ANALYSIS OF DEATHS CAUSED BY INTERPLATE AND INTRAPLATE EARTHQUAKES

A Thesis

by

PUSHKIN JOGUNOORI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Construction Management

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Approved by:

Chair of Committee,	John M. Nichols
Committee Members,	Leslie H. Feigenbaum
	Douglas F. Wunneburger
Head of Department,	Joseph P. Horlen

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ABSTRACT

Analysis of Deaths Caused by Interplate and Intraplate Earthquakes. (May 2011)

Pushkin Jogunoori, B.E., Birla Institute of Technology & Science, India

Chair of Advisory Committee: Dr. John M. Nichols

Two kinds of earthquakes, interplate and intraplate, occur in the world. Interplate earthquakes occur at the plate boundaries and are common. Intraplate earthquakes occur within the stable continental land mass and are less common. Fatality models have been developed by a number of different research groups in the last decades to estimate losses in these types of events. This is a relatively new research area, with the added problem that a fatal event only occurs every fortnight or so, so that the data collection process is long term. This research study has two objectives; the first is to update the Generalized Poissonian distribution parameters for the period 2000 to 2009. The second is to establish the statistical properties of the set of fatal earthquakes for the world, for the interplate region, and intraplate region in the last decade and for the twentieth century. This work has not been previously completed and represents a potential insight into the cost effectiveness of current earthquake mitigation schemes. The key hypothesis is that fatal interplate earthquakes occur at a higher rate than fatal intraplate events. The results of the two analyses show that there is an increase in the average number of earthquakes and the average number of deaths caused by these earthquakes for this decade, indicating this decade has proved to be worse when compared to the earlier recorded earthquake

period data. There was a total of 202 recorded fatal events in the period of 2000 to 2009. The interplate earthquakes proved to cause more fatalities compared to intraplate earthquakes during the past decade. The difference at the five percent confidence level is significant.

DEDICATION

To my mother

ACKNOWLEDGEMENTS

I convey my extreme gratitude to my committee chair Dr. John Nichols and my committee members' Prof. Leslie Feigenbaum and Dr. Douglas Wunneburger for all the motivation and help in my thesis work.

I also would like to thank my parents and friends for all the support I received from them.

NOMENCLATURE

CEUS	Central and Eastern United States
NOAA	National Oceanic and Atmospheric Administration
USGS	United States Geological Survey
Intraplate	Within a stable continental mass as defined by Johnson and Kantor (Johnston & Kanter, 1990)
Interplate	Between two stable land masses as defined to be within two degrees of the boundary (Wysession, Wilson, Bartkó, & Sakata, 1995)
Meizoseismal	Occurring with the area of highest movements (Kotò, 1893; Little, Fowler, Coulson, Onions, & Friedrichsen, 1973)
Modified Mercalli Scale	A scale from I to XII indicating damage in an earthquake (Richter, 1958)

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Earthquakes that occur on well-defined tectonic plate boundaries are called interplate earthquakes and those which occur within a tectonic plate are called intraplate earthquakes (Johnston & Kanter, 1990; Richter, 1958; Wysession, et al., 1995). Intraplate earthquakes are generally less frequent (Gutenberg & Richter, 1954, 1956). Figure 1 shows a sample of the estimated range of a major intraplate event (Saint Louis University Earthquake Center (SLU), 2002) within the USA.

This type of event is always more damaging in intraplate regions than in interplate regions, except in some special circumstances (Nichols & Beavers, 2003). The Southern Missouri event, shown in the figure, would be probably felt from Chicago to New Orleans and would cause a significant local death toll. An earthquake kills more than 5,000 people on average every 900 days (Nichols & Beavers, 2003). The observation made by Nichols and Beavers in 2003 was that the number of fatal earthquakes per annum is increasing as the world's population increase. There is increased population density in urban areas with people migrating from rural areas to industrialized areas and population, which are exacerbating the rate of fatal earthquakes.

This thesis follows the style of *Adult Education Quarterly*.

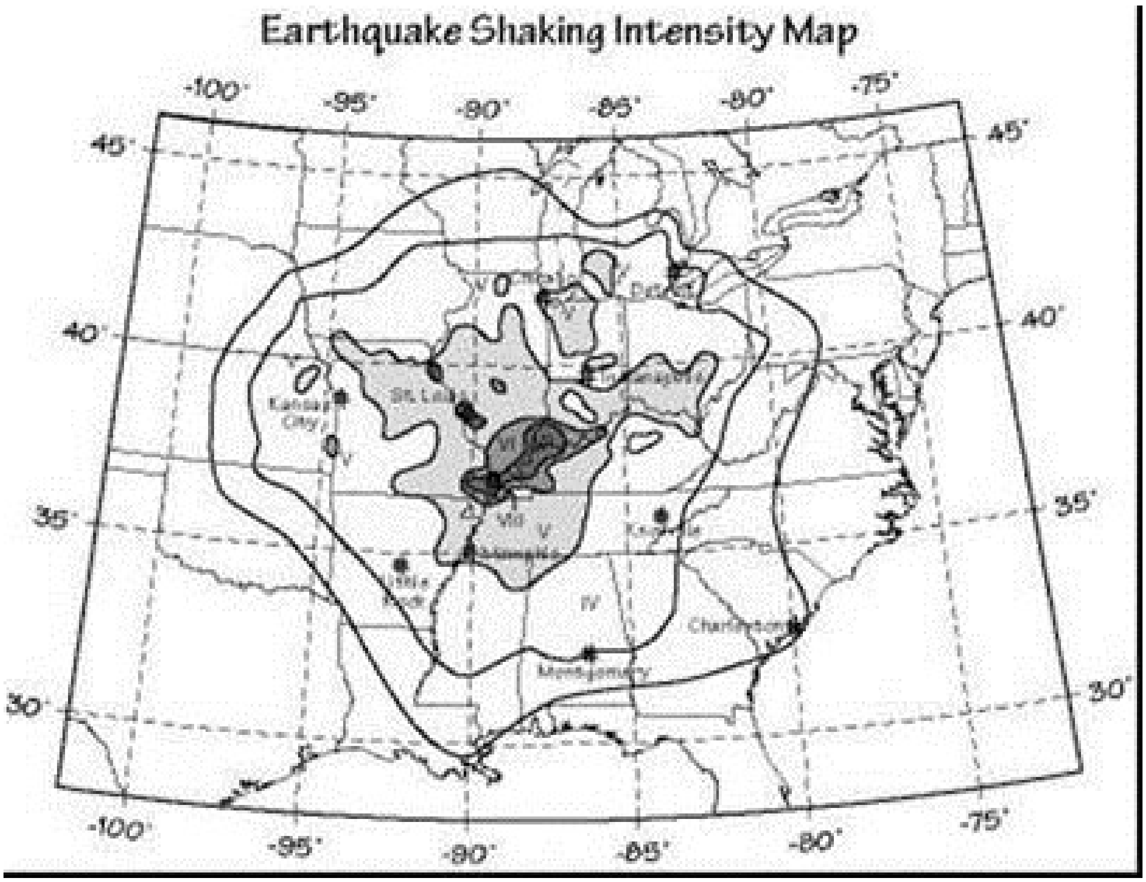

Figure 1 Earthquake intensity for a Southern Missouri event (after SLU, 2002)

The 20th century shows a fourfold increase in the world's population with a corresponding increase in the number of fatal events (J. M. Nichols & J. E. Beavers, 2008; U.S. Census Bureau, 1901, 1990, 1999, 2000).

A Generalized Poissonian distribution (GPD) model was developed to study deaths in earthquakes for the period 1900-1999 (P.C. Consul, 1989; P. C. Consul, 1993; J. M. Nichols & J. E. Beavers, 2008)). The model was used for analyzing the annual count of fatal earthquake events. This model has had limited use by the statistical community, except in the insurance industry. This type of model provides input to a non-stationary time based process and is useful for this type of data.

PROBLEM STATEMENT

The purposes of this thesis are to investigate the statistical difference between the set of interplate and intraplate fatal earthquake events and to update estimated parameters for the Generalized Poissonian distribution of fatal events.

The specific purposes of this research are:

1. Determine the difference in the statistical properties of the two sets of intraplate and interplate fatal earthquakes for the period of 2000-2010.
2. Establish the revised parameter for the Generalized Poissonian model for fatal earthquakes for the period 2000 - 2010.
3. Compare the results of the Generalized Poissonian model (GPD) parameters to the analysis completed for the twentieth century by others

RESEARCH OBJECTIVES

This research study has two objectives; the first is to update the Generalized Poissonian distribution data for the period 2000 to 2009. The second is to establish the statistical properties of the set of fatal earthquakes for the world, for the interplate region and intraplate region in the last decade and for the twentieth century.

This work has not been previously completed and represents a potential insight into the cost effectiveness of earthquake mitigation. The key hypothesis is that fatal interplate earthquakes occur at a higher rate than fatal intraplate events.

SIGNIFICANCE OF THE STUDY

To obtain a statistically significant analysis of the earthquake location and the fatality counts of the earthquakes ranging from year 2000 until 2009 over magnitude of 5.0. This would be achieved through spatial analysis of the locations of earthquakes plotted and the fatality count of each earthquake plotted with a buffer area on the map. The significance is to determine whether the current level of earthquake mitigation is reducing fatality counts.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This literature review outlines the development of the study of fatalities in earthquakes in the last century. The key research has been in the last two decades.

DEFINITIONS

These definitions are taken from the paper by Majmudar (2010):

1. Earthquake: An earthquake is the result of a sudden release of energy in the Earth's crust which produces seismic waves that can cause damage to man-made structures
2. Fault: A planar fracture or discontinuity across which there has been significant displacement
3. Hypocenter: The point where the fault begins to rupture
4. Epicenter: The point directly above hypocenter on the earth's surface
5. Types of Earthquakes: interplate and intraplate.
6. Interplate: Earthquake occurring at the tectonic plate boundaries
7. Intraplate: Earthquake occurring interior of the plate boundaries

HISTORICAL DATA

Kanamori and Anderson (1975) concluded that the intraplate earthquakes have higher stress drops compared to interplate earthquakes, but the study had an analysis of only the large earthquakes. According to Nichols and Beavers (2008), the number of recorded fatality counts was 1,010 in the twentieth century and in pre-twentieth was 729. The data from NOAA shows that two million people died in the twentieth century due to earthquakes with an annual average fatality rate of 20,000 people. The approximate mean fatalities in earthquakes for the twentieth century were around 4,500 with probability of death counts in excess of 100,000 deaths being 3.6% and 1.2% for a million deaths. A fata earthquake occurred on average every 33 days in the twentieth century.

The stress levels of the plate, along consuming plate boundaries, can be affected by the large interplate earthquakes (Mogi, 1969; Shimasaki, 1976). The stress drops for the intraplate earthquakes are about 6 times higher than interplate earthquakes, assuming the stress drop is proportional to the slip per unit area (Scholz, Aviles, & Wesnousky, 1986). This seems to indicate that the magnitude of intraplate earthquake is always higher than interplate earthquake thereby pointing to a possible larger death toll in intraplate earthquakes.

Matsuda (1967) stated that the recurrence time for large intraplate earthquakes on the same fault in Southwest Japan is estimated to be several or ten times longer than that of interplate earthquakes. According to Shimazaki (1976), once the local stress is released by an intraplate earthquake, it takes long time for the stress to build up to its crustal strength. Also, local stress is low in an area that experienced a great earthquake in recent times. This indicates that probability of occurrence of intraplate earthquake is lower when compared to interplate earthquake (Johnston & Kanter, 1990).

Gutenberg and Richter (1956) have indicated an increase in global seismicity around the start of the 20th century. Nuttli (1974) suggests that the lack of earthquake in central and eastern United States during the 20th century belies the current risk of an earthquake in the range of M 5.5 to M 7.

Deaths in earthquakes are recorded in the Bible (*The Holy Bible (King James Version)*, 1940). The Chinese have recorded earthquakes for a few thousand years (Lee, Wu, & Jacobsen, 1976). NOAA collects data on deaths, injuries and losses in earthquakes (NOAA, 2000). This study uses the NOAA data and published data to study fatalities in earthquakes.

Jones et al. (1993) summarized the methods used to estimate the fatalities in the earthquakes listing the estimated deaths and injuries in the Central and Eastern United States after researching the potential loss of life from the Memphis, TN earthquake.

Shiono (1995) completed the first extent study on deaths in an earthquake, specifically into the rate of fatalities with epicentral distance for the 1976 Tangshan event. Nichols et al., (2000) developed a fatality function in order to estimate fatality counts using a regression analysis technique. The fatality count function provides theoretical estimates of fatalities for an urban area. Nichols and Beavers (2003) summarize the results of this study by Tangshan and then move to study a number of other major fatal events. This group developed a variant model to that proposed by Shiono to allow for the discrete nature of the fatal earthquake data. Nichols and Beavers also discussed the issue of flawed and missing data from the fatal data set (Kuczera, 1994; J. M. Nichols & J. E. Beavers, 2008).

Figure 2 shows the conceptual ideas developed on the losses in fatal earthquakes. Whilst the damage is in part a continuum event, the counting becomes a discrete number problem. The assumption is that areas of uniform loss can be identified.

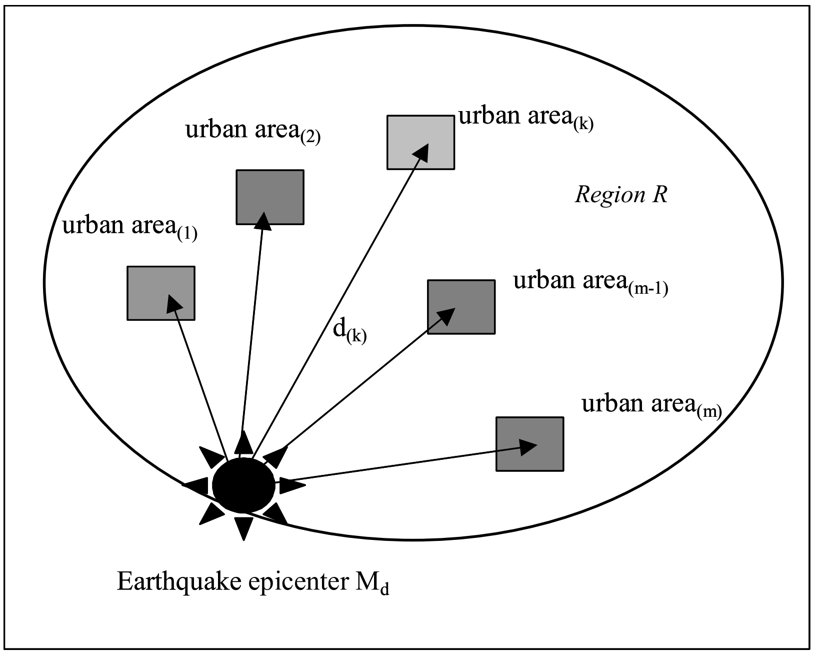

Figure 2 Modern urban areas subjected to earthquakes[1]

The statistical properties of world's recorded fatality data were investigated and fatality function was developed for the 1900-1999 period. Figure 3 shows the plot of the interesting events from the period 1800 to 1999, which was developed by Nichols and Beavers (2003). This plot presents a number of interesting features that are discussed in detail in their paper. This information is not repeated; merely the key points are summarized.

