Estimating Casualties for Large Earthquakes Worldwide Using an Empirical Approach

By Kishor Jaiswal, David J. Wald, and Mike Hearne

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Abbreviations Used in This Report

HDI	human development index
MMI	Modified Mercalli Intensity
PAGER	Prompt Assessment of Global Earthquakes for Response
PGA	peak ground acceleration
PGV	peak ground velocity
PSA	peak spectral acceleration
USGS	U.S. Geological Survey

Estimating Casualties for Large Earthquakes Worldwide Using an Empirical Approach

By Kishor Jaiswal,[1] David J. Wald,[2] and Mike Hearne[3]

Executive Summary

We studied the earthquake mortality rates for more than 4,500 worldwide earthquakes since 1973 and developed an empirical country- and region-specific earthquake vulnerability model to be used as a candidate for post-earthquake fatality estimation by the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) system. Earthquake fatality rate is defined as the ratio of the total number of shaking-related fatalities to the total population exposed at a given shaking intensity (in terms of Modified-Mercalli (MM) shaking intensity scale). An atlas of global Shakemaps developed for PAGER project (Allen and others, 2008) and the Landscan 2006 population database developed by Oak Ridge National Laboratory (Dobson and others, 2000; Bhaduri and others, 2002) provides global hazard and population exposure information which are necessary for the development of fatality rate. Earthquake fatality rate function is expressed in terms of a two-parameter lognormal cumulative distribution function. The objective function (norm) is defined in such a way that we minimize the residual error in hindcasting past earthquake

[1] U.S. Geological Survey, P.O. Box 25046, M.S. 966, Lakewood, Denver, CO 80225-0046 (contracted through Synergetics Incorporated - *http://www.synergetics.com*).
[2] U.S. Geological Survey, P.O. Box 25046, M.S. 966, Lakewood, Denver, CO 80225-0046.
[3] Senior Software Engineer, U.S. Geological Survey, P.O. Box 25046, M.S. 966, Lakewood, Denver, CO 80225-0046 (contracted through Synergetics Incorporated - *http://www.synergetics.com*).

fatalities. The earthquake fatality rate is based on past fatal earthquakes (earthquakes causing one or more deaths) in individual countries where at least four fatal earthquakes occurred during the catalog period. All earthquakes that have occurred since 1973 (fatal or non-fatal) were included in order to constrain the fatality rates for future estimations. Only a few dozen countries have experienced four or more fatal earthquakes since 1973; hence, we needed a procedure to derive regional fatality rates for countries that had not had enough fatal earthquakes during the catalog period. We propose a new global regionalization scheme based on idealization of countries that are expected to have similar susceptibility to future earthquake losses given the existing building stock, its vulnerability, and other socio-economic characteristics.

The fatality estimates obtained using an empirical country- or region-specific model will be used along with other selected engineering risk-based loss models (semi-empirical and analytical) in the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) system for generation of automated earthquake alerts. These alerts could potentially benefit the rapid earthquake response agencies and governments for better response to reduce earthquake fatalities. Fatality estimates are also useful to stimulate earthquake preparedness planning and disaster mitigation. The proposed model has several advantages as compared with other candidate methods, and the country- or region-specific fatality rates can be readily updated when new data become available.

Introduction

The problem of earthquake casualty estimation has been studied by various researchers in the past, and it can be categorized into three broad approaches of casualty estimation: empirical, hybrid and analytical. The empirical approach consists of estimating aggregate historic earthquake statistics and estimating casualty rates (total casualties for a given population) in terms of ground shaking hazard (Samardjieva and Badal, 2002). The analytical approach consists of seismic hazard analysis (estimating ground shaking defined in terms of peak ground acceleration (PGA), peak ground velocity (PGV), peak spectral acceleration (PSA) or seismic intensity and its likelihood), structural analysis (assessing response of structure given shaking hazard), damage analysis (estimating fragility characteristics for a given response of structural system), and loss analysis (estimating fatalities, injuries due to structural and nonstructural damage) (FEMA, 2006). In short, earthquake casualty estimation is performed at a building level by modeling the building damage using engineering-based ground motion parameters. The hybrid approach consists of estimating the fraction of the population killed due to the collapse of different types of structures at a given shaking hazard, generally represented in terms of macro-seismic intensities. Unlike the analytical approach, the hybrid approach does not attempt engineering-based structural and damage analyses but requires fewer parameters at building level and can be applied to regional or building-level casualty assessment (Coburn and others, 1989; Shiono and others, 1991a; Murakami, 1992; Yamazaki and others, 1996; Shakhramanian and others, 2000). Empirical modeling has been performed in a variety of different ways in the past depending upon the earthquake damage data available. Researchers in Japan attempted casualty estimation as early as the 1950s. Kawasumi (1951) estimated a measure of earthquake danger and expectation of maximum intensity in Japan. Similarly, early casualty estimation efforts in the United States were scenario specific and based on estimation of the casualty rate per 100,000 people and use of engineering judgment (Algermissen and others, 1972). Ohta and others (1983) developed an empirical relationship for estimating the number of casualties as a function of the number of completely destroyed houses. Oike (1991) proposed a relationship between earthquake magnitude and earthquake fatalities. A more recent attempt based on an analysis of 450+ global earthquakes obtains a log-linear relationship of fatalities as a function of magnitude and population density (Samardjieva and Badal, 2002).

Nichols and Beavers (2003) studied the fatality catalogue of the twentieth century and established a bounding function using the fatality count, and the U.S. Geological Survey (USGS) assigned earthquake magnitude.

Hybrid and analytical approaches involve objective assessment of casualties by incorporating various parameters such as structure types, occupancy characteristics, and state of building damage and level of shaking hazard. However such analysis requires a series of parameters (for example, knowledge of regional building inventory, structural vulnerability of each building type, occupancy at the time of earthquake, fatality rate given structural damage) which are often unavailable in certain countries or difficult to obtain in cases where it is available, due to inconsistent and poorly characterized historical earthquake casualty data. The empirical approach, on the other hand, is generally regression based, can effectively utilize the available quality and quantity of historical earthquake casualty data, and depends on very few free parameters of loss models.

In the present investigation, we propose a global empirical model derived by using historical data of earthquake casualties by country and by using a fatality rate. While developing an empirical model, we derive the fatality rate as a function of shaking intensity, a spatially varying parameter and an indicator of impact of ground motion on built environment, instead of using an earthquake magnitude which indicates only the size of an earthquake and can be completely misleading in the extreme cases of population exposure and vulnerability of built environments. A population exposed to higher shaking intensity will tend to have higher losses than a population in lesser shaking intensities. Similarly a moderate-sized earthquake in terms of magnitude will have various levels of shaking intensity distribution patterns depending upon local geologic and seismotectonic conditions, ground motion attenuation, and local site amplification characteristics. Magnitude-based empirical models are generally ineffective in capturing such variability unless they are derived for a unique seismogenic source. The ground shaking hazard map in the form of ShakeMap will incorporate earthquake source-specific parameters such as point source, fault finiteness (if any), and local soil characteristics to estimate the population exposure at different shaking intensities. The country-specific fatality rate estimation will be derived using historical earthquake data in the form of total shake-related deaths recorded for each earthquake and the associated population exposure at different shaking intensities at the time of earthquake. Allen and others (2009a) developed PAGER exposure database (called ExpoCat) by first recreating the ShakeMap for historical earthquakes, overlaying it on a map of the Landscan global population database developed by Oak Ridge National Laboratory (Bhaduri and others, 2002) and then correcting the 2006 population to the year of the earthquake by uniform reversal of population at different Modified Mercalli Intensity (MMI) levels using the country-specific population growth rates.

