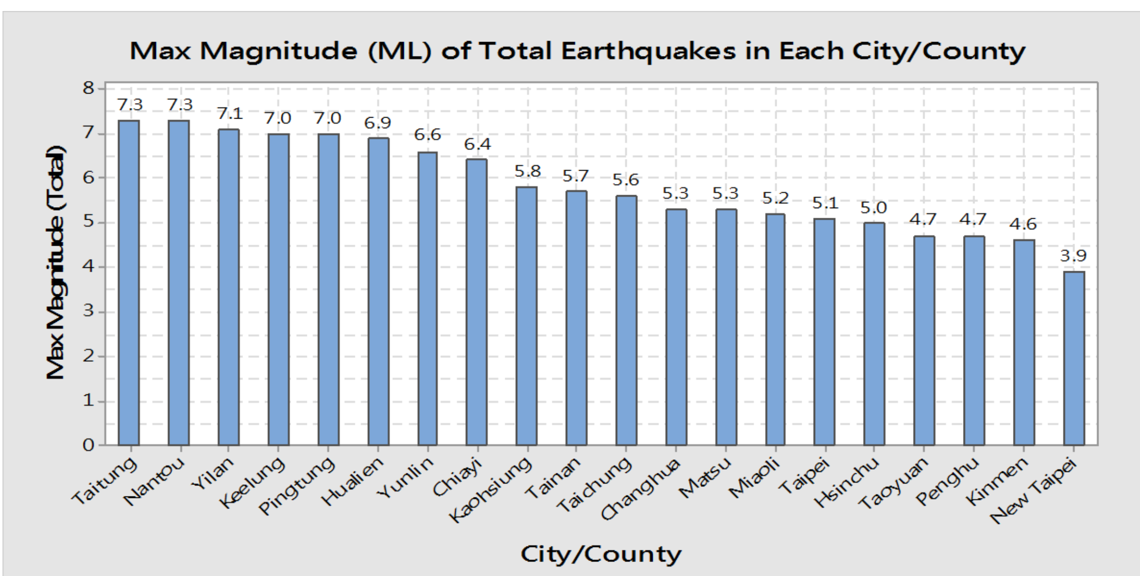

Figure 8: Maximum magnitude (M_L) of each city/county in Taiwan

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.

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

The average interval of time between two earthquakes in each area is discussed in this subsection.