[1] Professor Nichols (personal communication September 2010) has given permission to use these figures from his previous work.

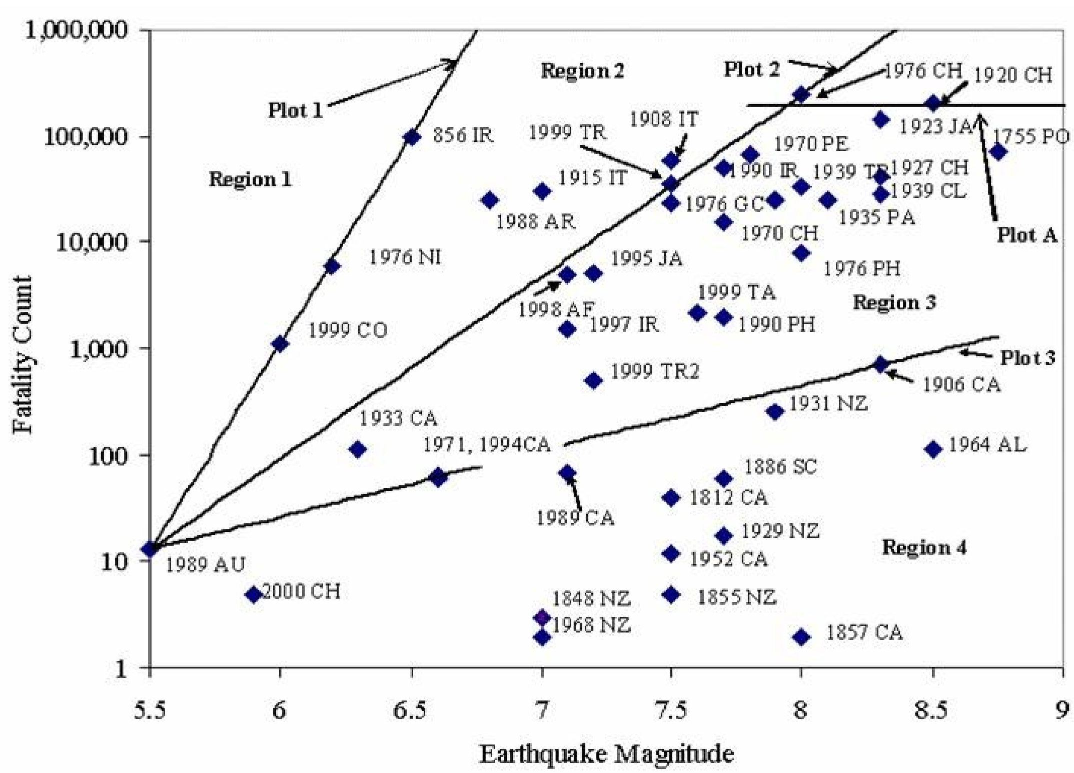

Figure 3 Earthquake fatalities and magnitude for the 20th century[2]

Region 4 represents the areas such as California and New Zealand that have frequent, but generally non-fatal or very low fatality events. The recent New Zealand earthquake of 2010 illustrates this issue. The early assumption in this work was there was no differentiation of interplate and intraplate earthquakes fatality rates. This early assumption by Nichols and Beavers (2008) is untested.

A Generalized Poissonian distribution (GPD) was developed to review the statistical properties of the fatal events during the 20th century. Consul (1989) developed the Generalized Poissonian distribution. As Nichols and Beavers noted in 2008:

[2] Professor Nichols (personal communication September 2010) has given permission to use these figures from his previous work.

"Three statistical techniques or methods are used in the analysis of the fatality data. After considering the fatality histograms against the normal and log-normal distributions, which both clearly fail to match the data, the first method is to determine the appropriate modified Power Series Distribution method to use for the analysis of the earthquake fatality count data. The form of a Power Series Distribution model is shown in equation (1):

$$p(x) = \frac{\alpha(x)[g(\theta)]^x}{f(\theta)} \quad x = 0,1,2...; \tag{1}$$

where $p(x)$ represents the probability function, α(x) represents a coefficient function in x, f(θ) is a parametric function, where θ >0 is an element of the parameter space, "Ω" . Ω is the radius of convergence of the power series f(θ) (Kocherlakota & Kocherlakota, 1992). The second method is linear regression and the third method is Fast Fourier transformation of linear regression residuals (Brigham, 1988)."

The National Oceanographic and Atmospheric Administration's list of earthquakes and fatality counts in these earthquakes from 2000 until 2009 was obtained for use in this study (NOAA, 2010). This data was obtained to continue the previous work of Nichols and Beavers whose research work had analyzed equivalent data for the period until 1999. The early work by Nichols and Beavers demonstrates that fatality data is best reviewed in terms of decades, rather than on an annual basis.

The NOAA data includes the date, time and location of latitude and longitude of each event. Unlike the assumption that was required to be made for the data prior to 1999 that the fatality set was censored because of reporting requirement issues, the current set is assumed to be complete. The key issue is not that a fatal event occurred, simply for the larger events confirming that the total count of deaths is accurate (Johnson, 2000; Nichols & Beavers, 2003). The data set also has a nominal magnitude of the earthquake with an estimated number of deaths.

Figure 3 shows an upper limit exists for the fatalities in earthquakes in the period before 2000. Nichols et al., (2000) developed a fatality function variation based on the loss model proposed by Shiono based on the available data from NOAA (2000) using the observations from the data in Figure 3.

Majmudar (2010) studied the rate of fatalities with the distance from epicentre using the 2001 Bhuj, Gujarat earthquake as a starting point. Figure 4 shows a typical failure from the Bhuj event. This failure must be considered to be a design failure and not a construction failure. He concluded that the lack of circular shear reinforcement in the columns is a design problem more than a construction problem, but was in essence a likely cause of the high fatality rate. The issue of liability and negligence in these matters is beyond the scope of this paper.

Figure 4 Column failure at 2001 Bhuj earthquake[3]

Nichols and Beavers (2003) postulated the bounding function, which is shown in the Figure 5. This fatality function was based in part on the 1915 Avezzano, Italy; 1886 Charleston, South Carolina; 1976 Tangshan, China; and 1931 Napier, NZ earthquakes.

[3] Majmudar (personal communication November 2010) has given permission to use these figures from his previous work.

The object was to identify the most savage events and determine if a function could be established to predict losses in other fatal earthquakes.

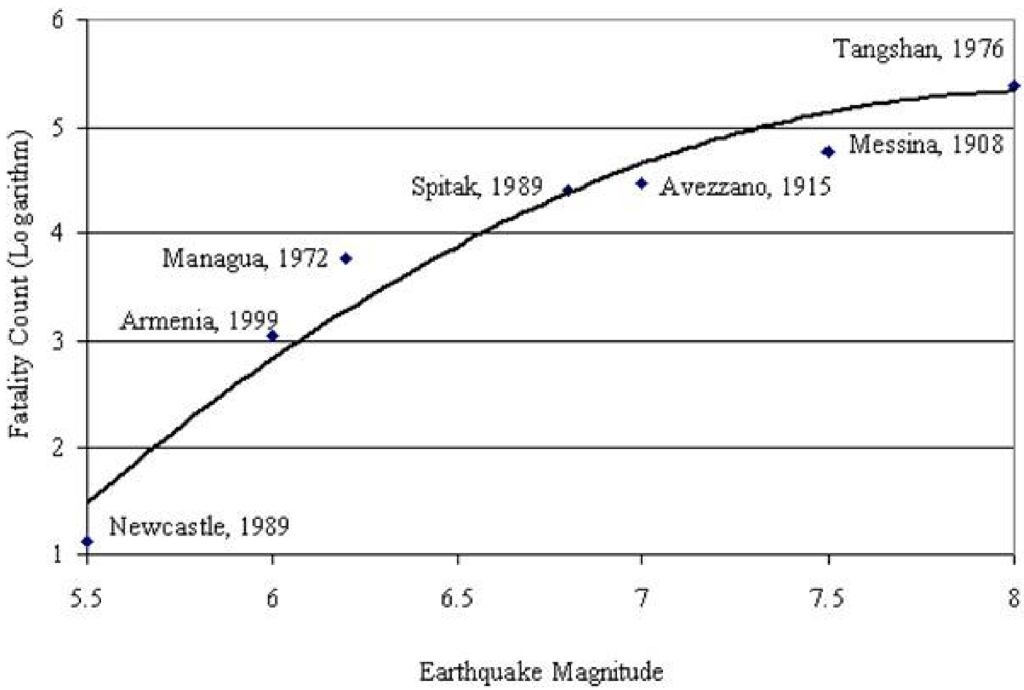

Figure 5 Bounding function development[4]

The fitted equation is given in Equation 1.

$$\log(\Xi_B(M)) = 9.335M - 0.577M^2 - 32.405 \quad (2)$$

As Nichols and Beavers developed the equation they observed that "The function has a regression coefficient of 0.95 for a fatality count of $\Xi_B(M)$ and an earthquake magnitude M . This interpolation function, $\Xi_B(M)$, provides a fatality estimate for an earthquake of magnitude M that can be used to predict the future losses in human terms

[4] Professor Nichols (personal communication September 2010) has given permission to use these figures from his previous work.

for specific earthquakes and conditions near or in an urban area. The lower bound is always zero deaths, which is the case for the vast majority of earthquakes and an earthquake magnitude.” Nichols and Beavers also developed an equation to relate potential fatalities in other “theoretical events” to the bounding function assuming five different multiplicative factors, with the critical factor for the research taken as “The fourth standard condition factor, λ_{four}.This factor relates the seismic intensity to a building collapse rate, and then fatality rate for each building type. The form of the equation relating the bounding function to an estimated fatalities is shown in equation (2).

$$\Xi_d(R, M_d) = \sum_{k=1}^{k=m} \prod_{i=1}^{i=n} \lambda_{i,k} \Xi_B(M_d) \tag{3}$$

where $\Xi_F(A)$ is the estimated fatality count for the specific circumstances of the event with a magnitude of M and a population area A, λ_i represents the series of standard condition factors that reduce the death count because of circumstances in each sub-region and n is the total number of factors This product function when determined for each subregion A_k can be summed over the m distinct homogenous areas that form a regional population centre A. i and k are the indices.”

The key work in this paper is to update the studies completed on the data up to 1999 to reflect the data obtained in the period 2000 to 2009. Nichols and Beavers (2003) had shown that the decade averaged data was normally distributed for the annual fatal earthquake counts, so that an analysis period of less than a decade is not warranted for this work.

SUMMARY

Significant work is now occurring into the study of deaths in earthquakes. However, the sad fact from the last decade is that the average annual total deaths in earthquakes in this period is double the twentieth century average. The average period between fata events has dropped from 33 days in the twentieth century to 8 days in this last decade. Large intraplate events, whilst rare are the key to the total losses in this century.

CHAPTER III

METHODOLOGY

INTRODUCTION

The research stages are:

1. To determine the population change in United States
2. To determine the areal extent of interplate and intraplate areas
3. Plot the earthquakes in ArcGIS
4. Analysis of the graphs plotted

DATA COLLECTION

The data required for the analysis of the earthquakes is taken from the National Oceanographic Atmospheric Administration website (NOAA, 2000, 2010). The data from NOAA contained redundant information, which was carefully removed and only unique earthquakes were kept in the data. The magnitude of 5.1 was taken as a base magnitude for considering fatal in this research topic, as no recorded fatal event has a lower threshold (BBC, 2002).

Population Data was obtained from the US Census Bureau (U.S. Census Bureau, 1901, 1990, 1999, 2000). The changes in population in the USA during the twentieth century provide guidance as to the likely world changes in the next fifty to one hundred years.

STAGES

Stage 1: Population Data for the United States

Stage 1 is to determine the population change that occurred from 1900, 1999 to 2009.

Stage 2: Areas of Interplate and Intraplate Earthquakes

Stage 2 is to determine the areal extent of interplate and intraplate areas on the world. This was done using the ArcGIS software.

Stage 3: Plotting in ArcGIS

The earthquakes that have a magnitude greater than 5.0 are chosen for this analysis, because there is no significant death toll recorded below this earthquake magnitude (BBC, 2002).

Stage 4: Analysis of Plotted Graphs

The data has been collected into an Excel spreadsheet from the GIS maps produced in the ArcGIS.

Stage 5: Data Analysis

Data analysis of the fatal events is done in this stage, including the Generalized Poissonian model.

CHAPTER IV

ANALYSIS

INTRODUCTION

This analysis is completed in five stages.

STAGE 1 POPULATION ANALYSIS

The population by each county for the United States of America is available in the census data for 1900, 1999 and in the estimated Census data of 2009 (U.S. Census Bureau, 1901, 1999, 2009). The plot of the data is shown in *Figure 6*.

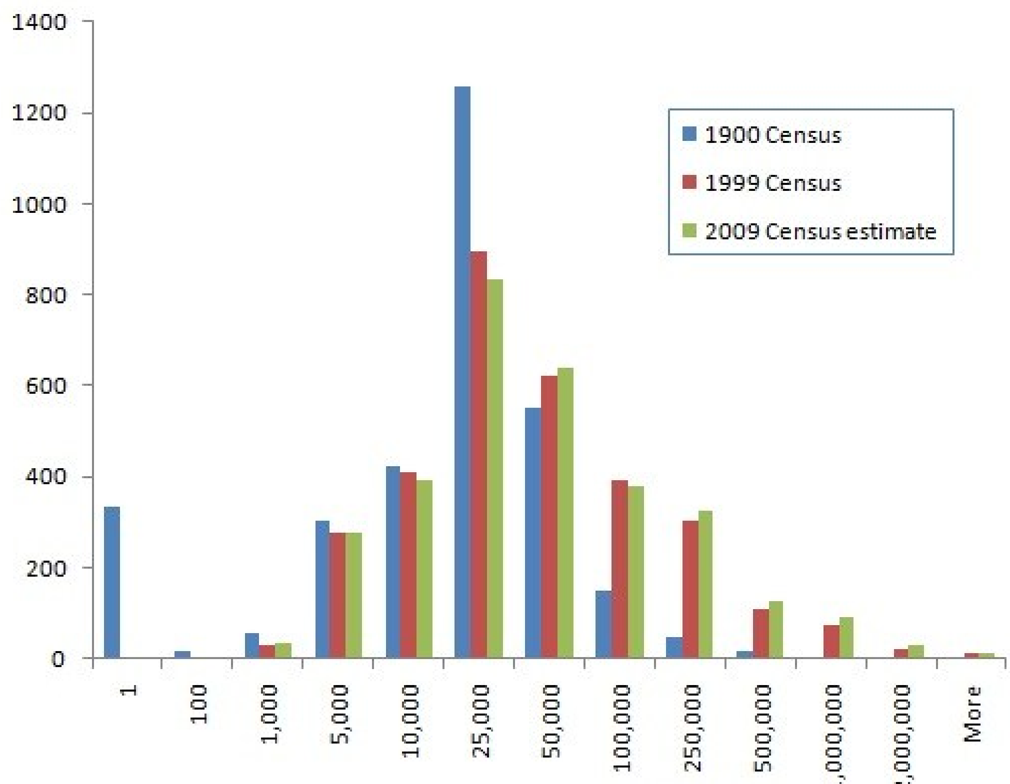

Figure 6 United States population grouped by county in 1900, 1999 and 2009

The distribution of county population from 1900 to 2009 shows that the number of counties with population over one million is more in 2009 compared to 1999 and 1900, clearly indicating the fact that the average counties population is increasing as the US population increases. Nichols and Beavers (2003) used this data in part to estimate the relationship between population size and number of annual fatal events. A direct linkage was shown to exist. The key population results in an increase in the number of fatal events. Thus it can be concluded that the extent to which an earthquake can cause social and economic in more than a few or many counties is increasing (Gutenberg & Richter, 1954; Johnston & Kanter, 1990; Jones, et al., 1993; Kotò, 1893; Nichols & Beavers, 2003; Richter, 1958). There are forty one counties in the United States with a population greater than 1 million. Table 1 shows the list of these counties, with populations greater than 3 million. Table 2 shows the counties with a population range of 1.3 to 3 million.