For the forward application of the empirical model proposed here, the U.S. Geological Survey's Prompt Assessment of Global Earthquake Response (PAGER) program already provides such estimates on a real-time basis for its global users (Wald and others, 2006). It is clear from recent earthquakes (for example, Bhuj, 2001; Kashmir, 2005; Wenchuan, 2008), and indeed for most earthquake disasters in the last few decades, that for large-scale disasters, it takes days or sometimes weeks before the actual scale of disaster is understood. PAGER estimates can be used not only to rapidly understand the size, location, and scale of catastrophe but also to inform national and international agencies about the assessment of post-earthquake needs in order to make decisions about humanitarian assistance based on the scale of the disaster. Clearly, the empirical loss estimation approach proposed for the PAGER system is designed to utilize existing casualty and exposure data and to have global capability with the possibility of real-time application.

Earthquake Fatalities Worldwide

We examined global earthquake fatality data since 1900, and Table 1 presents a list of countries that have experienced 10 or more shaking-related fatalities (not including other non-shaking related deaths—for example, deaths due to fire, land or mudslide, or ground failure). Clearly, countries like China, Pakistan, Iran, and Turkey dominate the list; Chinese earthquakes have caused 604,330 deaths since 1900 (fig. 1a). China experienced 122 fatal earthquakes since the year 1900. The Tangshan earthquake of 1976 caused nearly a quarter of a million deaths, and some researchers believe that the actual number might have exceeded half a million people. The entire city had to be rebuilt (Liu and others, 2002). On average, each fatal Chinese earthquake has caused nearly 5,000 deaths, clearly indicating China's vulnerability to future earthquakes. Similarly, Pakistan has experienced the most devastating earthquake in recent times in 2005 in Kashmir, which killed more than 85,000 people. Seventy-five Iranian earthquakes have claimed 161,215 lives, whereas Turkey has experienced 64 fatal earthquakes that killed more than 85,000 people. Surprisingly, in Indonesia, 62 fatal earthquakes have killed 10,870 people; more than 50 percent of the deaths are attributed to the Yogyakarta earthquake of May 26, 2006, which caused 5,749 deaths. Countries such as Armenia, Nepal, Argentina, Romania, and Nicaragua have experienced very few deadly earthquakes, but the number of deaths in any single event is quite large compared to other countries. Although Japan and Taiwan have experienced 43 and 38 fatal earthquakes, respectively, the deadliest earthquakes in these countries contribute more than 80 percent and 40 percent of total deaths, respectively. The great Kanto earthquake of 1923 in Japan took more than 142,807 lives, although most of the deaths were due to the fire following the earthquake and other non-shaking-related deaths and thus is not included in the present analysis. The United States has experienced 18 fatal earthquakes, but remarkably they caused only 270 deaths, averaging 15 deaths per event during the last 100 years.

On a global scale, 76 percent of the totals shaking related-deaths were in China, Iran, Pakistan, and Turkey, whereas 24 percent of the total deaths came from other countries. About 80 percent of the total shaking-related deaths since 1900 were due to only 25 earthquakes which occurred in 11 countries: China, Pakistan, Iran, Turkey, Italy, Chile, Armenia, Guatemala, India, Tajikistan, and Nepal. Figure 1b shows the cumulative fatality rate for a few countries and clearly shows that most fatalities are due to a small number of large earthquakes in these countries.

Methodology

Fatality rate (ν), which is a function of shaking intensity (S), can be expressed in terms of a two-parameter lognormal distribution function as follows:

$$\nu(S) = \Phi\left[\frac{1}{\beta}\ln\left(\frac{S}{\theta}\right)\right], \quad (1)$$

where Φ is the standard normal cumulative distribution function, S_j is discrete value of shaking intensity (S is bounded between MMI V to X and is expressed in numeric values with 0.5 increments; for example, 5.0, 5.5, 6.0,...10.0), and θ and β are parameters of the distribution. Let $P_i(S_j)$ denote an estimated population exposed to shaking intensity S_j for an event i. Then the expected number of fatalities E_i can be denoted as

$$E_i \approx \sum_j \nu_i(S_j).P_i(S_j) \quad (2)$$

In order to estimate the total number of fatalities from any given earthquake, we need to find a population exposure at each shaking intensity level and a fatality rate associated with the shaking intensity. The fatality rate depends on the two free parameters of the cumulative distribution function of lognormal distribution, θ and β For each country or a geographic location k, if there are N historical fatal earthquakes then each event-specific fatality number could be used to determine the fatality rate by reconstructing the Shakemap for each earthquake and estimating population exposure at each interval of shaking intensity. If we suppose that O_i is the number of recorded deaths for an earthquake *i*, then we can determine the parameter of the distribution function (that is, the estimated fatality rate) in such a way that the residual error (that is, the error estimate between estimated and recorded deaths) is minimized. It is assumed that the recorded number of deaths from an earthquake in the catalog is free from any errors and is generally obtained from a well documented, peer reviewed source of literature or dataset for a particular earthquake. Thus a residual error in the estimate could be written in a variety of ways, for example:

$$\varepsilon_{1,k} = \sum_{i=1}^{N} | E_i - O_i | \qquad or \quad L1 \ norm \tag{3a}$$

or

$$\varepsilon_{2,k} = \sum_{i=1}^{N} \left(E_i - O_i \right)^2 \quad or \quad L2 \ norm \tag{3b}$$

or

$$\varepsilon_{3,k} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[\ln\left(E_i / O_i \right) \right]^2} \quad or \quad \log residual\,(G) \ norm \tag{3c}$$

Clearly, each of the above norms provides a window of search-space for determining the parameters of the distribution function that minimizes the residual error. The *L1* norm (eq. 3a) provides a search space for parameters that result in an error estimate which is a minimum of total error between recorded and estimated deaths. In other words, in the error estimate in *L1* norm all the earthquakes are treated equally, even though the search space is influenced by earthquakes with high fatality where the absolute deviation between the estimated and recorded deaths is much higher than the deviation associated with the low fatality earthquakes. Figure 2a shows the plot of recorded versus estimated deaths using the *L1* norm for all the earthquakes globally that have caused 10 or more deaths since 1973. The estimated lognormal distribution parameters for *L1* norm are θ= 21.44 and β= 0.30. The logarithmic mean of the ratio of recorded versus estimated deaths is 0.41, whereas the logarithmic standard deviation is 0.99. The *L2* norm as shown in equation 3b provides a search space that results in an error estimate which is a sum of squared differences between recorded and estimated deaths. Again, the search space for estimating the parameters of the distribution in *L2* norm is such that in case of high-fatality earthquakes, the squared differences tend to dominate the overall contribution of squared error (fig. 2b). Between *L1* and *L2* norm, *L2* norm generally provides a search space that better satisfies high fatality earthquakes (that is, minimizes the squared difference of amplitudes of the data). However, in the case of the *G* norm (eq. 3c), we take the natural logarithm of the squared difference between the recorded and estimated deaths, which tends to reduce the contribution of high-fatality earthquakes in the total error term and generally better satisfies the low-fatality earthquakes (fig. 2c). Clearly, none of the above norms satisfies the present requirement to minimize the error at both ends (low and high fatality earthquakes simultaneously). We need a norm that combines the advantages of both *L2* and *G* norms (that is, provides a search space that satisfies both low and high fatality earthquakes simultaneously in the natural logarithm space) to estimate the parameters of the distribution function. The objective function to determine the residual error could be written using a combination of *ln*(*L2*) and *G* norms as

$$\varepsilon_{4,k} = \ln\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_i - O_i)^2}\right) + \sqrt{\frac{1}{N}\sum_{i=1}^{N}[\ln(E_i / O_i)]^2} \quad or \quad L2G\ norm \qquad (4)$$