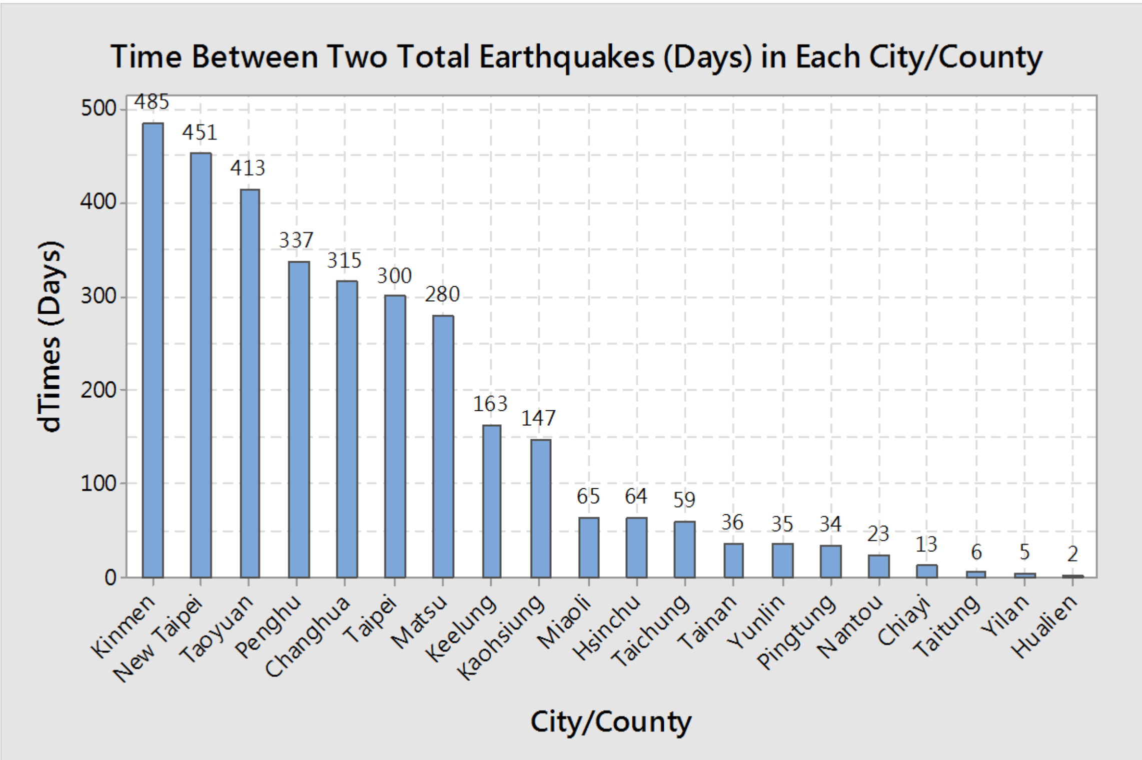

Figure 9: Mean interval of time (days) between two total earthquakes for each city/county from January 1995 to June 2017

In Hualien, the average interval 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.

2.9Ratio of Energy (ergs) Released from Total Earthquakes in Each City/County

Since the energy released from an earthquake is usually large, 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.

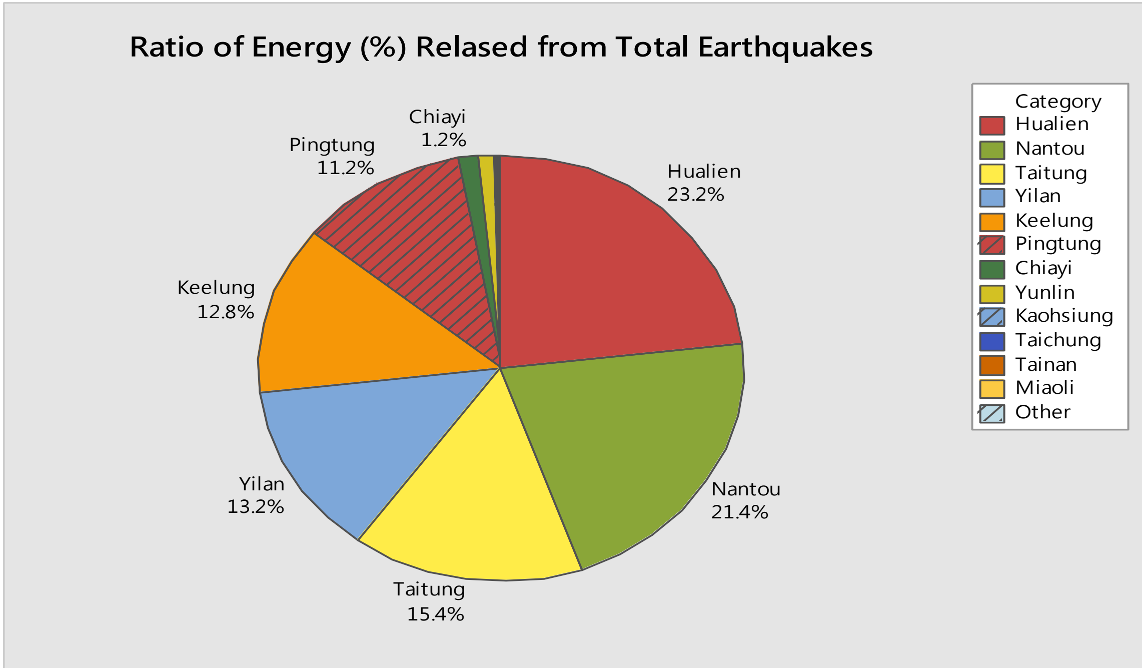

Figure 10: The ratio (%) of energy released in each city/county to total energy released by total earthquakes in Taiwan from January 1995 to June 2017

The ratio of energy released by earthquakes of each area to that of 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 energy released is counted by total earthquakes, the above results are more accurate.