Table 1 *United States counties with more than 3 million residents*

County	State	Population	County Seat
Los Angeles County	California	9,848,011	Los Angeles
Cook County	Illinois	5,287,037	Chicago
Harris County	Texas	4,070,989	Houston
Maricopa County	Arizona	4,023,132	Phoenix
San Diego County	California	3,053,793	San Diego
Orange County	California	3,026,786	Santa Ana

Table 2 *United States counties with more than 1.3 million to 3 million residents*

County	State	Population	County Seat
Kings County	New York	2,567,098	Brooklyn
Miami-Dade County	Florida	2,478,745	Miami
Queens County	New York	2,306,712	Kew Gardens, Queens
Riverside County	California	2,125,440	Riverside
San Bernardino County	California	2,017,673	San Bernardino
Wayne County	Michigan	1,925,848	Detroit
King County	Washington	1,916,441	Seattle
Clark County	Nevada	1,902,834	Las Vegas
Tarrant County	Texas	1,789,900	Fort Worth
Santa Clara County	California	1,784,642	San Jose
Broward County	Florida	1,766,476	Fort Lauderdale
Bexar County	Texas	1,651,448	San Antonio
New York County	New York	1,629,054	Manhattan
Philadelphia County	Pennsylvania	1,547,297	Philadelphia
Suffolk County	New York	1,518,475	Riverhead
Middlesex County	Massachusetts	1,505,006	Cambridge and Lowell
Alameda County	California	1,491,482	Oakland
Sacramento County	California	1,400,949	Sacramento
Bronx County	New York	1,397,287	The Bronx
Nassau County	New York	1,357,429	Mineola

Table 3 shows the US counties with a population range of 1.0 to 1.3 million residents.

Table 3 *United States counties with a population range of 1.0 to 1.3 million.*

County	State	Population	County Seat
Palm Beach County	Florida	1,279,950	West Palm Beach
Cuyahoga County	Ohio	1,275,709	Cleveland
Allegheny County	Pennsylvania	1,218,494	Pittsburgh
Oakland County	Michigan	1,205,508	Pontiac
Hillsborough County	Florida	1,195,317	Tampa
Hennepin County	Minnesota	1,156,212	Minneapolis
Franklin County	Ohio	1,150,122	Columbus
Orange County	Florida	1,086,480	Orlando
Contra Costa County	California	1,041,274	Martinez
Fairfax County	Virginia	1,037,605	Fairfax
Salt Lake County	Utah	1,034,989	Salt Lake City
Fulton County	Georgia	1,033,756	Atlanta
Travis County	Texas	1,026,158	Austin
Pima County	Arizona	1,020,200	Tucson

The number of counties with population over one million has increased from 32 to 41. There is a clear picture of an increasing level of urbanization from 1900 to 2000 and this has apparently continued in this last decade. A large earthquake can affect several counties, to be within the fatal meizoseismal area as is clearly shown on Figure 1.

STAGE 2: AREAS OF INTERPLATE AND INTRAPLATE EARTHQUAKES

Stage 2 is to determine the areal extent of interplate and intraplate areas on the world's surface. This was done using the ArcGIS software (Krivoruchko, 2011). The exact latitude and longitude location of the earthquakes that occurred during 2000 to 2009 were plotted on a world map in ArcGIS 9.3 from the NOAA data.

The tectonic plate coordinates were taken and plotted in ArcGIS software, to determine the tectonic plate boundary area. The intra-plate boundaries are defined according to the locations suggested at 2 degrees outside the plate boundary for intraplate events (Wysession, et al., 1995). Johnston and Kanter (1990) also provide a check on the assumption of two degrees from the plate boundary. Once the tectonic plate boundaries are plotted in Geographic Information system software, the boundary area also was plotted in ArcGIS defining the 2 degree area on either side of plate boundary.

Figure 7 shows the inter-plate and intra-plate boundary regions. The red line indicates the tectonic plate boundary and the green buffer area corresponding to the line is the interplate boundary area.

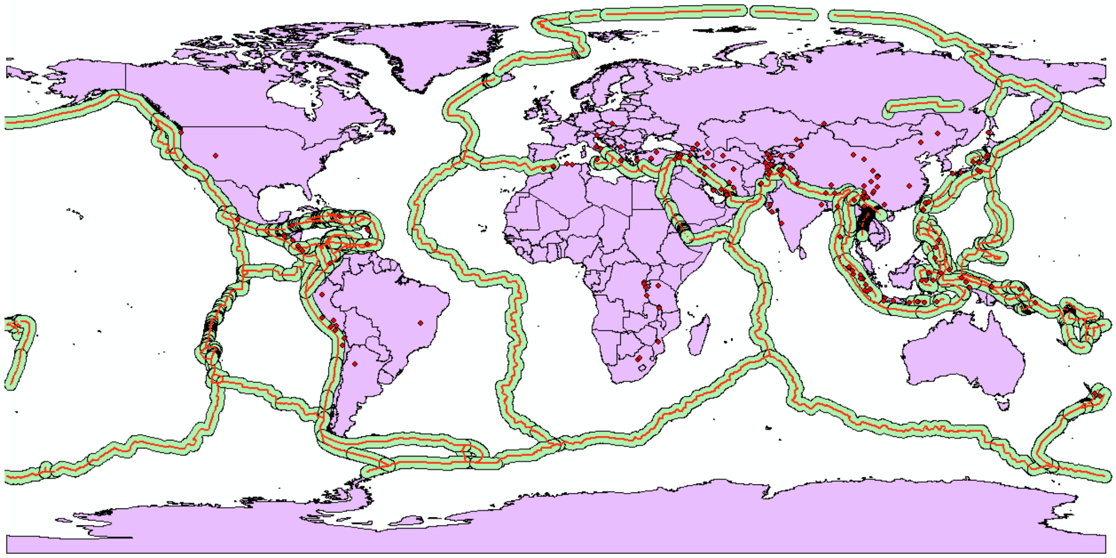

Figure 7 Tectonic plates with inter and intraplate areas

The area outside the green buffer region is the intraplate area. Figure 7 shows that most of the world is intraplate. Further work is required on the two degree definition.

STAGE 3: PLOTTING IN ARCGIS

The earthquakes that have a magnitude greater than 5.0 are chosen for this analysis, because there is no significant death toll recorded below this earthquake magnitude (BBC, 2002). The latitude and longitude of all fatal and non-fatal earthquakes were obtained from USGS data and plotted on the digital map.

Figure 8 shows all the earthquakes recorded by USGS, which are above the magnitude of 5.0 for the period 2000 to 2009. 86.18 % of the earthquakes occur on the boundaries.

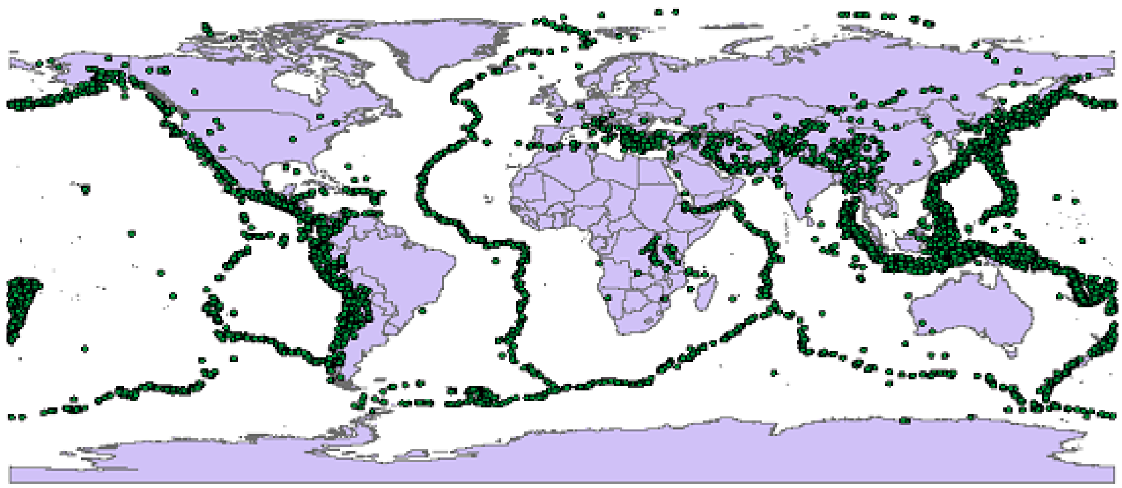

Figure 8 Earthquakes above magnitude 5.0 (USGS)

Figure *9* shows the location interplate earthquakes taken from USGS database. The highlighted blue points on the map are the interplate earthquakes that fall in the buffer region, which is the interplate region generated according to the two degree definition (U.S. Geological Survey, 2011; Wysession, et al., 1995).

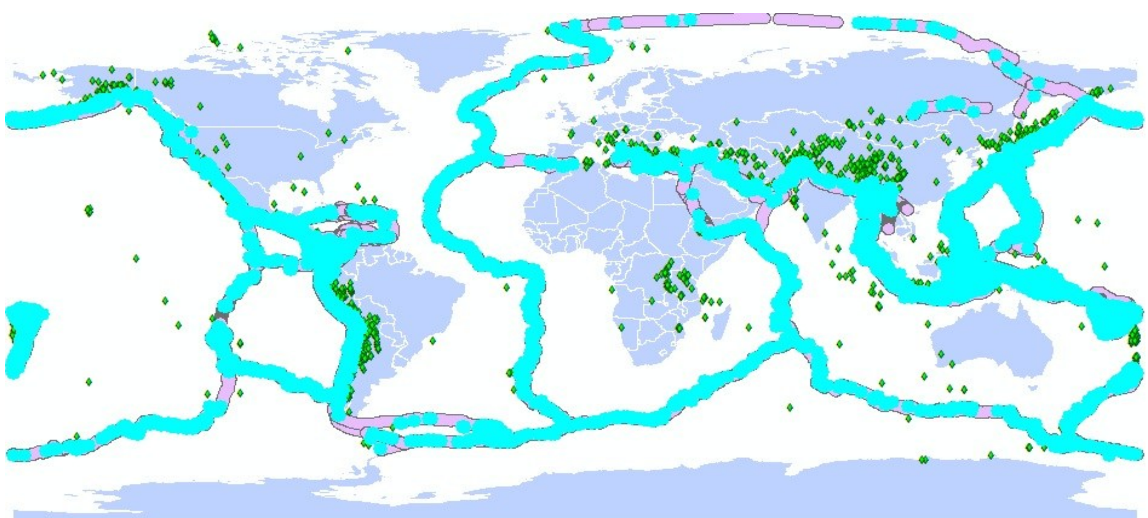

Figure 9 USGS interplate earthquakes (2000-2009)

The analysis from this data shows that there are 11658 and 1869 interplate and intraplate earthquakes above 5.0 respectively in the last decade. The interplate earthquakes occur 6.23 times as frequently as the intraplate. On average there are 22.4 interplate events per week or about 3 per day, whereas for the intraplate events there are 3.6 per week or about one every two days. A summary of this data is presented in Appendix A.

Figure 10 shows the intraplate earthquakes, which are highlighted in blue on the map. The earthquake data was obtained from USGS database of earthquakes (2001, 2011).

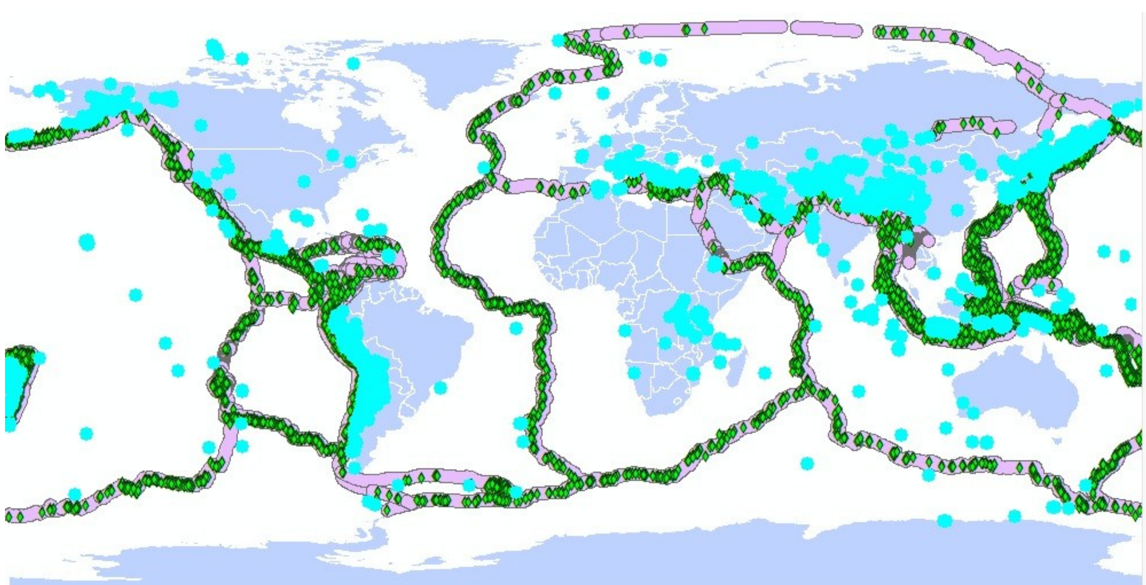

Figure 10 USGS intraplate earthquakes (2000-2009)

Figure 11 shows the fatal interplate events that lie inside the buffer region and are highlighted in blue. The NOAA data is shown on this figure (NOAA, 2000, 2010). These recorded NOAA events cover damage, injury and fatality data.