Note that we take the natural logarithm of the squared difference term of *L2* norm which satisfies the criteria required for high fatality earthquakes in combination with *G* norm. The objective function *ln*(*L2*)+*G* or, say, the *L2G* norm defined in equation 4 can be used to evaluate the parameters of the distribution function, which in turn can be used to estimate country-specific earthquake fatality rates. We use a standard iterative search algorithm available in Matlab Ver., R2007a for minimizing the objective function with the two free parameters of the distribution function, θ and β As expected, we obtain a better constraint on both ends of the fit (lower as well as higher amplitudes of the dataset) as shown in figure 2d. Clearly, we obtain a better fit to the data without sacrificing much in terms of logarithmic standard deviation of ratio of recorded versus estimated deaths (0.97 as against 0.95 for *G* norm (fig. 2c)). We have a higher accuracy for large fatal events, and still we did not increase the number of unknowns (free parameters) in our procedure. The advantage of *L2G* norm as compared with the other two norms became evident as we developed a country-specific model and is discussed in subsequent sections. This approach is simple and suitable for countries with at least three or more fatal earthquakes in the catalog, and thus it helps us to obtain earthquake fatality rates for a large number of countries.

Goodness of Fit

The Lilliefors goodness-of-fit test is a special and stricter case of the Kolmogorov-Smirnov test commonly used in statistics to test whether an observed distribution is consistent with normality. We have used the Lilliefors goodness-of-fit test (Lilliefors, 1967) at 5 percent significance level in order to test the hypothesis that the residual error $\psi_i = \log(E_i / O_i)$ can be modeled using a lognormal distribution. We estimate the mean and variance of the data and then find the maximum discrepancy between the empirical distribution function and the cumulative distribution function of the normal distribution with the estimated mean and estimated variance.

The observed cumulative distribution is estimated using $F_N(X) = i / (N+1)$. The data pass the Lilliefors test: $N = 194$; Max$| F^*(X) - F_N(X) | = 0.0681$, as shown in figure 3, which is less than the critical value $D_{0.05} = 0.886N^{-0.5} = 0.0976$. This value indicates that it is reasonable to model the residual error as lognormally distributed about the median estimate with a logarithmic standard deviation equal to the value of G calculated in equation 3c.

Sources of Uncertainty

In most of the countries, the available earthquake-fatality data are very limited and are often insufficient alone to derive an empirical earthquake fatality model. The fatality rate as a function of ground shaking intensity is defined by using a two-parameter lognormal cumulative distribution function. This rate is better constrained theoretically when we have sufficient earthquakes with a wide range of fatalities, meaning that the larger the number of small and large fatality earthquakes, the better is the constraint on the fatality rate. Also, if the epicenters of the past fatal earthquakes are widely distributed within a country across its various inhabited places in terms of their vulnerabilities, the empirical model will better estimate deaths during future earthquakes irrespective of their location compared to the model which is derived from earthquakes limited to a particular source zone of a country. However, it is for practical purposes difficult to have data that record both the spatial and temporal aspects of this problem.

Similarly, there are a number of additional sources that can contribute to the uncertainty in the model's fatality estimates. For example, input hazard from Shakemap, fatality variation due to day or night occupancy pattern, accuracy in estimated population exposure, and accuracy of fatality records of historical earthquakes may significantly affect the accuracy of the model's estimation. While developing the country- or region-specific empirical model, most of these factors have already been accounted for collectively as a part of the datasets that span more than 35 years.

In order to estimate the total uncertainty, the PAGER models (empirical, semi-empirical, and analytical) currently employ a country-specific error term determined from hindcasting of past losses as discussed by Porter and others (2008). Let ζ denote a residual error in loss L, a variable representing normalized standard deviation of the logarithmic ratio of expected to recorded losses, which can vary by country. As shown in the previous section, the lognormal probability distribution fit to ratio of loss E_i / O_i commonly passes a Lilliefors goodness-of-fit test. In the empirical model, we have estimated the two free parameters of the distribution function (θ and β) from the historical data; hence we reduce the total sample by two and then estimate ζ as:

$$\zeta = \sqrt{\frac{1}{N-2}\sum_{i=1}^{N}\left[\ln\left(E_i + 0.5 / O_i + 0.5\right)\right]^2} \tag{5}$$

A constant value of 0.5 deaths is added to the numerator and the denominator when the expected or recorded deaths are zero. We note that the error estimated in hindcasting the total shaking deaths using the empirical model already incorporates the total variability that comes from the uncertainty in shaking hazard for each earthquake, the uncertainty in the population exposure, and also possible errors in the number of recorded deaths in the catalog for these events. Variability in each of these inputs may have different effects depending upon the country under consideration (countries that experience frequent fatal earthquakes or countries that have relatively low vulnerability) or the nature of the constraints for shaking hazard estimates.

In the forward sense, we can use the uncertainty in hindcasting the median loss estimates (refer to appendix II) through use of a country-specific residual error term (ζ) to estimate the probability for the upper and lower bounds of losses. If we let *P* denote the probability that the actual loss will be within one order of magnitude of deaths *D*, we can express this probability as:

$$P = \phi\left[\frac{\log(D) - \log(E(L))}{\zeta}\right] \tag{6}$$

Estimation of probabilities within one order of magnitude of median deaths (that is, an actual value could be within 1/10 to 10 times the model's median fatality estimation) along with the median (50 percent probability) fatality estimate generally provides a very useful range, especially considering the wide variety of PAGER user-base and their responses at a global scale. Alternatively, the deaths quantiles (that is, the deaths D associated with different probability ranges p ~ (10 percent, 20 percent, 90 percent)) can be represented by rearranging equation 6 as follows:

$$D = \exp\left[\zeta\phi^{-1}(p) + \log(E(L))\right] \tag{7}$$

For PAGER alert purposes, we also need to provide the probability of different alert levels (see appendix III) such that the actual deaths could exceed certain predefined alert thresholds. The probability P that the actual death d may be between predefined thresholds a and b is given as:

$$P(a < d \leq b) = \Phi\left[\frac{\log(b) - \log(e)}{\xi}\right] - \Phi\left[\frac{\log(a) - \log(e)}{\xi}\right] \tag{8}$$

Need for Regionalization

As described above, the empirical model development consists of estimation of the two free parameters for the lognormal distribution function. Statistically, in order to develop a country-specific empirical model, we need at least three fatal earthquakes in each country. However various uncertainties are associated with fatality records in the catalog (for example, the actual number of deaths for a particular earthquake is uncertain), so we considered the minimum number of fatal earthquakes to be four rather than three.

Only 30 countries in our database have had at least four fatal earthquakes since 1973. For those countries with fewer fatal events, we devised an approach that aggregates fatal events from like-countries through a regionalization scheme that focuses on likely indicators of comparable country vulnerability. The proposed regionalization scheme (shown in fig. Ia in appendix I) is based primarily on geography, building inventory, and socio-economic similarities for the 213 countries without the minimum number fatal earthquakes during the catalog period for properly constraining a country-specific model. The choices we made in aggregating countries by these indicators are discussed below.