2.10 Released Energy from Total Earthquakes Expressed in Number of Atomic Bombs

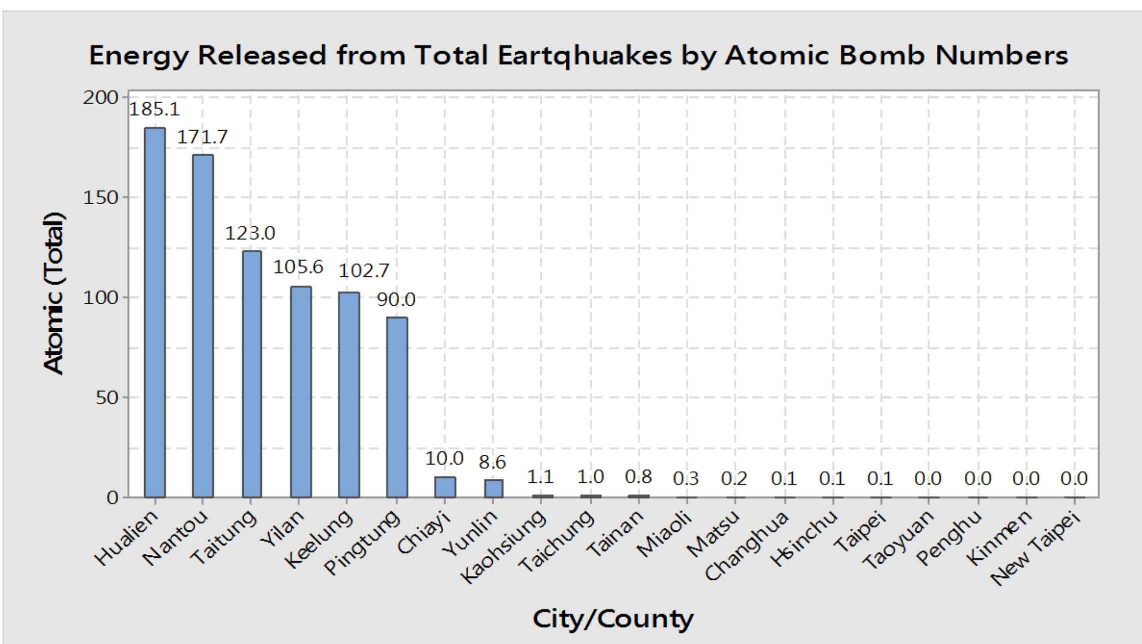

Figure 11: Energy released from total earthquakes in each city/county by atomic bomb numbers

The energy released from earthquakes accumulate to 5.04E+23 ergs, which is equivalent to 800.31 atomic bombs. In each year the average energy released from total earthquakes is equivalent to 35.57 atomic bombs.
If the unlabeled earthquakes are neglected, the energy accumulation value will be inaccurate. Such a gap may increase by the increasing of time, and taking all earthquakes into consideration is appropriate.

3. Relationship of Intensity with Other Factors for Eight Municipal Areas

Intensity is the effects of an earthquake on people, structures and environment, and its scale is determined by the acceleration of the ground motion. In CWB, the unit of intensity is gal (1 gal= 1 cm/s^2). There are eight categories of intensity, from 0 (micro, below 0.8gal) to 7 (great, 400 gal and above). From the physical theory, one can expect the acceleration of the ground motion is the function of magnitude, depth of hypocenter and location of an earthquake. If one can find correlation of the intensity and the parameters mentioned above, then the mathematical relationship can be established. The statistical regression analysis can be used to fulfil this purpose.
This section is dedicated to find out the relationship of intensity and magnitude as well as the location of an earthquake. The location of an earthquake is determined by latitude, longitude, and depth of hypocenters of an earthquake. First, to find out a mathematical expression for entire Taiwan. Second, to obtain the equation which is suitable for the eight most frequent earthquakes areas of Taiwan. These areas start from high to low are: Hualien, Yilan, Taitung, Chiayi, Nantou, Pingtung, Tainan and Yunlin.