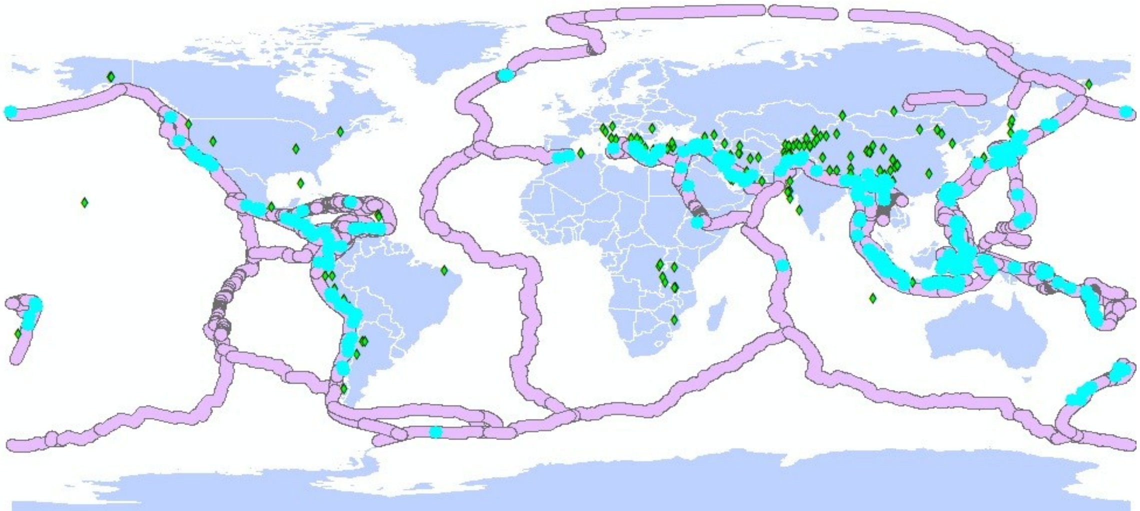

Figure 11 NOAA recorded events interplate (2000-2009)

The Figure 12 shows the fatal intraplate events that occurred this decade. Again, the data for this figure was obtained from NOAA.

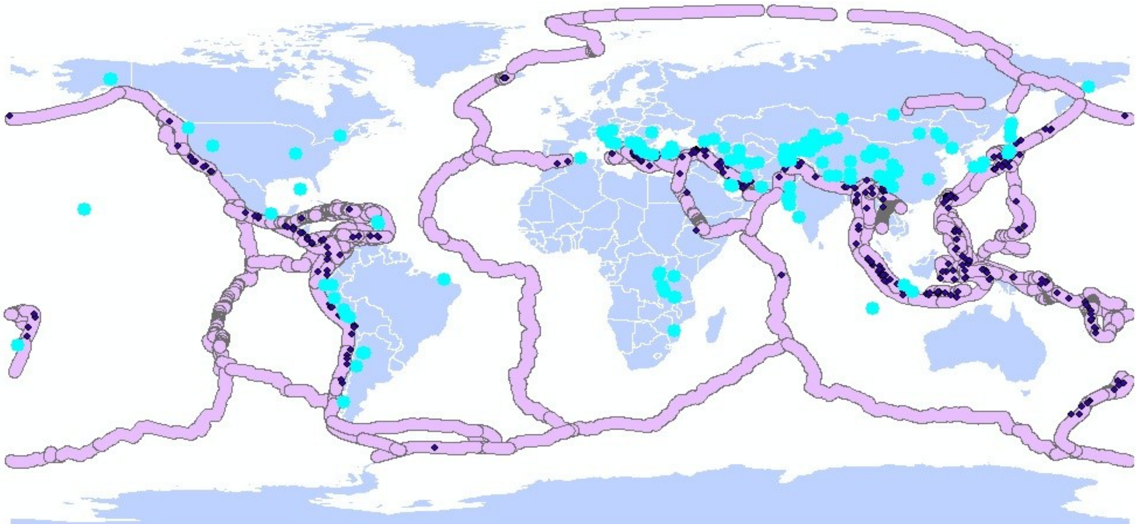

Figure 12 NOAA recorded events fatal intraplate (2000-2009)

Figure 13 deals with all of the recorded earthquake events that caused death, which occurred from 2000-2009.

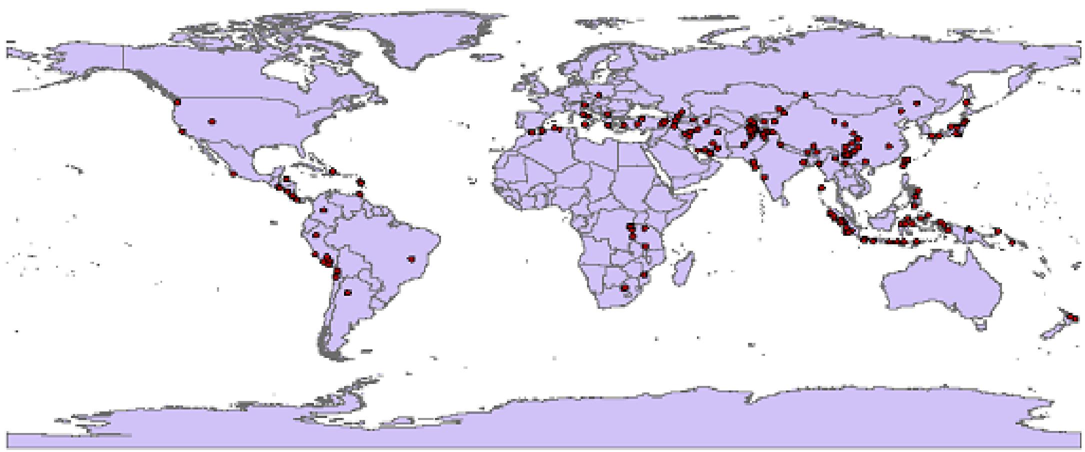

Figure 13 Earthquakes death events (NOAA)

Figure *14* shows the sites of the earthquakes that caused fatalities and the earthquakes that caused damage to the property.

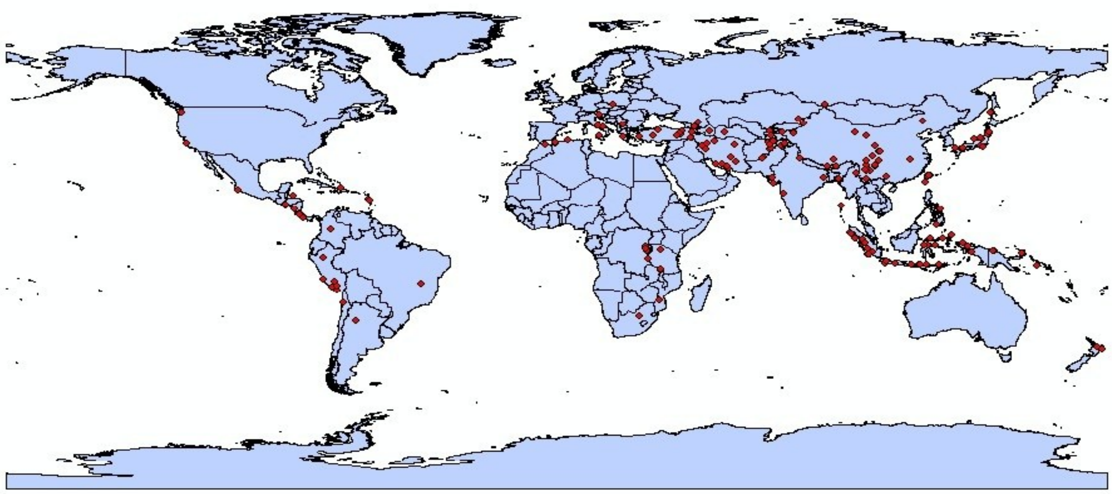

Figure 14 Damage and death events (NOAA)

In summary, the analysis from this data shows that there are 11658 and 1869 interplate and intraplate earthquakes above 5.0 respectively in the last decade. The interplate earthquakes occur 6.23 times as frequently as the intraplate. On average there are 22.4 interplate events per week or about 3 per day, whereas for the intraplate events there are 3.6 per week or about one every two days. The figure shows the issue of the fatal corridor from Indonesia to Italy, which has been a persistent loss area for the human population for a long time. Some losses also occur along the western perimeter of the Americas.

STAGE 4: ANALYSIS OF PLOTTED GRAPHS

The data has been collected into an Excel spreadsheet from the GIS maps produced in the ArcGIS. The table on page 53 shows the number of deaths for each magnitude of earthquake above 5.0 magnitude. The graph of the magnitude of earthquake and the number of fatalities in each event is shown in Figure 15.

Figure 15 is consistent with the data obtained by Nichols and Beavers (2003) for the period 1900 to 1999. A linear regression equation exists for this data and shows a weak relationship with an R^2 of 0.27. The simple conclusion is increasing size of earthquake may increase the death toll.

Figure 16 shows the interplate death toll events.

Three events are significant in this data accounting for most of the interplate death tolls.

Figure 17 shows the fatal intraplate events death toll for the last decade. There is a clear difference in the form of the two data sets from interplate to intraplate, which confirms the observations made by Nichols and Beavers in 2003.