Human Development Index

The Human Development Index (HDI) is an index combining normalized measures of life expectancy, literacy, education, and gross domestic product per capita for countries worldwide. The HDI is a standard means of measuring human development, a concept that, according to the United Nations Development Program, refers to the process of widening the options of persons, giving them greater opportunities for education, health care, income, and employment. One general use of the HDI is to rank countries by level of "human development," which usually also implies whether a country is a developed, developing, or underdeveloped country (fig. Ib).

Socio-economic conditions affect the way people live and also tend to influence building construction and maintenance practices. With some notable exceptions, the built infrastructure in developed countries has greatly improved with passing years and is generally engineered to withstand country-specific natural hazards. For example, the strong and persistent economic advancements in United States, Japan, New Zealand, and some Northern European countries have resulted in significant improvement of their building stock with consistent efforts on both maintenance and retrofitting of poor building stocks. This improvement is evident from the fact that strong earthquakes in these countries result in significantly fewer collapsed buildings and hence a significant reduction in the loss of lives. However, in developing countries such as Indonesia, Pakistan, China, and India, poorer socio-economic conditions affect the standard of living and hence also the way people build and maintain their houses. The existence of poor building stock in these countries results in a large number of building collapses and disruption of life after significant earthquakes (for example, the 2001 Gujarat earthquake in India, the Pakistan earthquake of 2005, and the Wenchuan, China earthquake of 2007). Despite relatively low earthquake hazards in central and east African countries, the low human development index is an indicator of poor socio-economic conditions within these countries. It results in building stocks in these countries that are, in general, poorly built and maintained and are therefore highly vulnerable to earthquake shaking. Similarity of human development indicator values among neighboring countries indicates a commonality among these countries concerning their socio-economic conditions and hence we group them together. However, even with similar HDI indices, countries with varying climates require further consideration.

Climate Classification

Climate also is a considerable determinant of the way people live and build their places of shelter. Since ancient times, building architecture has been influenced by the local climate. The primary objective of the shelter was to protect the inhabitants from the weather elements. However in recent times, the climate-responsive architecture has evolved around the world to effectively tap into natural resources such as heat and light (Bensalem, 1997). Buildings constructed in cold climates tend to have large size openings in the direction of the Sun to exploit maximum exposure, and have low ceilings to minimize and reduce heat loss within the interior of the building. In hot climates, the buildings tend to have their peripheral system (outer walls) thicker whereas in cold climates the walls inside the structure are made thicker to insulate and keep the heat in. For example, the climate in the eastern Black Sea region, which lies in northern Turkey, plays an active role in the formation and diversity of the vernacular houses in the region (Engin and others, 2007). The warm, humid climate of the region has different effects on the spaces, elements and annexes of the vernacular houses. Similarly, in arid desert regions, buildings are designed with flat roofs, small openings, and heavy-weight materials. The configuration is such that the thick exterior roof and walls will absorb the temperature fluctuations and keep the internal temperature steady and lower than the outside temperature. The buildings in hot climate tend to have patios, verandas or courtyards. Vernacular architecture does vary between hot and cold regions but many of the same techniques are employed, which makes vernacular houses unique in each respective climate.

While having thicker walls and roof serve insulation purposes well for hot climates, seismically such configuration may not be sound if constructed using brittle material. In fact, the absence of an effective lateral load transfer mechanism may increase its vulnerability. The size and position of opening in the walls also significantly affect the lateral load resistance capacity of walls. Such design must be considered in the earthquake vulnerability of such structures. Some of architecture practices have evolved adapting to not only the local climate, social, and cultural patterns but also to the natural hazards. For example, the construction of traditional houses called bhongas in the western Kachchh region of India resists both the arid desert climate and natural hazards such as cyclones and earthquakes. With light-weight roofs, cylindrical walls, and adequate roof- wall connections, such structures can withstand the lateral shaking considerably better than conventional architecture (Choudhary and others, 2002). Thus, local climate conditions do play a crucial role in determining common building configurations and, in certain cases, building configurations have evolved with passing years. We could not establish a direct relationship between building configuration and vulnerability to earthquakes. The effect of building configuration on seismic vulnerability is not easily quantifiable and is beyond the scope of the present investigation. Further research is necessary to establish a more coherent and direct relationship between local climate, building configuration, and associated vulnerability to earthquakes. Nevertheless, it is clear that the local climate affects the building configurations and architecture and, hence, indirectly influences the overall seismic vulnerability of the region's built environment. We considered climate as one useful, broad indicator in understanding the seismic resilience at a regional scale in the absence of more detailed information.

German scientist Wladimir Köppen in 1900 provided the first quantitative classification of world climates, which was later updated by Rudolf Geiger in 1954 and 1961. A large number of climate studies and subsequent publications adopted this scheme of climate classification (Kottek and others, 2006). Figure Ic of appendix I provides the most recently updated climate classification map, which we have referred to while developing the regionalization scheme. The hot, dry equatorial climate and low HDIs of central Africa affect its built environment. Buildings in central African countries are generally adobe, mud wall, and clay burnt-brick masonry constructions. Rural areas constitute 60percent of informal construction. In the absence of an adequate number of fatal earthquakes during the catalog period, we have grouped the countries in this region together (fig. Ia of appendix I) so as to develop a regional empirical model. Such a model can be used as a proxy empirical model for estimation of likely fatalities in future earthquakes in these countries. Appendix I details the regionalization scheme proposed for empirical model along with the list of countries in each region, their range of HDI, climate conditions and also notes about their built environments. The PAGER regionalization scheme is used mainly to develop the fatality model considering earthquake vulnerability of structures in these countries at a regional scale rather than at the country level. Thus, countries that have sufficient fatal earthquakes will still have their own country-specific fatality model; however their historical earthquakes will also be utilized in developing a regional model that can be used for countries with few or no fatal earthquakes during the past several decades.

Model Implementation

We have used the global Shakemap catalog developed by Allen and others (2008), which consists of 5,600 global earthquakes that occurred since 1973. In addition, we employ the PAGER-CAT database (Allen and others, 2009b) that combines high-quality earthquake source information (that is, hypocentral location and magnitude) and casualty data gathered from several published catalogs. Of the large earthquakes since 1973, only 700 earthquakes are known to be fatal and thus could be utilized for empirical model development. The Landscan 2006 population database developed by Oak Ridge National Laboratory (Bhaduri and others, 2002) has been used as a primary input for estimation of population exposure. By overlaying the Shakemap of a particular earthquake on the Landscan 2006 database, we retrieve the total population at each interval. In order to hindcast the year 2006 population of Landscan database to the year of an earthquake, we used population growth rates compiled by United Nations (United Nations, 2006) and applied a correction factor to the 2006 population to get the population exposure during the earthquake. Thus for each catalog earthquake '*i*', we estimate population exposure $P_i(S_j)$ due to shaking intensity S_j, using a 0.5 intensity unit interval provided in the PAGER-CAT database.

In order to estimate country-level fatality rates as a function of shaking intensity, we used a standard numerical minimization algorithm (Nelder-Mead, or modified simplex procedure) to estimate parameters θ and β for each country. The development of country-specific empirical fatality rates to be used for the PAGER system is discussed in detail in the following section. We also discuss the comparison of minimizing different norms by first deriving empirical model parameters and comparing the estimation of the model for each norm for selected countries (figs. 4 and 5). As discussed in the previous section, the *L2G* norm clearly provides the best estimates when one combines both low- and high-fatality events.