3.1 Entire Twenty Municipal Areas of Taiwan

The whole 9,871 earthquakes recorded from January 1995 to June 2017 are used for the regression analysis. The first subsection is for the relationship between intensity (gal) and magnitude (M_L) and depth (km) of earthquakes. The second subsection parameters incorporated into consideration include magnitude (M_L), depth (km), latitude, and longitude of earthquakes.

3.1.1 Regression among Intensity, Magnitude, and Depth of Earthquakes for Entire Taiwan

The regression equation of intensity and magnitude and depth for all the earthquakes in Taiwan can be expressed as:

$$\text{Intensity} = 0.82865\, M_L - 0.019920\, \text{Depth} \qquad (1)$$

$R^2_{adj} = 91.57\%$

Where R^2_{adj} is the adjusted coefficient of determination that can be explained through the knowledge of the variability in the independent variable (Hanke and Wichern, 2009; Hill, Griffiths, and Lim, 2012).

3.1.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes for Entire Taiwan

The regression equation can be expressed as:

$$\text{Intensity} = 0.6965\ M_L - 0.019318\ \text{Depth} - 0.03671\ \text{Longitude} + 0.2080\ \text{Latitude} \quad (2)$$

$$R^2_{adj} = 91.96\%$$

From equations (1) and (2), one finds R^2_{adj} (adjusted coefficient of determination) are both larger than 91%, which is very high. In other words, equations (1) and (2) can explain the relationship between intensity and aforementioned parameters up to and more than 91%, and which is a very satisfactory value.

3.2 Hualien

3.2.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Hualien

The regression equation of intensity and magnitude and depth for all the earthquakes in Hualien is:

$$\text{Intensity} = 0.91401\ M_L - 0.03650\ \text{Depth} \quad (3)$$

$$R^2_{adj} = 92.40\%$$

3.2.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Hualien

The regression equation can be expressed as:

$$\text{Intensity} = 0.7299\ M_L - 0.03285\ \text{Depth} - 0.0878\ \text{Longitude} + 0.4705\ \text{Latitude} \quad (4)$$

$$R^2_{adj} = 92.82\%$$

3.3 Yilan

3.3.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Yilan

The regression equation of intensity and magnitude and depth for all the earthquakes in Yilan is:

Intensity=0.93916 M_L- 0.024441 Depth (5)

R^2_{adj} = 92.23%

3.3.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Yilan

The regression equation can be expressed as:

Intensity=0.5213 M_L- 0.018909 Depth+ 0.2034 Longitude- 0.951 Latitude (6)

R^2_{adj} = 93.45%

3.4 Taitung

3.4.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Taitung

The regression equation of intensity and magnitude and depth for all the earthquakes in Taitung is:

Intensity=0.78115 M_L- 0.01801 Depth (7)

R^2_{adj} = 92.76%

3.4.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Taitung

Intensity=0.7142 M_L- 0.01632 Depth- 0.02343 Longitude+ 0.1352 Latitude (8)

R^2_{adj} = 92.82%

3.5 Chiayi

3.5.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Chiayi

The regression equation of intensity and magnitude and depth for all the earthquakes in Chiayi is:

Intensity=0.8675 M_L- 0.03757 Depth (9)

R^2_{adj} = 91.59%

3.5.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Chiayi

$$Intensity=0.9117\ M_L - 0.02423\ Depth + 0.1911\ Longitude - 0.999\ Latitude \quad (10)$$

$R^2_{adj} = 91.87\%$

3.6 Nantou

3.6.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Nantou

The regression equation of intensity and magnitude and depth for all the earthquakes in Nantou is:

$$Intensity=0.7743\ M_L - 0.01828\ Depth \quad (11)$$

$R^2_{adj} = 92.66\%$

3.6.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Nantou

$$Intensity=1.2528\ M_L + 0.01224\ Depth - 0.3538\ Longitude + 1.687\ Latitude \quad (12)$$