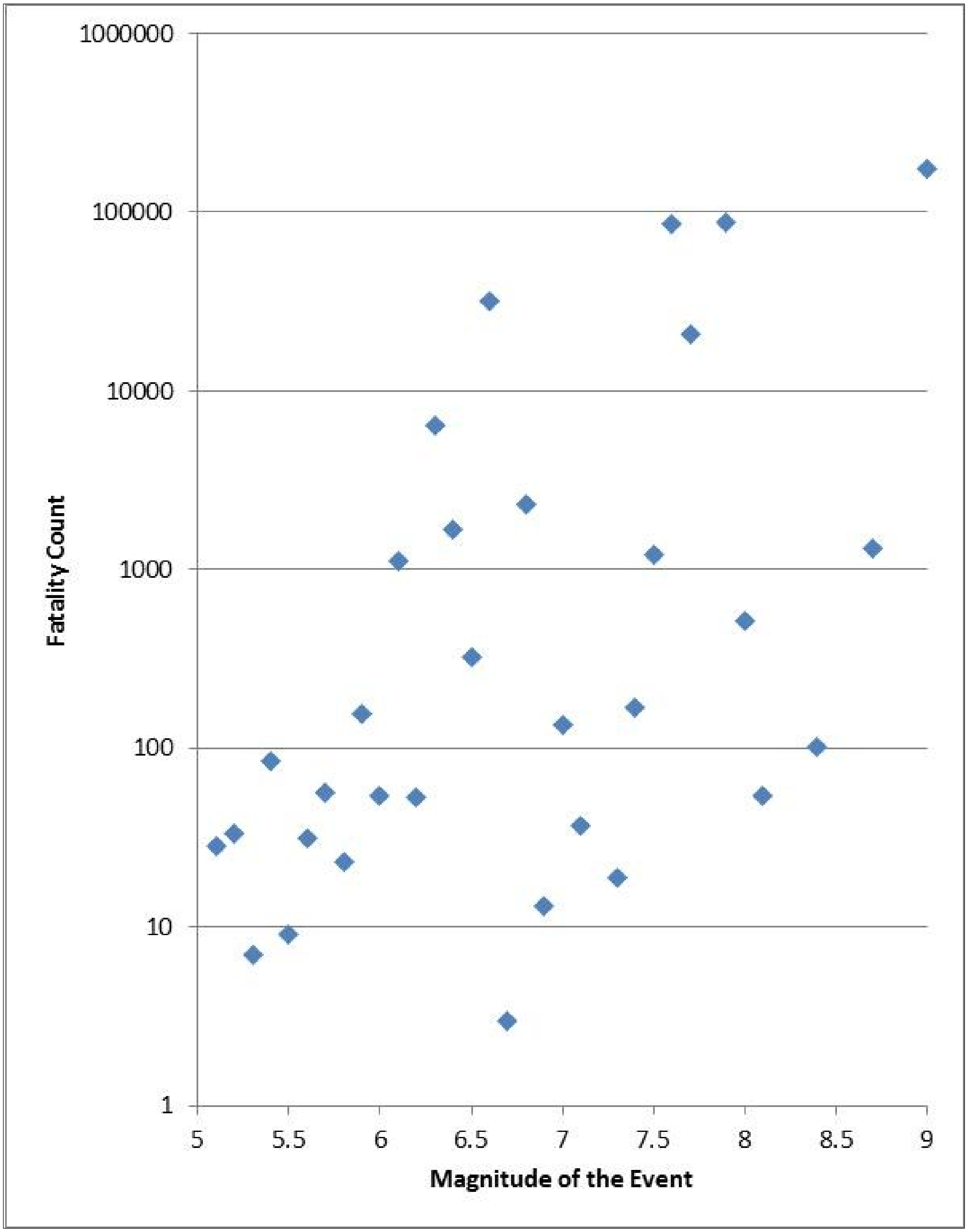

Figure 15 Total fatal count for earthquakes in period 2000 to 2009

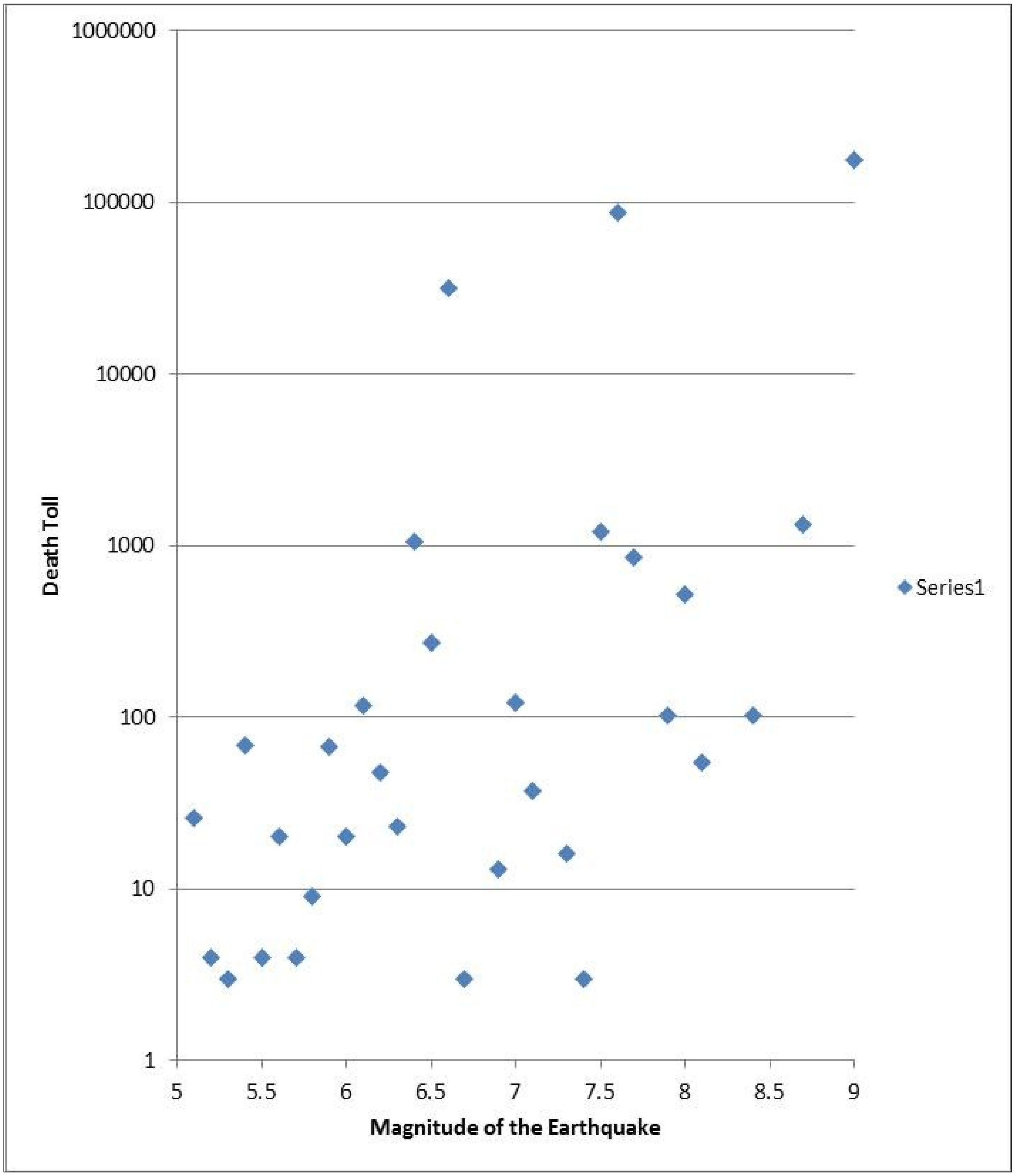

Figure 16 Interplate death toll events

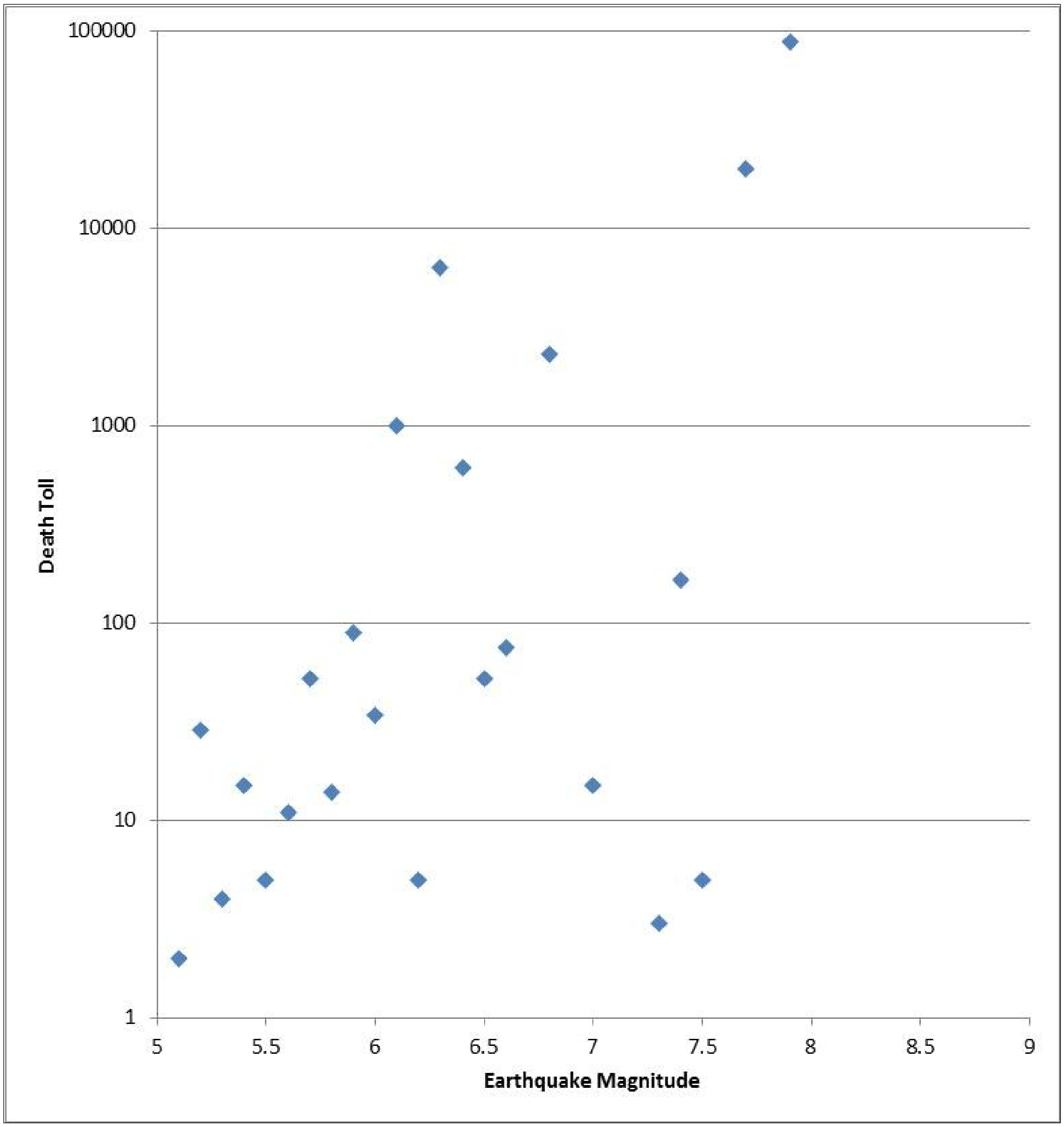

Figure 17 Intraplate fatal events

Figure 18 shows the revised bounding function for the largest events for each given earthquake magnitude. The average difference between 1900 to 1999 and the 2000 to 2009 data is an eleven percent increase.

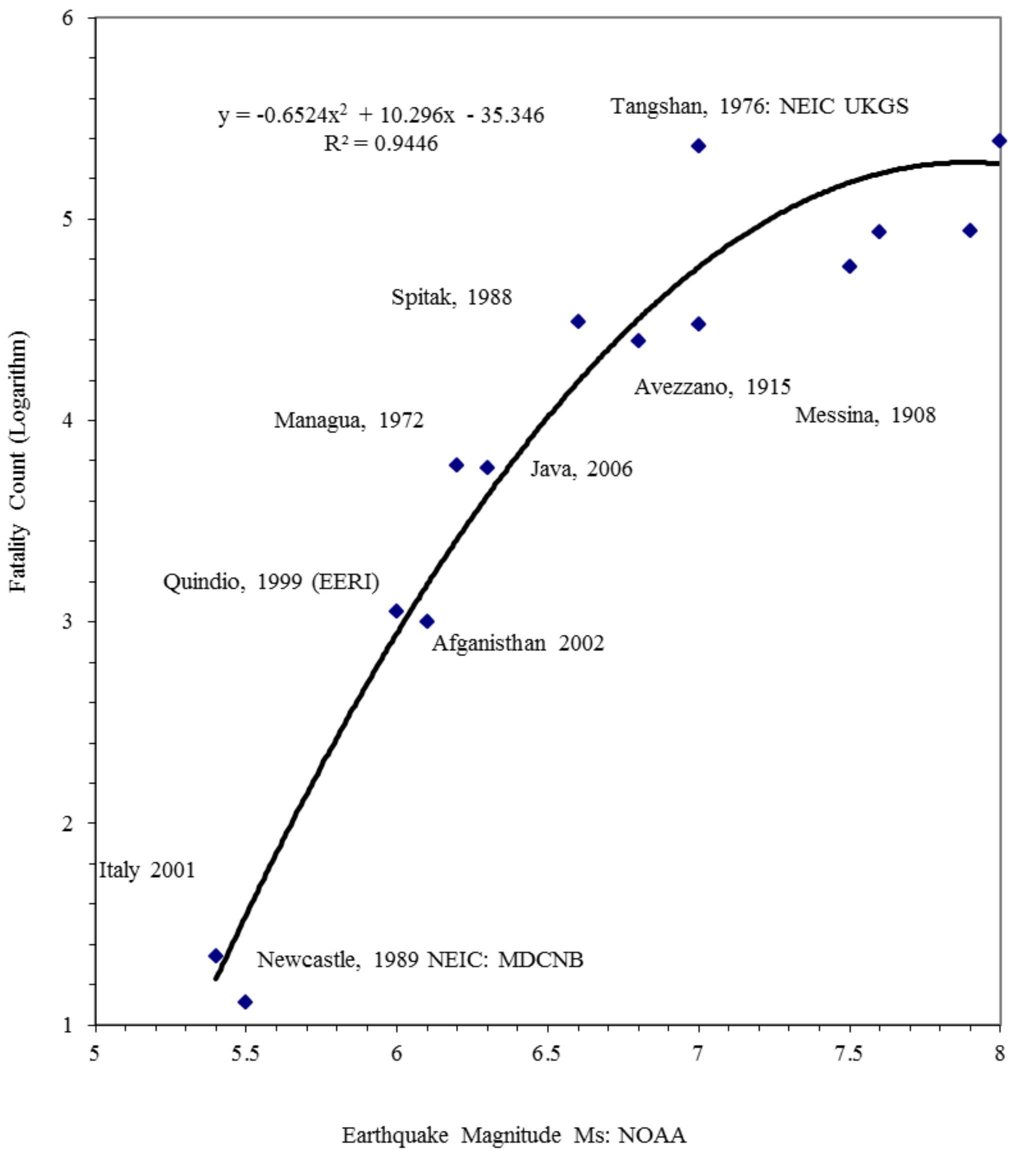

Figure 18 Revised bounding function

The graphs of death toll and earthquake count is also plotted from the interplate and intraplate earthquake data collected from ArcGIS based on the boundary defined by Wysession (1995) is shown on Figure 19.

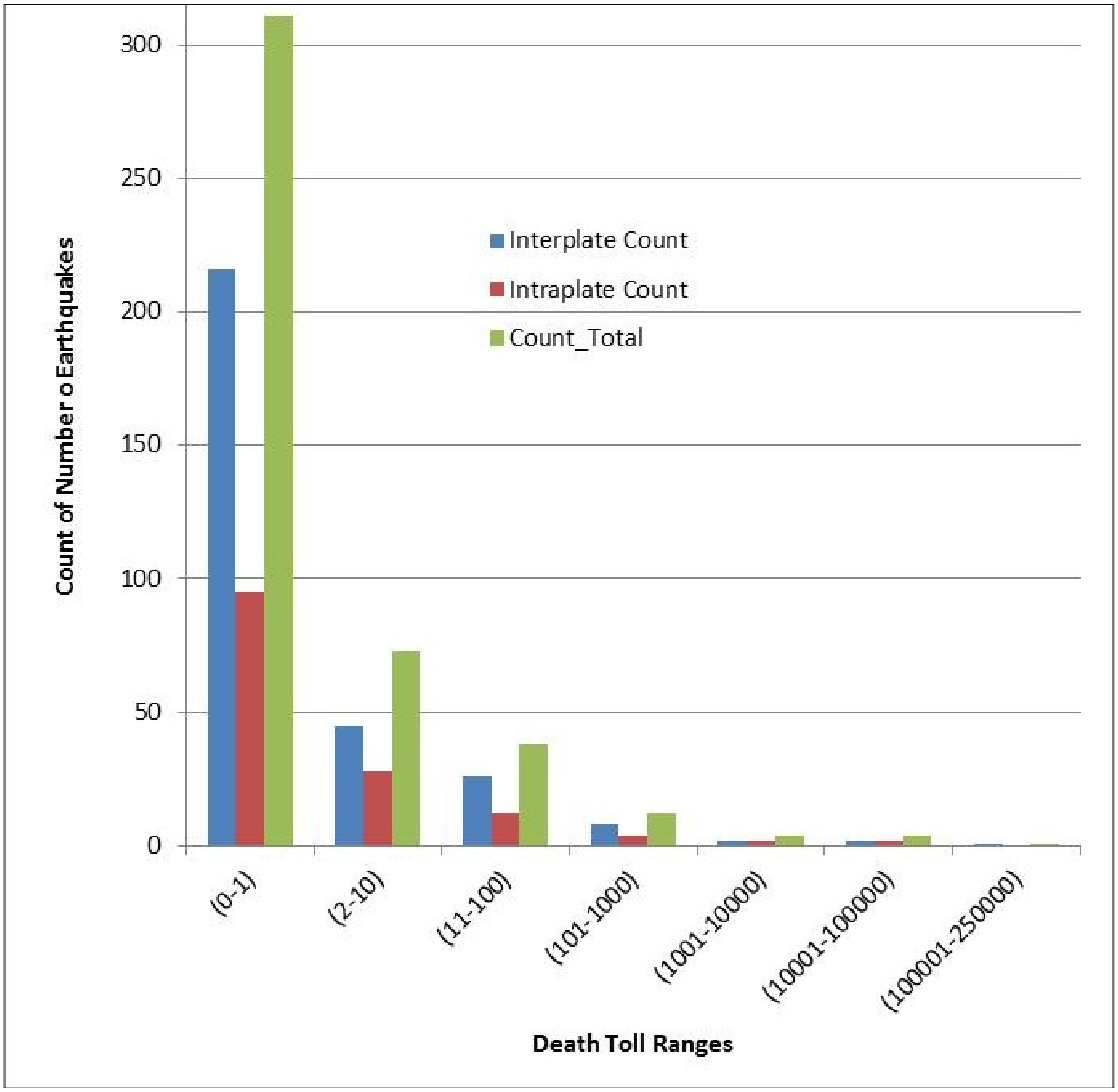

Figure 19 Count of deaths for fatal earthquakes

This graph shows that the interplate earthquakes have a higher number of earthquake events for the given range of death toll when compared to intraplate earthquake events. This data is presented in Appendix A.

Figure 20 shows a plot of the logarithm of count of earthquakes and a log of magnitude of earthquakes.

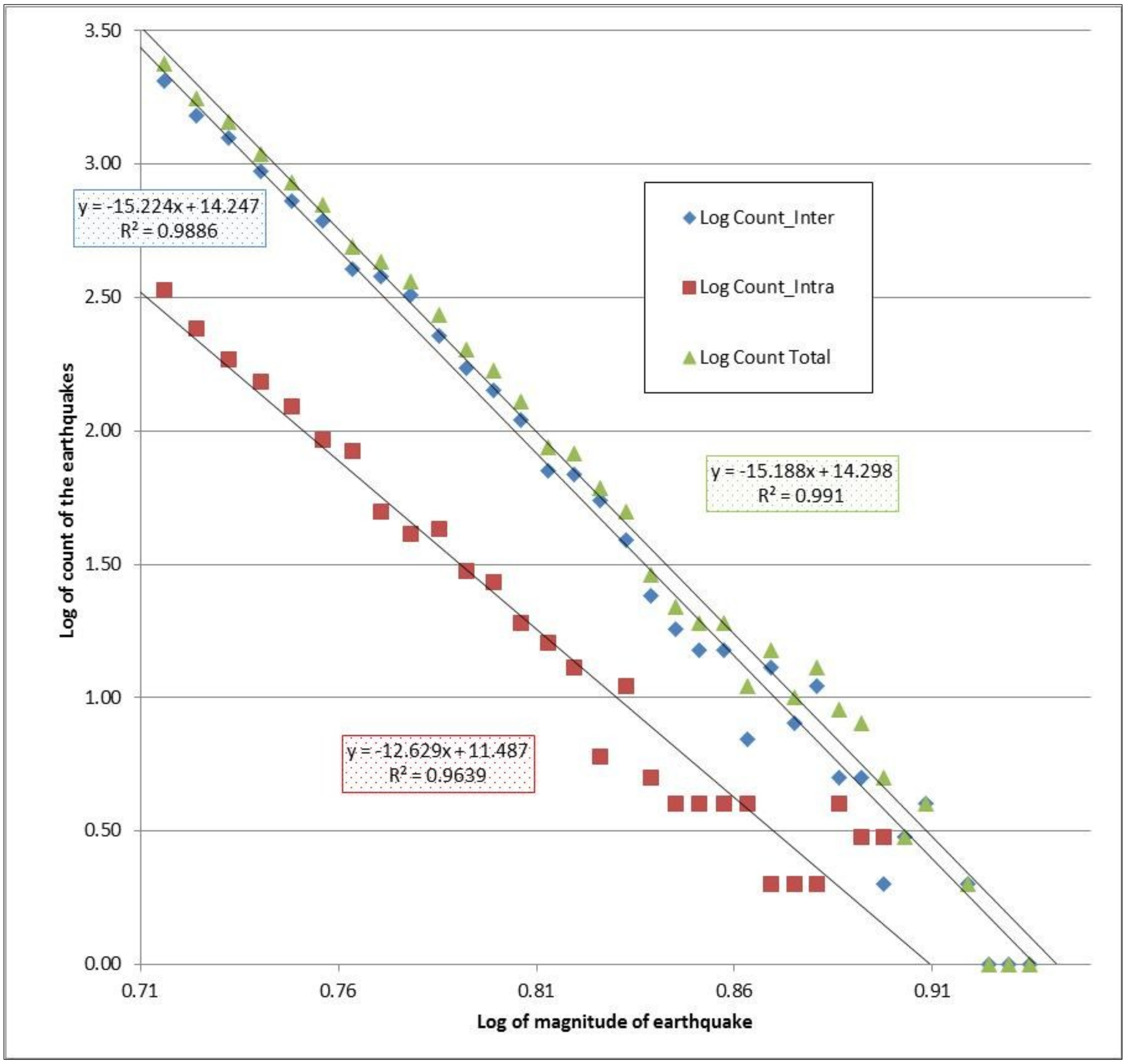

Figure 20 Log to log plots of magnitude to count

This data clearly matches the observations by Gutenberg and Richter (1954, 1956).