Example Analysis

We discuss the development of empirical fatality rates using historical earthquakes for selected countries to provide examples of models for the range of constraints and regionalization approaches necessary in our model. We discuss some historical events in these countries, but the loss models developed are limited to calibrations using exposure and fatality data for only the past 35 years.

Indonesia

Indonesia is an earthquake-prone country; it has experienced 53 fatal earthquakes during the last 35 years. About 78 earthquakes with zero or more deaths that have occurred since 1973 were used to develop the empirical model shown in figure 4. Only shaking related deaths (not tsunami deaths) were used to constrain the empirical fatality model which estimates that approximately 1 in 267 people will be killed at shaking intensity IX and about 1 in 2,782 at intensity VIII. We also compared other norms such as *L2* and *G* norm of equation 3b and 3c respectively. Clearly, the estimated deaths are significantly overestimated for smaller earthquakes in the *L2* norm; however the deaths for the largest earthquakes were estimated with higher accuracy. Similarly, the *G* norm significantly under-estimates total fatalities for larger earthquakes. The newly proposed combination norm (*L2G*) estimates both small- and large-fatality earthquakes with higher accuracy than the individual norms. The empirical fatality rate indicates 1 death per 270 people exposed to shaking intensity IX and it reduces to 1 death per 2,800 people at intensity VIII. The May 26, 2006, Yogyakarta earthquake in Indonesia, which occurred south-southeast of the city of Yogyakarta on Java, Indonesia (*http://earthquake.usgs.gov/eqcenter/eqinthenews/2006/usneb6/*) resulted in 5,749 deaths. More than 127,000 houses were destroyed and an additional 451,000 were damaged in the area. About 75,100 people were exposed to shaking intensity X and about 856,900 people were exposed to intensity IX.

India

Earthquakes have claimed more than 50,000 lives in India during the last 107 years. More than 150 large earthquakes have struck the country since 1973, of which 28 were fatal and caused a total of 31,994 deaths. We have used 28 earthquakes to develop a country-specific empirical model as shown in figure 5. We also show the comparison of three norms (*L2*, *G*, and a combination norm *L2G)*. Again, as expected, the *L2* norm estimates the deadliest earthquakes with higher accuracy than the *G* norm, which provides a better fit to the smaller events. Although the *L2* norm estimates deadlier earthquakes better, it estimates on the order of 1,000 deaths for an earthquake that had no fatalities. The combination norm provides a way to constrain both low- and high-fatality domains and suggests a model that can be used for future earthquake fatality estimates. The empirical fatality model for India indicates a rate of 1 death per 25 people exposed to shaking intensity IX and 1 death per 5250 people exposed to intensity VII. The Bhuj earthquake of 2001 in Gujarat state of India caused widespread damage and killed more than 20,000 people. The earthquake had a population exposure of 212,000 at shaking intensity IX and above, and about 982,600 at intensity VII.

Slovenia

Slovenia has not experienced a fatal earthquake during the past 35 years although there were large earthquakes in 1974, 1998 and 2004, which caused damage but no fatalities. The April 12, 1998, earthquake was the strongest earthquake in Slovenia in a century and caused billions of dollars in damage (*http://www.ukom.gov.si/*). In order to develop an empirical fatality model for Slovenia, we used the regionalization scheme to combine fatality data from neighboring countries of the group: Czech Republic, Slovenia, Slovakia, Hungary, Bosnia and Herzegovina, Croatia, Serbia, Montenegro, Romania, Albania, former Yugoslav Republic of Macedonia, Bulgaria, and Republic of Moldova (refer to appendix I). Most of these countries have similar construction practices although some variation might be expected due to the effect of World War II and its influence on local infrastructure and economies. We used 21 fatal earthquakes in this group along with 8 nonfatal events to construct the empirical lognormal fatality model as shown in figure 6. The estimated fatality rate for Slovenia (and the group as a whole) indicates that about 1 in 310 people exposed to Modified Mercalli shaking intensity IX will be killed; approximately 1 in 17,600 will be killed when exposed to intensity VII. We use this model for all the countries within this group since individually, with the exceptions of Romania, they do not have a sufficient number fatal earthquakes to construct country-specific models. For Romania, which has had six fatal earthquakes, we developed a country-specific model as shown in appendix II.

Albania

In the past several decades, Albania experienced only one fatal earthquake, on Nov 16, 1982. For that event, 1 person was killed, 12 were injured, and extensive damage (intensity VIII) was reported in the Fier, Berat, and Lushjne districts. It was felt at Titograd, Yugoslavia, and also in northwestern Greece and in southern Italy (see *http://earthquake.usgs.gov/eqcenter/eqarchives/significant/sig_1982.php*). We estimate that more than 183,900 people were exposed to shaking intensity VII and above. We used the fatal earthquakes within the group of countries (Bulgaria, former Yugoslav Republic of Macedonia, Republic of Moldova, and others) to develop an empirical model for Albania. There have been 29 earthquakes within the group of which 21 were fatal, as discussed above in case of Slovenia. Both Slovenia and Albania have a group-based model.

Chile

The great earthquake of May 22, 1960, off the coast of south central Chile was one of the largest earthquakes in the twentieth century (magnitude 9.5) and caused a tsunami that killed 61 people in Hawaii and 122 in Japan. Death estimates from the tsunami for the entire Peru-Chile coastline ranged from 330 to 2,000 people (see *http://www.drgeorgepc.com/Tsunami1960.html*). In addition, about 2,000 lives were lost there from the widespread shaking damage (Atwater and others, 1999). Chile has experienced more than 180 earthquakes since 1973, of which 11 were fatal. We used 26 earthquakes with zero or more deaths in Chile to develop the empirical fatality estimation model as shown in figure 7. The L2G norm fits both smaller and large size earthquakes and the estimated parameters are θ= 40.93 and β= 0.44 with log residual error (ζ) of 1.77. The estimated fatality rate is 1 per 3,800 people exposed at Modified Mercalli shaking intensity IX and 1 per 10,800 at shaking intensity VIII. An earthquake of magnitude 7.8 struck offshore of Valparaiso in Chile. More than 5,433,200 people were estimated to have experienced shaking intensity VII for an event in which 177 people were killed, 2,575 injured, and extensive damage occurred in central Chile, including the cities of San Antonio, Valparaiso, Vina del Mar, Santiago and Rancagua (*http://earthquake.usgs.gov/regional/world/events/1985_03_03.php*).

Georgia

Georgia experienced 9 earthquakes since 1973; 7 of them were fatal, and the largest struck Racha-Java on April 29, 1991, causing an estimated 114 shaking fatalities. More than 105,000 people were estimated to have experienced shaking intensity IX and above and about 547,300 exposed at intensity VI and above. The estimated empirical model parameters for Georgia are θ= 26.49 and β= 0.33 with log residual error (ζ) of 0.74 as shown in figure 8.

We estimate a fatality rate of one per 2,180 people exposed to shaking intensity IX and one per 8500 people exposed to shaking intensity VIII. For intensity VII, the rate is much lower, approximately one per 45,600.