$R^2_{adj} = 94.55\%$

3.7 Pingtung

3.7.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Pingtung

The regression equation of intensity and magnitude and depth for all the earthquakes in Pingtung is:

$$Intensity=0.7646\ M_L - 0.03120\ Depth \quad (13)$$

$R^2_{adj} = 90.96\%$

3.7.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Pingtung

$$Intensity=1.1228\ M_L - 0.02052\ Depth - 0.1211\ Longitude + 0.568\ Latitude \quad (14)$$

$R_{adj}^2 = 92.20\%$

3.8 Tainan

3.8.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Tainan

The regression equation of intensity and magnitude and depth for all the earthquakes in Tainan is:

$$\text{Intensity}=1.0200\ M_L - 0.0625\ \text{Depth} \quad (15)$$

$R_{adj}^2 = 93.10\%$

3.8.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Tainan

$$\text{Intensity}=1.1307\ M_L - 0.0410\ \text{Depth} - 0.309\ \text{Longitude} + 1.578\ \text{Latitude} \quad (16)$$

$R_{adj}^2 = 93.33\%$

3.9 Yunlin

3.9.1 Regression among Intensity, Magnitude, and Depth of Earthquakes in Yunlin

The regression equation of intensity and magnitude and depth for all the earthquakes in Yunlin is:

$$\text{Intensity}=0.8301\ M_L - 0.01407\ \text{Depth} \quad (17)$$

$R_{adj}^2 = 94.18\%$

3.9.2 Regression among Intensity, Magnitude, Depth, Longitude, and Latitude of Earthquakes in Yunlin

$$\text{Intensity}=1.0645\ M_L - 0.0221\ \text{Depth} - 0.352\ \text{Longitude} + 1.766\ \text{Latitude} \qquad (18)$$

R^2_{adj} = 94.53%

All the regression equations for entire Taiwan and eight most frequent areas are summarized in the following table. By the theory of parsimony (Hanke and Wichern, 2009; Hill, Griffiths, and Lim, 2012), the parameters magnitude (ML) and depth (km)are recommended to be used in the regression equation. Including longitude and latitude can increase the explanation R^2_{adj} only slightly, and thus it seems unnecessary to include these two factors.

Table 1: Regression Analysis of Intensity with Respect to Magnitude (M_L), Depth (km), and Location of Earthquakes

No.	Location	Data Numbers	Regression Equation	R^2_{adj} (%)
1	Entire Taiwan	9,871	Intensity = 0.82865 M_L- 0.019920 Depth	91.57
2	Entire Taiwan	9,871	Intensity= 0.6965 M_L - 0.019318 Depth - 0.03671 Longitude + 0.2080 Latitude	91.96
3	Hualien	4,457	Intensity=0.91401 M_L - 0.03650 Depth	92.40
4	Hualien	4,457	Intensity=0.7299 M_L - 0.03285 Depth - 0.0878 Longitude+ 0.4705 Latitude	92.82
5	Yilan	1,760	Intensity=0.93916 M_L - 0.024441 Depth	92.23
6	Yilan	1,760	Intensity=0.5213 M_L - 0.018909 Depth + 0.2034 Longitude- 0.951 Latitude	93.45
7	Taitung	1,481	Intensity=0.78115 M_L - 0.01801 Depth	92.76
8	Taitung	1,481	Intensity=0.7142 M_L - 0.01632 Depth - 0.02343 Longitude+ 0.1352 Latitude	92.82
9	Chiayi	653	Intensity=0.8675 M_L - 0.03757 Depth	91.59
10	Chiayi	653	Intensity=0.9117 M_L - 0.02423 Depth + 0.1911 Longitude- 0.999 Latitude	91.87
11	Nantou	347	Intensity=0.7743 M_L- 0.01828 Depth1	92.66
12	Nantou	347	Intensity=1.2528 M_L + 0.01224 Depth - 0.3538 Longitude+ 1.687 Latitude	94.55
13	Pingtung	238	Intensity=0.7646 M_L- 0.03120 Depth	90.96
14	Pingtung	238	Intensity=1.1228 M_L- 0.02052 Depth - 0.1211 Longitude + 0.568 Latitude	92.20
15	Tainan	227	Intensity=1.0200 M_L- 0.0625 Depth	93.10