STAGE 5 DATA ANALYSIS

Nichols and Beavers (2003) observed that the number of fatal events was rising with time. This analysis has been repeated for the period 1870 to 2009 using their technique. Figure 21 shows the number of fatal events per year. Nichols (personal communication, 2010) had postulated that it might rise slightly during this decade. However, it has jumped up sharply.

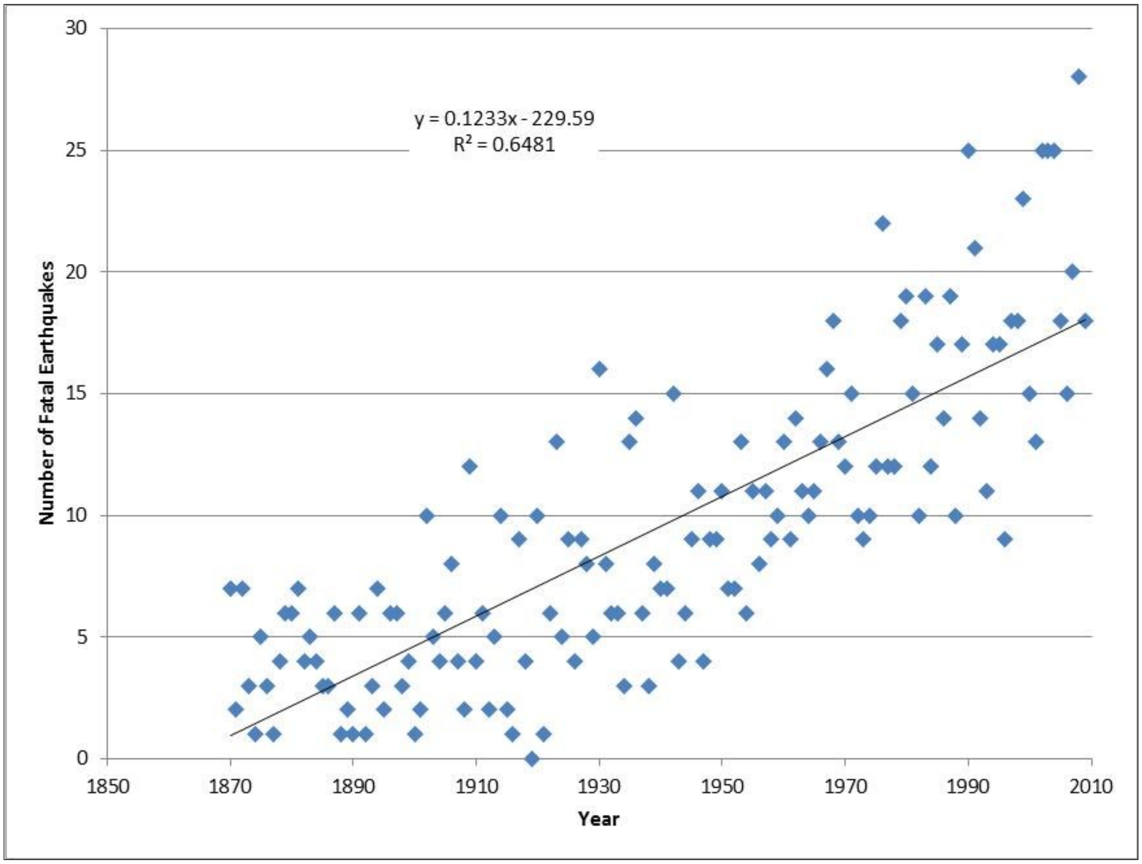

Figure 21 Number of fatal events per year

Figure 22 shows the three year moving average for the fatal events. The trend line on the three year data has a higher regression coefficient, indicating that the annual fatal count has an underlying functional relationship as identified by the previous research team that extends past the annual count data.

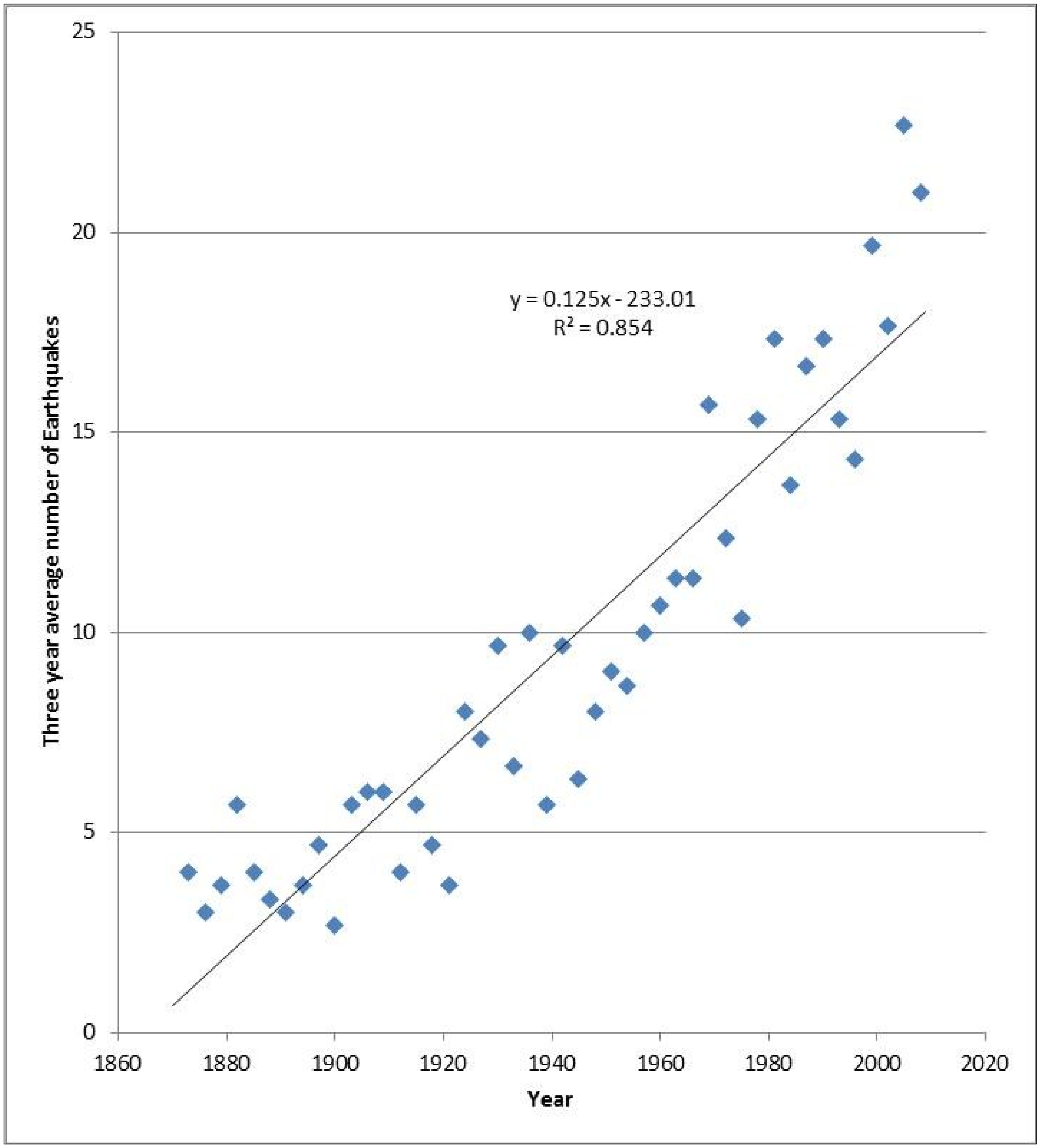

Figure 22 Three year moving average for fatal events

Figure 23 shows the decade averaged data. This has a high regression coefficient as previously demonstrated by Nichols and Beavers (2003).

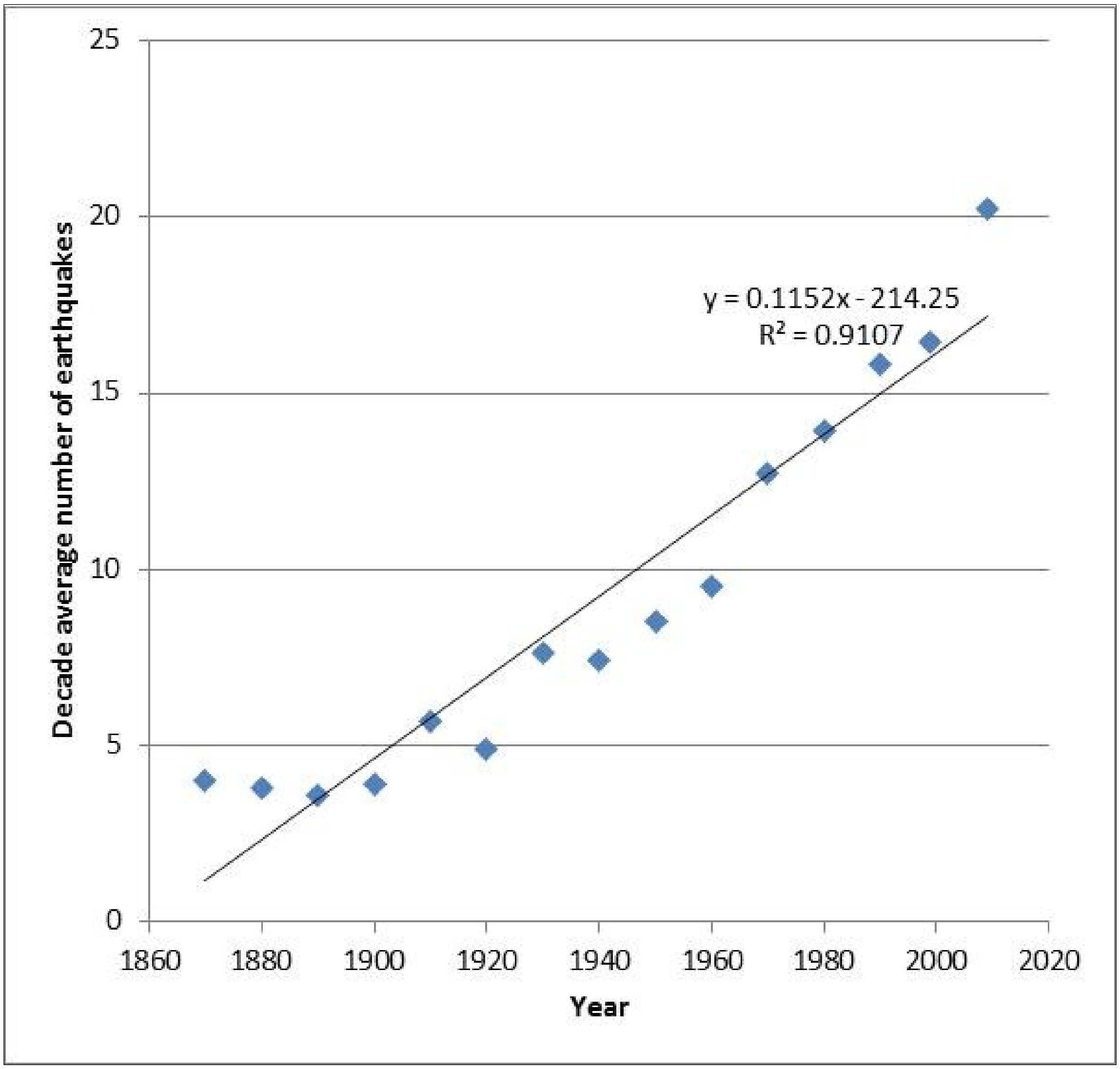

Figure 23 Decade averaged data for fatal events

The pre 1950s, post 1950s and the last decade (2000-2009) data has been analysed to show the difference in distribution of the histograms for the number of fatal counts per year in these three periods. Figure 24 shows this data plotted against the period 1900 to 1949 and 1950 to 1999.