Greece

Twenty-five fatal earthquakes occurred in Greece in the past 3 decades resulting in 1,300 fatalities. The largest earthquake since last century was an earthquake of magnitude 7.2 that occurred on Aug 12, 1953, causing an estimated 800 deaths. Thirty earthquakes have been used to develop an empirical fatality model and the estimated parameters are θ= 21.48 and β= 0.28 with log residual error (ζ) of 1.43 as shown in figure 9. The fatality rate developed for Greek earthquakes is one death per 1,270 people exposed to shaking intensity IX which reduces to one per 43,300 at shaking intensity VII. The most recent deadly earthquake in Greece was the magnitude 6.0 Athens earthquake of Sept 9, 1999 which resulted in 143 deaths and caused extensive damage (*http://www.geo.uib.no/seismo/quakes_world/Athens-earthq/HTML/Pavlides1.htm*). About 65 buildings were reported collapsed killing 143 people and injuring about 7,000. The earthquake had an estimated exposure of 9,700 people at shaking intensity IX and 278,200 at shaking intensity VIII.

Algeria

Earthquakes have caused devastating effects in Algeria during the last few centuries. Recently, the magnitude 6.8 May 21, 2003, earthquake struck Boumerdes and Algiers, caused widespread damage in the epicentral region, claimed 2,271 human lives, injured about 10,000, damaged approximately 20,000 housing units, and left about 160,000 homeless (Bouhadad and others, 2004). In the past three decades, there were 23 significant earthquakes in Algeria, of which 12 caused one or more fatalities. The El Asnam earthquake of Algeria occurred on Oct 10, 1980, and was the deadliest since 1973; it killing an estimated 3,500 people. In our calculations, about 29,000 people were exposed to shaking intensity IX and an estimated 320,000 people exposed to intensity VIII.

Eighteen earthquakes since 1973, were used to develop an empirical fatality model for Algeria by considering recorded shaking deaths and associated population exposure at different shaking intensity levels (fig. 10). We estimate a fatality rate of one in 190 people exposed to shaking intensity IX and it decreases to one death per 8,940 people exposed at shaking intensity VII.

Italy

Earthquakes have claimed more than 36,000 human lives in Italy since beginning of 1900. About 32,610 people were killed in a single magnitude 7.0 earthquake that struck on Jan 13, 1915 that devastated buildings in Rome and Chieti (Davison, 1915). Historically there are several earthquakes that killed more than 200,000 (Jan 11, 1693 killed 60,000; Feb 4, 1783 killed 50,000; Dec 16, 1857 killed 11,000; Dec 28, 1908 killed 70,000 people) from a USGS compilation of historical earthquakes (*http://earthquake.usgs.gov/regional/world/historical_country.php#italy*).

Forty-three earthquakes, of which fifteen were fatal, were used to estimate the empirical model parameters for Italy. The largest earthquake that struck Italy since 1973 was the magnitude 6.9 Irpinia earthquake on Nov 23, 1980, which caused 2,483 deaths. The estimated population exposure was 37,200 people at shaking intensity IX and above and 250,180 at shaking intensity VIII. The empirical model parameters estimated are θ= 13.23 and β= 0.18, with log residual error (ζ) of 1.60 as shown in figure 11. The model corresponds to a fatality rate of one death per 68 people exposed to shaking intensity IX which reduced to one death per 6310 people exposed at shaking intensity VII.

Japan

Earthquakes are more common in Japan than most other countries of the world. There are 22 fatal earthquakes recorded in Japan since 1973 that have killed 5,945 people, and the deadliest one was the Jan 16, 1995, Kobe earthquake which alone took 5,502 lives. The Kobe earthquake had an estimated population exposure of 1,740,200 at shaking intensity IX and about 3,176,200 at shaking intensity VIII. We used 108 earthquakes in Japan since 1973 with zero or more deaths to estimate empirical model parameters as θ= 11.93 and β= 0.10 with log residual error (ζ) of 1.49 (fig. 12). We estimate a fatality rate that corresponds to an estimated one death in every 330 people exposed at shaking intensity IX and one in every 20,100 at shaking intensity VIII.

Pakistan

Pakistan is one of the most seismically vulnerable countries of the World and has already witnessed several devastating earthquakes in the last century which in total have killed more than 150,000 people. There are 84 earthquakes with magnitude 5.5 and above that have occurred in Pakistan in the last 35 years; 16 of them were fatal and claimed more than 93,000 lives. The magnitude 7.6 Kashmir earthquake of 2005 was the largest and most lethal in recent times, causing very heavy damage in the Muzaffarabad area and in the Kashmir region of north Pakistan, where entire villages were destroyed in the epicentral areas (*http://earthquake.usgs.gov/eqcenter/eqinthenews/2005/usdyae/#summary*). The Kashmir event caused 87,351 deaths and more than 69,000 injuries. The earthquake had an estimated 290,200 people exposed to shaking intensity IX and about 769,000 people exposed to shaking intensity VIII. The empirical model, developed using 23 fatal earthquakes since 1973, indicates a death rate of 1 per 4 people exposed to shaking intensity IX and about 1 per 1,850 people at shaking intensity

VII (fig. 13). These fatality rates are extremely high, confirming the extreme vulnerability of the region's structures and population to earthquakes.

Peru

Located on a circum-Pacific seismic belt, an active seismotectonic region which witnesses more than two-third of the world's large-magnitude earthquakes, Peru has experienced dozens of fatal earthquakes in the past several decades. The Ancash earthquake of November 10, 1946, was the deadliest and caused 1,400 fatalities. Widespread destruction to the building stock was reported in this earthquake near the Sihuas-Quiches-Conchucos area of Ancash, an area also affected by landslides (*http://earthquake.usgs.gov/regional/world/events/1946_11_10.php*).

Despite experiencing 122 earthquakes with magnitude 5.5 or greater since 1973, Peru surprisingly had reported fatalities from only 27 of them. We used 33 events that have experienced zero or more fatalities since 1973 to estimate the model parameters as shown in figure 14. The estimated parameters correspond to a fatality rate of 1 death per 4,180 people exposed to intensity IX shaking and 1 death per 31,000 at shaking intensity VII. The recent magnitude 8.0 August 15, 2007, Pisco earthquake, which killed 514 people, affected an estimated 493,400 people at shaking intensity VIII and 307,200 at shaking intensity VII.

Philippines

The Philippines has a long history of earthquake occurrence (Bautista and Bautista, 2004), and the earliest earthquake reported was as far back as 1589. The magnitude 7.7 earthquake of July 16, 1990, in Luzon was the strongest earthquake in the Philippines in recent times; it caused 1,621 fatalities. For that event, an estimated 892,500 people were exposed to shaking intensity IX and above and 1,217,700 were exposed at intensity VIII.

The Philippines has experienced more than 300 earthquakes of magnitude 5.5 or greater of which 20 were fatal, totaling an estimated 1,773 shaking-related deaths. We used all the earthquakes since 1973 with zero or more deaths to develop an empirical fatality model. The estimated rate corresponds to 1 death per 1,700 people exposed at intensity IX and 1 death per 22,100 people at shaking intensity VIII, as shown in figure 15.

Romania

The magnitude 7.4 Bucharest earthquake of March 4, 1977, one of the most destructive earthquakes in Vrancea, Romania, in recent times, killed 1,581 people and injured 7,576. Thirty-two 8–12-story buildings collapsed and another 150 old buildings (4–6 stories) were heavily damaged (Mandrescu and others, 2007). The empirical model developed using six earthquakes with zero or more deaths since 1973 provides θ= 17.50 and β= 0.24 with slightly higher log residual error (ζ) of 2.60 as shown in figure 16. The estimated fatality rate corresponds to 1 death per 360 people exposed at shaking intensity IX and 1 death per 15,200 at intensity VII.