16	Tainan	227	Intensity=1.1307 ML- 0.0410 Depth - 0.309 Longitude+ 1.578 Latitude	93.33
17	Yunlin	204	Intensity=0.8301 ML- 0.01407 Depth	94.18
18	Yunlin	204	Intensity=1.0645 ML- 0.0221 Depth - 0.352 Longitude+ 1.766 Latitude	94.53

4. Three-Dimensional Plots of Magnitude, Depth, and Intensity of Totally 9,871 Earthquakes from January 1995 to June 2017

The three-dimensional diagrams substantiate the abstract data into meaningful pictures. The magnitude, depth, and intensity of all 9,871 earthquakes in the past 22.5 years are plotted in this section to show the distribution of the aforementioned factors one is interested in.

4.1 Three-Dimensional Plot of Magnitude, Latitude, and Longitude of all Earthquakes

The magnitude of all 9,871 earthquakes from January 1995 to June 2017 is plotted as in the following figure. From the figure, one finds the magnitudes from 3 to 5 account for large percentage of all earthquakes.

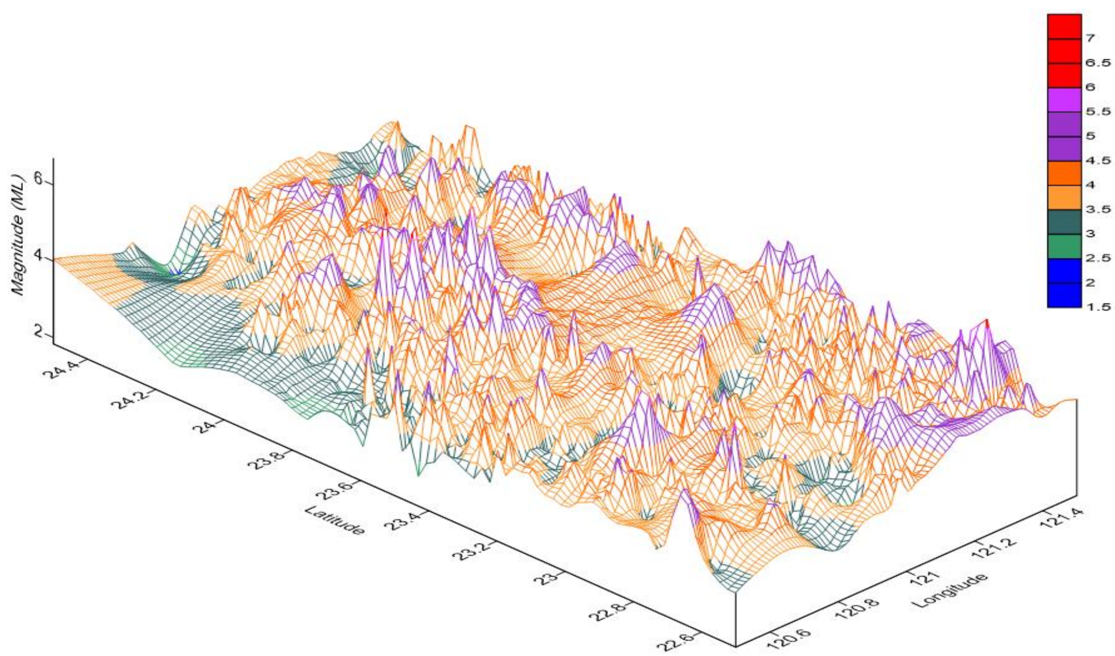

Figure 12: Magnitude (ML) of total 9,871 earthquakes in Taiwan from January 1995 to June 2017

4.2Three-Dimensional Plot of hypocenter depth, Latitude, and Longitude of all Earthquakes

The hypocenter depths (km) of all 9,871 earthquakes from January 1995 to June 2017 are plotted as in the following figure. From the figure, one finds the majority of depths are shallower than 30 km. The shallower the hypocenter, the more intensity of the ground acceleration will be.