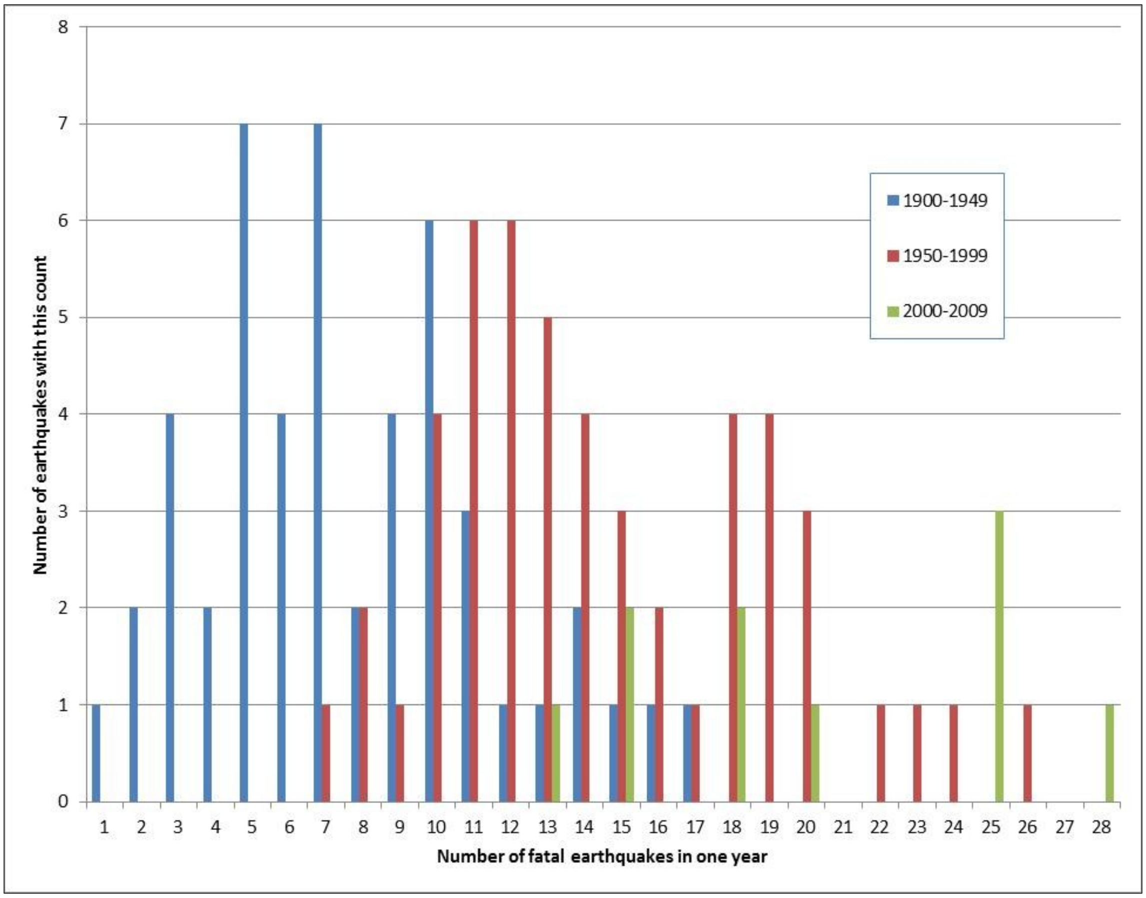

Figure 24 Histograms of the annual fatal earthquake counts for the pre, post 1950s and last decade

Histograms of the Annual Fatal Earthquake Counts for the pre, post 1950s and last decade clearly shows a movement in the fatal events. This trend is exceedingly worrying.

Table 4 shows the slope and the R^2 value of the equations developed by Nichols and Beavers (2008) and also the changed values of the slope and R^2 when the data for the last decade is added to the analysis of the earthquakes. The annual, Three year and Decade average R^2 are increasing indicating that the proper time period for doing an analysis for earthquakes is a decade, henceforth the decade data after year 1999 is chosen for the analysis.

Table 4 *Linear regression results for the count of fatal earthquakes*

		a		b	
Average in Period	Year from :to	Slope on the linear regression equation (earthquakes per annum) Nichols and Beavers (2008)	Regression co-efficient R^2 Nichols and Beavers (2008)	Changed Slope on the linear regression equation (earthquakes per annum)	Changed Regression co-efficient R^2
Annual	1870 to 1999	0.414	0.030	0.123	0.648
Three year	1870 to 1999	0.115	0.839	0.125	0.854
Decade	1870 to 1999	0.105	0.913	0.115	0.911

The next step in the data analysis is the probability analysis. The Generalized Poissonian Distribution Analysis for the pre 2000 data is shown in Figure 25 (J. M. Nichols & J. E. Beavers, 2008). The GPD data has a Θ has value of 2.2 and the Λ has a value of -0.11. The Λ represents the change rate in the distribution.

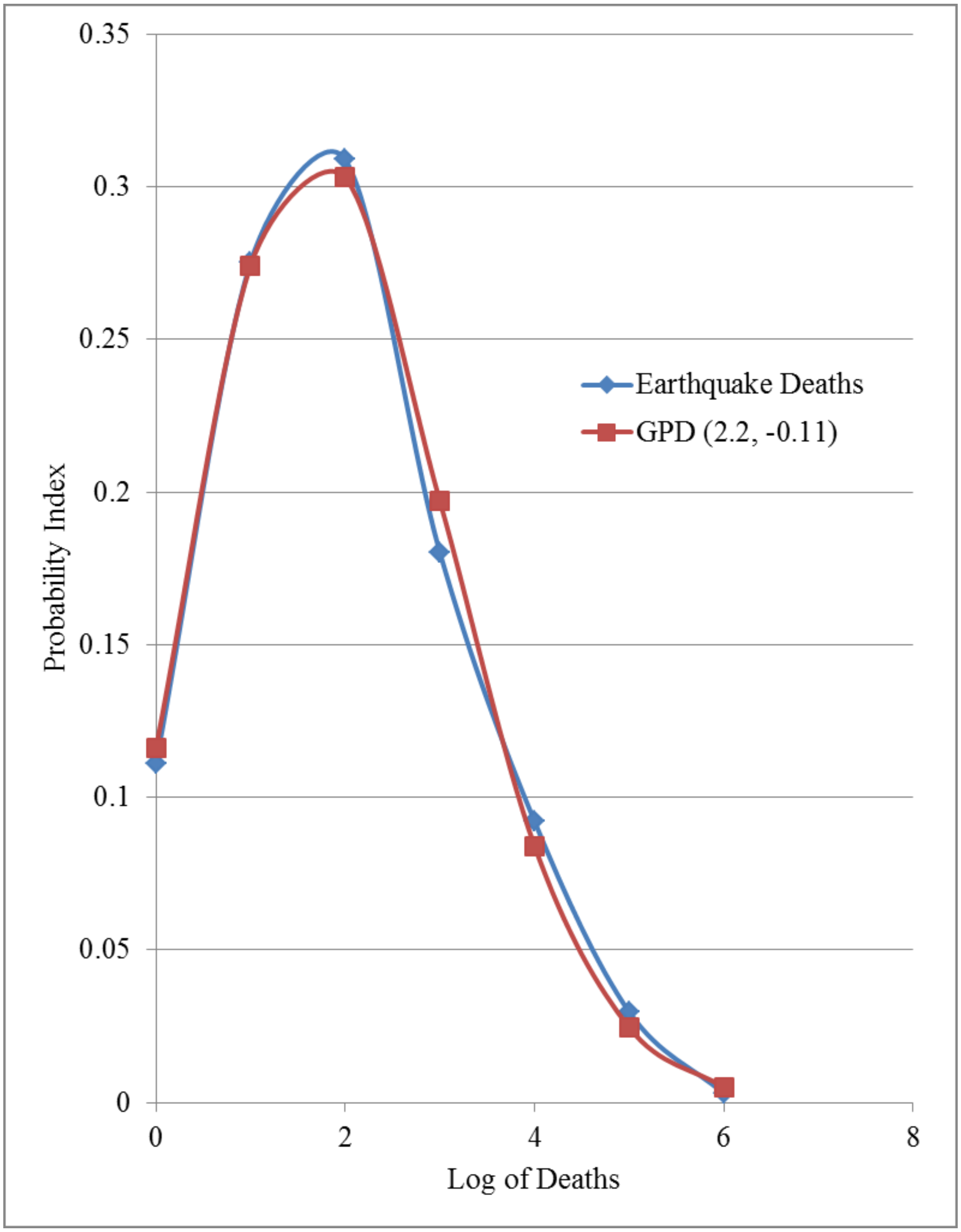

Figure 25 Twentieth century earthquake death statistical analysis

Table 5 shows the Poisson mean and the earthquake distribution for the different ranges of fatalities. The Poisson distribution has a mean of 1.2 and the corresponding

Figure 26 Distribution of the fatal events for the period 1900- shows the distribution of earthquake data from this decade and also for the Poisson distribution.

Table 5 shows the distribution data for the last decade for fatal earthquakes and the data from 1900 to 2009.

Table 5 *Earthquake distribution table for the period of 2000-2009*

Fatality Count (Deaths)	Log of the Fatality Count	Number of earthquakes last decade	Probability Distribution Last Decade	Deaths 1900 to 2009	Probability Distribution 1900 to 2009
1	0	43	0.245	155	0.130
10	1	73	0.417	351	0.296
100	2	38	0.217	350	0.295
1,000	3	12	0.068	194	0.163
10,000	4	4	0.022	97	0.081
100,000	5	4	0.022	34	0.028
1,000,000	6	1	0.005	4	0.0033
Total		175	1	1185	1

Figure 26 shows the distribution of the earthquake data for the decade of 1900 - 1999. The GPD data has a Θ has value of 2.2 and the Λ has a value of -0.11. The Λ represents the change rate in the distribution. The results show a θ of 2.2 and a λ of -0.11. This result shows the Poissonian data is not from a steady state process.

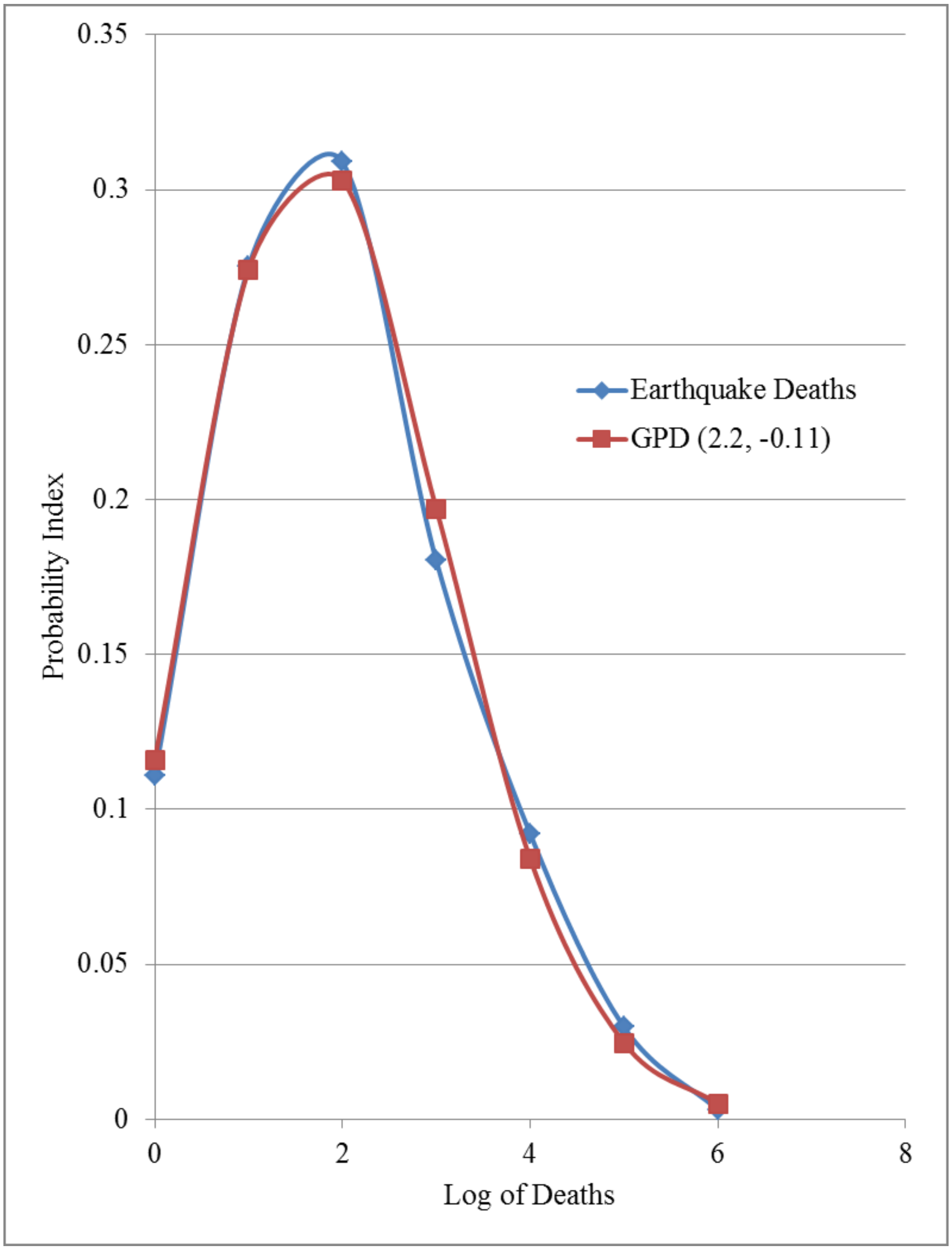

Figure 26 Distribution of the fatal events for the period 1900-1999

The GPD analysis for the data for the last decade is shown in Figure 27. The short data period does have problems in the ten bin, but the GPD fit is better than the Poisson Fit. The GPD data has a Θ has value of 1.26 and the Λ has a value of 0.02.

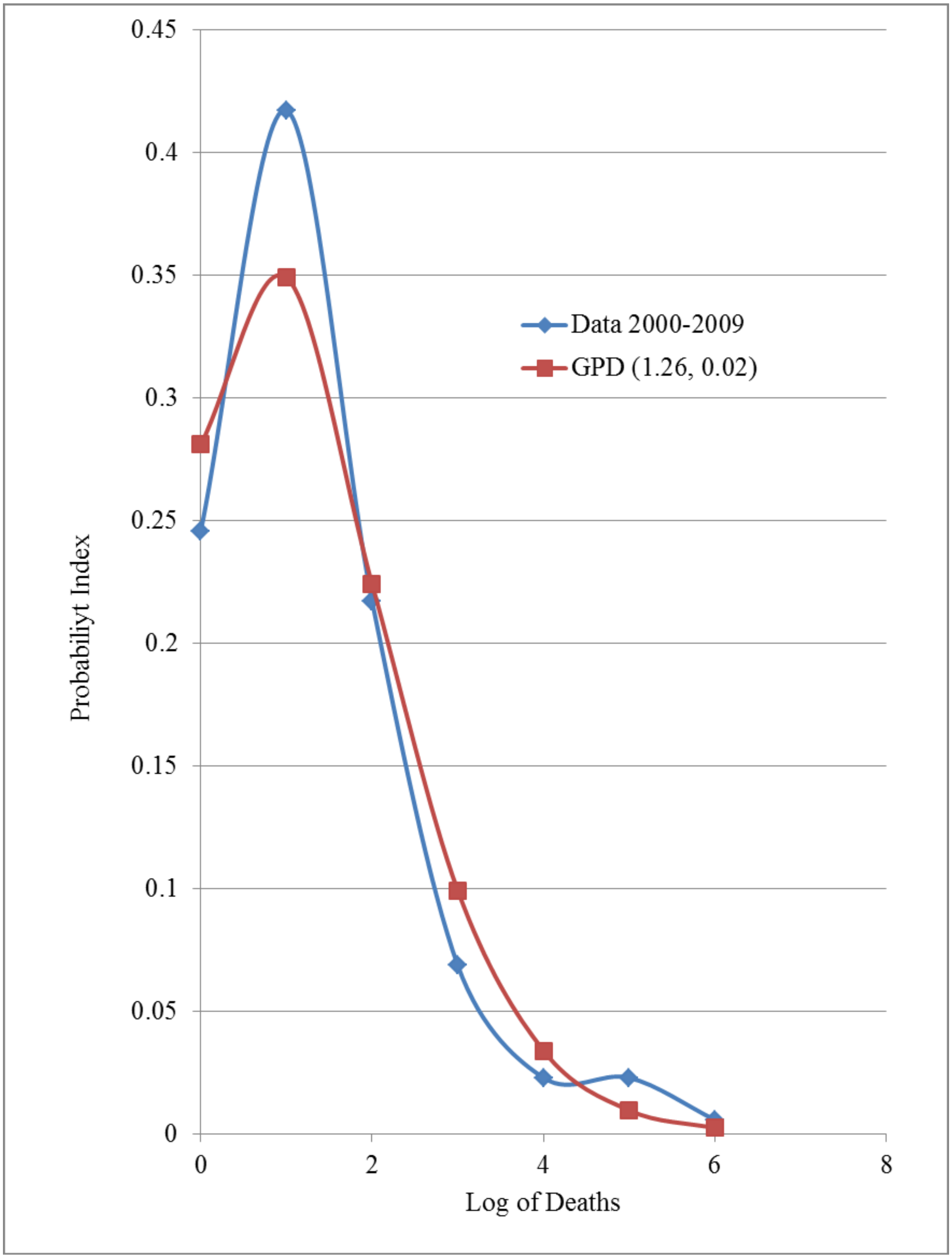

Figure 27 Distribution of the fatal events for the period 2000-2009

Figure 28 shows the GPD for the 1900 to 2009 earthquake deaths.