Turkey

Earthquakes in Turkey during the 20th century have caused enormous loss of life and property with a total of 110,000 deaths and 250,000 injuries while destroying more than 600,000 housing units (Erdik, 2003). The Marmara region (the western portion of the North Anatolian fault zone) in Turkey has been the site of numerous destructive earthquakes (Erdik and others, 2004). There have been 64 fatal earthquakes in Turkey since 1900; 40 of them struck the country since 1973 killing more than 27,000 people. The Aug 17, 1999, Kocaeli earthquake caused an estimated 17,439 shaking-related deaths with an estimated population exposure of 572,400 at shaking intensity IX and above. The empirical model developed for Turkey as shown in figure 17 indicates a death rate of 1 per 38 people exposed at shaking intensity IX; about 1 death per 1,000 exposed at shaking intensity VIII.

United States

The PAGER regionalization scheme proposed in this investigation treats California differently than rest of the United States. The existence of seismically resistant building stock with stringent building code enforcement and construction practice, and sustained efforts towards seismic risk reduction for future earthquakes, demands such demarcation. The rest of the conterminous United States is less prone to frequent, large earthquakes compared to California. Due to lack of fatal earthquakes in United States, it was not possible to deduce an empirical fatality model from past earthquake data alone. In the first internal release of empirical model (v1.0), we have used expert judgment to develop the fatality rate model shown in figure 18. It is mainly based on comparing the fatality rate among several groups of countries. The fatality rate derived from past earthquake data in Taiwan appears to be slightly higher than California but lower than Northern Europe. The proposed empirical fatality rate for the rest of the United States lies between Northern Europe and Taiwan with estimated death rate of 1 person per 12,470 exposed at shaking intensity IX and above. The rate reduces to 1 person per 61,300 exposed at shaking intensity VIII and almost no deaths at shaking intensity VI or below.

In the current release (v1.1), we have used all fatal as well as nonfatal earthquakes from a group of countries including Canada, Australia, Mexico, and others (refer to appendix I) to deduce the empirical fatality rate. Despite the higher vulnerability of overall Mexican building stock, both Mexico and the rest of the United States (without California) have a substantial amount of unreinforced masonry buildings, which are extremely vulnerable at higher intensities. The estimated empirical fatality rate for a group of countries indicates 1 death per 23,400 people exposed at intensity IX, and it reduces to 1 death per 52,900 at intensity VIII. The newly estimated rate is lower at intensity IX than estimated by the v1.0 model but slightly higher at lower intensity. We think this difference is partially due to the influence of earthquakes from Mexico on the group model. Further investigations are necessary in order to estimate the validity of a regional or expert-judgment model to be used for fatality estimation in the rest of United States. Other candidate loss-modeling approaches, such as semi-empirical and analytical models being developed for PAGER casualty assessment, will also be used along with the empirical model (v1.1) for future casualty estimates.

Fatality Estimation for Recent Earthquakes

We have implemented the PAGER empirical model to test the fatality estimation for recent earthquakes not used in the calibration process. We provide a summary of estimated earthquake deaths of all the earthquakes of magnitude 5.5 and above that occurred from January to June 2008 and compare the estimated with the deaths recorded by credible reporting agencies. As shown in table 2, more than 77 percent of the smaller events which had zero recorded deaths were estimated correctly. For events with few shaking deaths, the estimated deaths were within ±½ order of magnitude. For large earthquakes such as Sichuan in China, the model computation was based on data prior to 2007 and we estimated 51,000 deaths. Since this earthquake was such a profound catastrophe, and it is well documented, we have now included it in recalibration of the empirical model for China.

The current PAGER system that runs internally at the USGS has implemented the empirical model discussed in this report as well as semi-empirical and analytical models (Wald and others, 2008). We are currently monitoring the performance of the system (stability in terms of triggering events, performing automatic casualty estimates, alarming, and distribution) before making fatality estimates public.

Summary and Conclusions

We studied global earthquake fatality data (1973–2007) and propose a new approach for estimating earthquake fatalities worldwide. We use a two-parameter empirical lognormal distribution to express country-specific mean fatality rate as a function solely of MMI, without reference to other earthquake parameters (for example, magnitude, location, or time of day). Our model development compares the total recorded shaking-related deaths for each earthquake in our catalog to the estimated populations exposed to each MMI intensity level determined using the ShakeMap and LandScan population database. For countries with low seismic hazard and thus limited fatality data, we combined fatality data from neighboring countries that have similar vulnerabilities. The regionalization scheme proposed in this investigation is preliminary and based on qualitative analysis. Further investigations are necessary in order to validate the applicability of regional empirical model for countries where there are few or no fatal earthquakes.

For more than 200 countries, we employed our regionalization scheme, combining data from several different countries (appendix II). We envision that the addition of more-recent earthquakes (both fatal and nonfatal) and the incorporation of additional constraints (for example, in terms of macroseismic intensities, choice of appropriate ground motion prediction equations, or new PGA-MMI conversion rules) will be necessary to put boundaries on the empirical fatality rates globally. This new information may require re-creation of Shakemaps of past fatal earthquakes and frequent recalibration of the empirical model parameters. In order to include such changes, we plan to update the electronic version of appendix II (*http://earthquake.usgs.gov/eqcenter/pager/*) regularly as new data trigger the updating of fatality rates for a particular country or region.

We also presented a comparison of fatality estimations based on the empirical model with the actual recorded fatalities for recent (2008) earthquakes and found a very good match in more than 95 percent of the events. Using this initial model, PAGER could estimate total event-level fatalities in future earthquakes within an average ½ to 1 order of magnitude, with higher accuracy in highly fatal events.

One obvious limitation of the empirical model is the paucity of data in low-seismic countries or few fatal earthquakes in large countries during the limited time period for which quality hazard, loss, and population data are available. This empirical approach will therefore be supplemented with other engineering-based models for the PAGER casualty estimation system. In addition, for larger countries which warrant sub-country level fatality models, given their diversity of regional construction practices, we will investigate the potential for countries or regions with sufficient empirical data.

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Appendix I. PAGER Regionalization Scheme for the Empirical Model

[The following table describes the regionalization scheme with respect to data on the human development index (HDI), climate characteristics, and common building types in the group of countries. Refer to figure Ia for the map of proposed regionalization scheme with colors indicating individual regions. Figure Ib shows a global map of countries based on the HDI, and figure Ic shows a map associated with climate characteristics]

Region	List of Countries	Human development and climatic characteristics (refer to figures Ib & Ic)	Description
1. Australia, USA, and Canada	Australia, Canada, and United States (without California), Mexico, Saint Pierre and Miquelon, United States Minor Outlying Islands	**HDI:** Mostly high, more than 0.95 with higher end for United States and lower of 0.84 in Mexico. **Climate:** Varies significantly within country. For example, within Australia, the climate varies from warm temperate, to arid with desert precipitation and mostly hot arid temperature. In the United States, it is warm and temperate, with high humidity in the East and dry in West. In Canada, the main climate is snow, with high humidity precipitation and cool summer temperatures in the North to hot in southern Canada.	This group consists of countries which have a) most of its building stock engineered b) very few vulnerable structures and c) stringent building design and construction standards. Except Mexico, all the other countries in this region have fewer fatal earthquakes during the catalog period to have country-specific fatality models. Most of the residential building stock in North America (except California) is of unreinforced masonry construction and wood frame construction. Mexican building stock, although comparatively more vulnerable given its performance in recent earthquakes, provides a useful basis for developing a regional vulnerability/fatality model.
2. New Zealand and California	New Zealand and California state of USA	**HDI:** Mostly high, in the range of 0.94. For California, a country level index is representative. **Climate:** Varies significantly. In New Zealand, it is temperate oceanic climate with heavy winter snows. California has Mediterranean climate (warm temperate) with summer dry precipitation. Summers are hot and dry, due to domination of subtropical high pressure system.	Through sustainable developments, both California and New Zealand have achieved higher earthquake safety standards than rest of the world. Most of the residential building stock in this region is a single-family wood-frame construction designed to resist earthquake shaking. Historical earthquakes in this region have caused very few fatalities relative to other countries for similar-sized earthquakes.