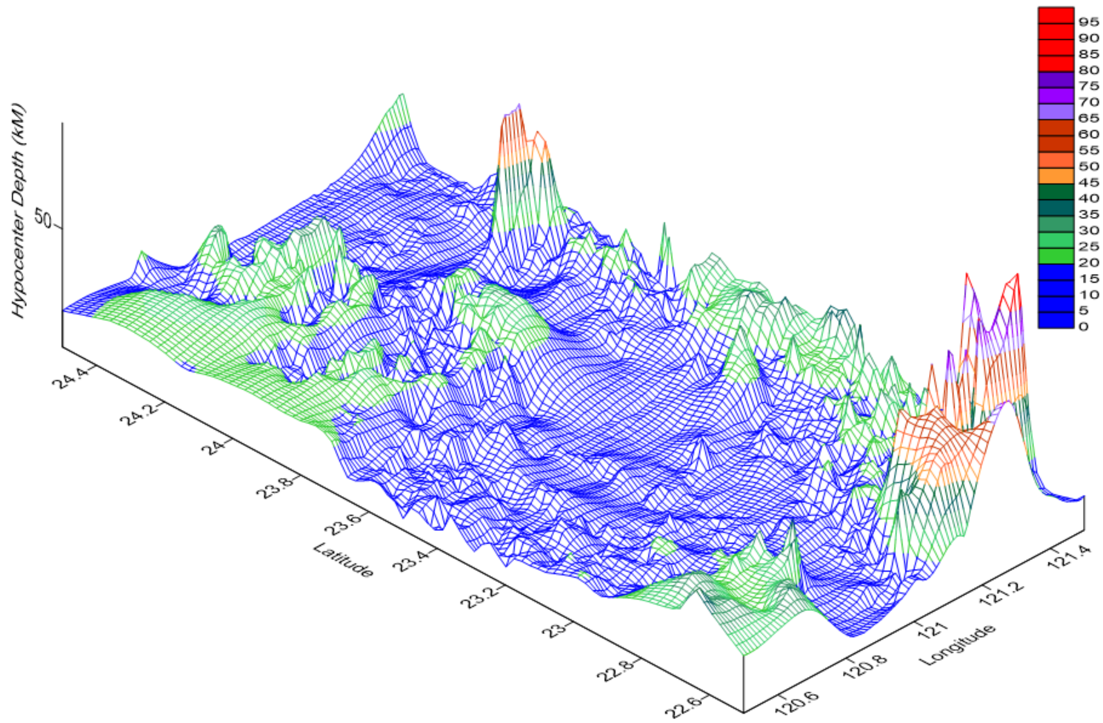

Figure 13: Depth in km of total 9,871 earthquakes in Taiwan from January to June 2017

4.3Three-Dimensional Plot of Intensity, Latitude, and Longitude of all Earthquakes

The intensity of all 9,871 earthquakes from January 1995 to June 2017 is plotted as in the following figure. From the diagram, one finds the intensity of most earthquakes is below 5.0, and only a few can reach and above 7.1. The intensity more than 5.0 may induce certain disasters to that area.