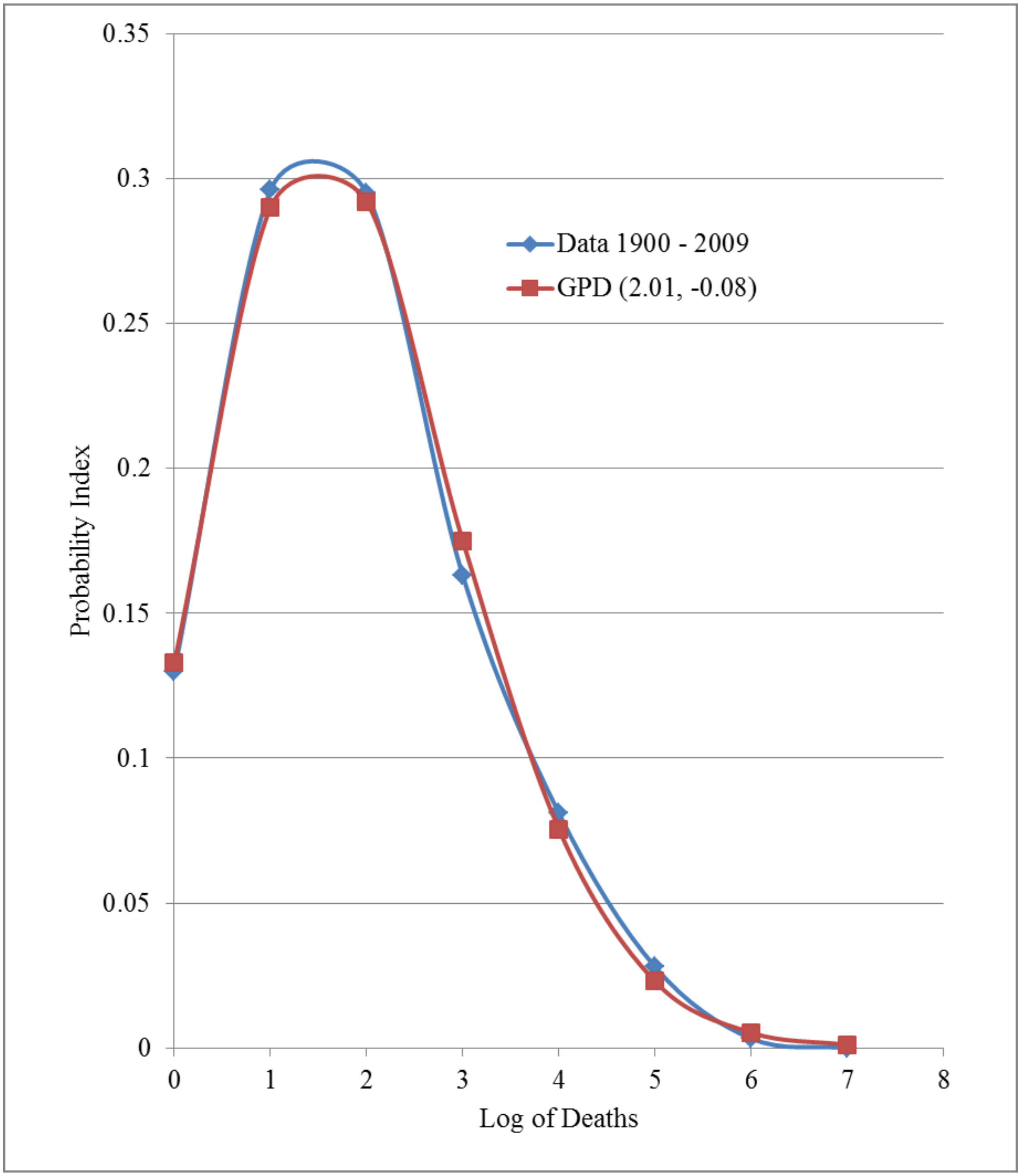

Figure 28 Distribution of the fatal events for the period 1900-2009

The critical result is that the probability of deaths in the range of 1,000,000+ is excess of one percent per annum. The GPD data has a Θ has value of 2.01 and the Λ has a value of -0.08. The Λ has decreased.

CHAPTER V

CONCLUSIONS

Earthquake deaths continue to plague the world population. More than 400,000 people died in earthquakes in this last decade, which is an average of 40,000 per annum. The twentieth century data is 2,000,000 deaths at a rate of 40,000 per annum. The Generalized Poissonian distribution continues to provide a reasonable fit to the data, with a Θ has value of 1.26 and the Λ has a value of 0.02 for the last decade and with a Θ has value of 2.01 and the Λ has a value of -0.08 for the period since 1900. The decrease in the Λ indicates some potential improvement for the peak death tolls, but the rate change should not be seen as significant at this time.

The number of fatal earthquakes per annum continues to climb. The last decade saw an increase of eleven percent in the bounding function developed by others. The world needs to improve building standards to reduce death tolls.

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APPENDIX A

SUPPLEMENTAL TABLES

This appendix provides a list of the data used in the analysis. Table 6 presents the number of deaths caused by intraplate and interplate earthquakes for the range M 5.0 to M 6.9. There is no known event with a magnitude less than 5.0 causing a human death.

Table 6 *Number of deaths caused by interplate and intraplate earthquakes (M > 5.0 and M < 7)*

Magnitude	Inter-plate deaths	Intra-plate deaths	Total Count of deaths
5.1	26	2	28
5.2	4	29	33
5.3	3	4	7
5.4	69	15	84
5.5	4	5	9
5.6	20	11	31
5.7	4	52	56
5.8	9	14	23
5.9	67	90	157
6	20	34	54
6.1	117	1,006	1,123
6.2	48	5	53
6.3	23	6,350	6,373
6.4	1052	612	1664
6.5	273	52	325
6.6	31,372	75	31,447
6.7	3	0	3
6.8	0	2,307	2,307
6.9	13	0	13
Total for this range	33,127	10,663	43,790
% of Total Loss	7.93	2.55	10.48

Table 7 presents the deaths in the intraplate and interplate events with an M greater than or equal to 7.

Table 7 *Number of deaths caused by interplate and intraplate earthquakes (M ≥ 7.0)*

Magnitude	Inter-plate deaths	Intra-plate deaths	Total Count of deaths
7	121	15	136
7.1	37	0	37
7.2	0	0	0
7.3	16	3	19
7.4	3	167	170
7.5	1,199	5	1,204
7.6	86,064	0	86,064
7.7	857	20,005	20,862
7.8	0	0	0
7.9	103	87,652	87,755
8	516	0	516
8.1	54	0	54
8.2	0	0	0
8.3	0	0	0
8.4	102	0	102
8.5	0	0	0
8.6	0	0	0
8.7	1,314	0	1,314
8.8	0	0	0
8.9	0	0	0
9	175,827	0	175,827
Total for this range	175,827	107,847	374,060
% of Total Loss	63.71	25.81	89.52

Table 8 lists the number of earthquakes in each of the death toll ranges for the 2000 to 2009. Earthquakes that caused damage, but no deaths are included in this list.

Table 8 *Number of earthquakes for the death toll range*

Range	Inter-plate Earthquake Count	Intra-plate Earthquake Count	Total Earthquake Count
(0-1)	216	95	311
(2-10)	45	28	73
(11-100)	26	12	38
(101-1000)	8	4	12
(1001-10000)	2	2	4
(10001-100000)	2	2	4
(100001-250000)	1	0	1
Total	300	143	443
% of Total	67.7	32.8	100

Table 9 shows the count of earthquakes for each magnitude range from 5.1 to 5.7. These are generally the events with low death tolls, but can be savage.

Table 9 *Number of earthquakes count occurred (M>5.0 and M ≤ 5.7)*

Magnitude	Inter-plate Earthquake Count	Intra-plate Earthquake Count	Total Earthquake Count	Ratio of Interplate to Intraplate Count
5.1	2432	358	2790	6.79
5.2	2042	336	2378	6.08
5.3	1522	242	1764	6.29
5.4	1248	186	1434	6.71
5.5	941	153	1094	6.15
5.6	727	124	851	5.86
5.7	614	93	707	6.60

Table 10 shows the earthquake count for events larger than M 5.7

Table 10 *Number of earthquakes count occurred (M ≥ 5.8)*

Magnitude	Inter-plate Earthquake Count	Intra-plate Earthquake Count	Total Earthquake Count	Ratio of Interplate to Intraplate Count
5.8	406	84	490	6.79
5.9	380	50	430	6.08
6	324	41	365	6.29
6.1	228	43	271	6.71
6.2	172	30	202	6.15
6.3	142	27	169	5.86
6.4	110	19	129	6.60
6.5	71	16	87	4.83
6.6	69	13	82	7.60
6.7	55	6	61	7.90
6.8	39	11	50	5.30
6.9	24	5	29	5.73
7	18	4	22	5.26
7.1	15	4	19	5.79
7.2	15	4	19	4.44
7.3	7	4	11	5.31
7.4	13	2	15	9.17
7.5	8	2	10	3.55
7.6	11	2	13	4.80
7.7	5	4	9	4.50
7.8	5	3	8	3.75
7.9	2	3	5	3.75
8	3	0	3	1.75
8.1	4	0	4	6.50
8.2	0	0	0	4.00
8.3	2	0	2	5.50
8.4	1	0	1	1.25
8.5	1	0	1	1.67
8.6	1	0	1	0.67
8.7	0	0	0	NA
8.8	0	0	0	NA
8.9	0	0	0	NA
9	1	0	1	NA

A total of 443 earthquake caused damage and deaths in the decade, which is an average damaging earthquake every 8.2 days. Figure 29 shows the plot of the ratio of interplate events to intraplate events for the magnitude range 5.1 to 7.9. Insufficient data exists to plot the ratio above 8.0.

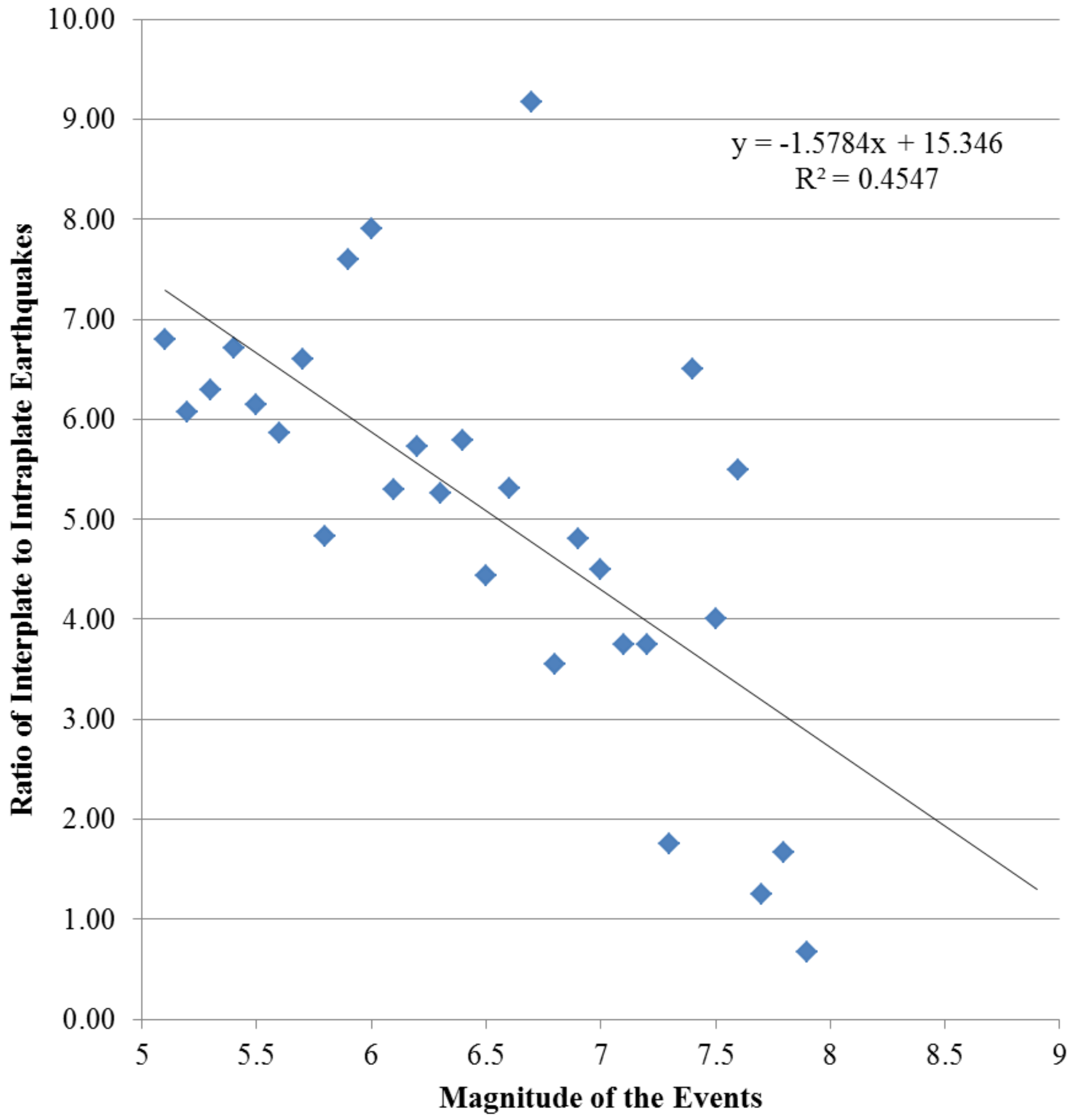

Figure 29 Ratio of the count of interplate earthquakes to intraplate Events

Table 11 lists the number of earthquakes in each of the death toll ranges for the 2000 to 2009. Earthquakes that caused damage, but no deaths are included in this list.

Table 11 *Number of earthquakes for the death toll range*

Range	Inter-plate Earthquake Count	Intra-plate Earthquake Count	Total Earthquake Count
(0-1)	24	19	43
(2-10)	45	28	73
(11-100)	26	12	38
(101-1000)	8	4	12
(1001-10000)	2	2	4
(10001-100000)	2	2	4
(100001-250000)	1	0	1
Total	108	67	175
% of Total	61.7	38.2	100

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