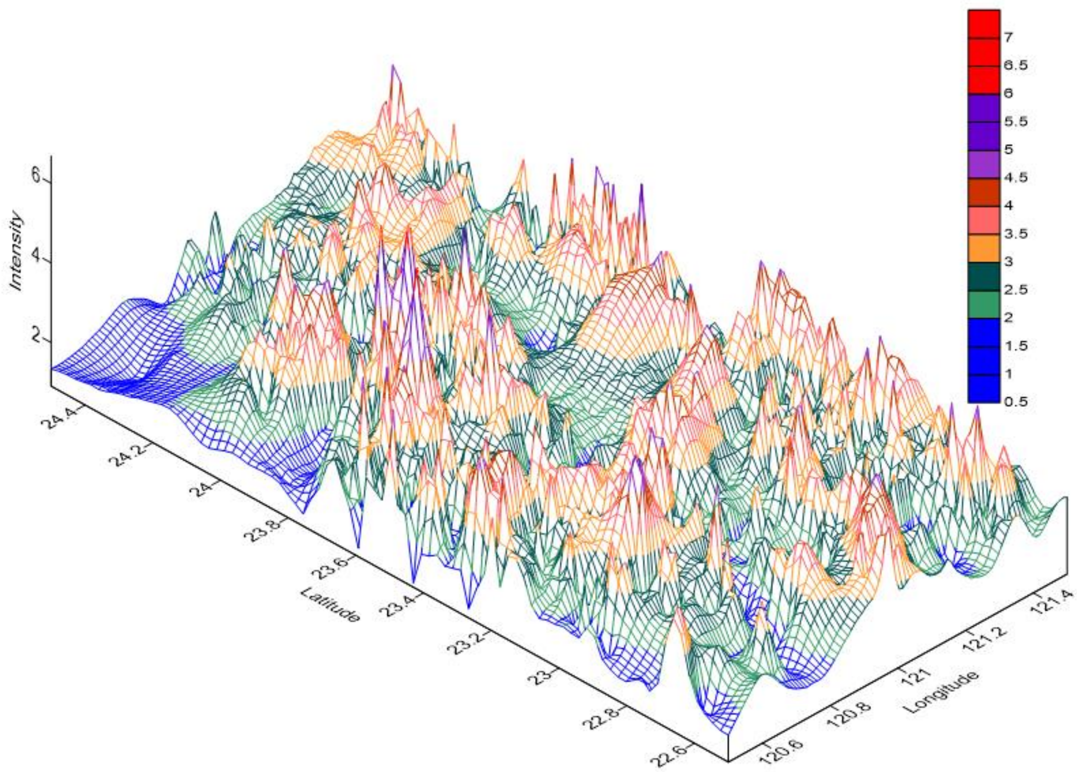

Figure 14: Intensity distribution of all 9,871earthquakes in Taiwan from January 1995 to June 2017

5. 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:

(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 strike 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 January 1995 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 the all 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, 185.1 bombs. Nantou 171.7 is the second, and followed by Taitung, 120.3 bombs.

(10) The regression between intensity (gal) and magnitude (ML), depth (km), longitude, and latitude were obtained. The adjusted coefficient of determination for the entire Taiwan and other eight most frequent areas are all above 90%. It means the proposed regression equations can explain the data quite well. From the parsimony point of view, two independent variables magnitude (ML) and depth (km) are good enough to explain the intensity of an earthquake.

(11) Three-dimensional diagrams of magnitude (ML), depth (km), and intensity (gal) were plotted to substantiate the abstract data to graphs to make readers easily catch the picture of the properties of earthquakes in Taiwan.

6. References

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Appendices:

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

Appendix A:

Table A1: 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)		Total Energy Released (ergs)	Mean dTime (days)
						Mean	Max		
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
Kaohsiung	56	0.21	2.49	0.57	33.7	3.83	5.8	6.99E+20	146.5
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+	164.5

								23	
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: Released energy of earthquakes from January 1995 to June 2017 in Taiwan

City/County	Energy released of total earthquakes and equivalent to atomic bomb numbers	
	Energy released (ergs)	Equivalent atomic bomb numbers
Yilan	6.65E+22	105.63
Hualien	1.17E+23	185.12
Taitung	7.75E+22	122.95
Nantou	1.08E+23	171.68
Keelung	6.47E+22	102.65
Taipei	3.69E+19	0.06
New Taipei	5.11E+17	0.00
Taoyuan	1.59E+19	0.03
Hsinchu	4.16E+19	0.07

Miaoli	2.12E+20	0.34
Taichung	6.33E+20	1.00
Changhua	7.70E+19	0.12
Yunlin	5.43E+21	8.62
Chiayi	6.28E+21	9.96
Tainan	4.99E+20	0.79
Kaohsiung	6.99E+20	1.11
Pingtung	5.67E+22	90.0
Penghu	8.91E+18	0.01
Kinmen	6.48E+18	0.01
Matsu	1.0E+20	0.16
Total	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 energy released up to 2.2E+22 ergs, or more graphically speaking, equivalent to 35.36 atomic bombs dropped in Hiroshima, Japan during WWII.