3. Central America	Costa Rica and Panama	**HDI:** 0.85 in Costa Rica and 0.83 in Panama. **Climate:** Tropical rain forest climate that is monotonously wet throughout the year.	Both Costa Rica and Panama have experienced substantial losses during past fatal earthquakes. Earthquakes from Costa Rica contribute to the development of regional empirical mode to be used for Panama.
4. South Central America	Dominican Republic, Jamaica, Guadeloupe, El Salvador	**HDI:** Mostly in the range of 0.75–0.77 with high of 0.92 in Guadeloupe. **Climate:** Tropical rain forest climate with monotonously wet throughout the year.	The building stock and construction practice in this group suits the local conditions (predominant use of wood/mud/concrete for construction of houses).
5. Caribbean and Central America	Guatemala, Belize, Honduras, Nicaragua, Haiti, Puerto Rico, Cayman Islands, Turks and Caicos Islands, Anguilla, Montserrat, Cuba, Bahamas, Saint Kitts and Nevis, Saint Lucia, Antigua and Barbuda, Trinidad and Tobago, Aruba, Netherlands Antilles, Dominica, Grenada, Saint Vincent and the Grenadines, Martinique, British Virgin Islands, U.S. Virgin Islands, Barbados, Saint Barthelemy, Saint Martin (France)	**HDI:** Medium in the range of 0.69–0.71 in Nicaragua, Honduras, Guatemala with 0.77 in Belize and 0.52 in Haiti. High in the range of 0.8–0.9 with higher in Barbados, Bahamas, Cuba. **Climate:** Equatorial climate with fully humid or monsoonal precipitation throughout the region.	This is a group of islands and oceanic countries in Pacific and Atlantic oceans. None of the countries except Guatemala has enough fatal earthquakes to generate country-specific empirical models. It is assumed that these places have similar vulnerability to earthquakes primarily due to similar geographic and weather conditions.
6. Western South America	Colombia, Ecuador, Peru, Chile, Argentina	**HDI:** Mostly high in the range of 0.85–0.9. In the medium range, it is 0.79 in Colombia. **Climate:** It varies from arid to warm temperate from east to west and temperature is mostly between hot to warm summer.	Countries in this group have similar construction practices and building stock.
7. Eastern South America	Venezuela, Bolivia, Brazil, Uruguay, Guyana, Suriname, Paraguay, French Guiana	**HDI:** Mostly high in the range of 0.75–0.9 with 0.85 in Uruguay and 0.8 in Brazil, and 0.76 in Paraguay. **Climate:** Mixed climate zone with equatorial and winter dry precipitation in Central Brazil. Equatorial with fully humid to monsoonal precipitation in Northern Brazil. Mostly warm temperate with hot and warm summer temperature in Southern Brazil.	Unreinforced clay brick/block masonry construction, confined masonry, and adobe construction are most common in this group of countries. Some of the countries in this group may have significantly different building stock; however none of the countries have adequate earthquake casualty data to develop a country-specific empirical casualty model.
8. North Africa	Algeria, Egypt, Tunisia, Western Sahara	**HDI:** Medium to high level with 0.77 for Tunisia, and 0.73 for Algeria. **Climate:** Mixed climate condition with slight variation within a country. Most parts	Countries like Algeria and Egypt have experienced earthquakes in the past centuries and have vulnerable construction as a part of its building stock.

		of Algeria and Western Sahara has arid climate with desert precipitation and hot arid temperature. Northern parts of Morocco Tunisia and Algeria have warm temperate and summer dry precipitation with hot summer temperatures.	
9. South-central Africa	Botswana, Namibia, South Africa, Swaziland, Zimbabwe, Morocco, Sudan, Chad, Central African Republic, Cameroon, Congo, DRP Congo, Gabon, Equatorial Guinea, Sao Tome and Principe, Angola, Mauritania, Senegal, Gambia, Guinea-Bissau, Sierra Leone, Liberia, Cote d'Ivoire, Ghana, Togo, Benin, Niger, Nigeria, Mali, Burkina Faso, Guinea, Yemen, Eritrea, Djibouti, Ethiopia, Somalia, Kenya, Uganda, Rwanda,Burundi, United Republic of Tanzania, Malawi, Madagascar, Mozambique, Zambia, Lesotho	**HDI:** Mostly in low range (less than 0.5) in the east coast except in Kenya and Madagascar with lower medium range that is, between 0.50–0.55. No HDI index data is available for Somalia. Gabon being highest at 0.68. **Climate:** Mostly equatorial climate except in Somalia and parts of Ethiopia where it is arid desert and high arid temperatures. Equatorial climate throughout central part with winter dry precipitation and arid desert climate in northern part of Central Africa. Parts of Central Africa receive monsoonal precipitation.	Buildings in central African countries are generally adobe, mud wall, and clay burnt brick masonry constructions. Rural areas constitute 60% of informal construction. This is mainly due to cheaper locally available material, climatic condition, age-old construction practices and lack of adequate infrastructure.
10. Italy	Italy, Holy See, Malta, San Marino	**HDI:** Mostly high in the range of 0.94–0.95 for Italy and other countries but slightly lower value of 0.88 for Malta. **Climate:** Warm temperate climate with fully humid precipitation in northern part to summer dry in southern part of the Italy.	Concrete, moment-frame construction and masonry construction constitute more than 80% of the building stock in this region.
11. Northern Europe	Norway, Sweden, Finland, Denmark, Germany, Belgium, France, Austria, Switzerland, Aland Islands, Monaco, Poland, Bouvet Island, United Kingdom, Ireland, Guernsey, Isle of Man, Jersey, Falkland Islands (Malvinas), Saint Helena, South Georgia and the South Sandwich Islands, Iceland, Faroe Islands, Greenland, Svalbard and Jan Mayen, Liechtenstein, Luxembourg, Netherlands, Greece, Spain, Portugal, Gibraltar, Cape Verde, Andorra	**HDI:** High index through northern Europe with highest in Norway, Ireland and Sweden around 0.96–0.98. HDI is 0.89 in Portugal and 0.95 for Spain but slightly lower in the range of 0.87 for Poland. **Climate:** Warm temperate climate with fully humid precipitation and warm summer throughout northern Europe except Norway, Sweden, and Finland where it is mostly snow climate and fully humid with cool summer temperature.	These countries have not experienced large fatal earthquakes in the past. The building stock in these countries generally consists of ancient European-style massive stone masonry and block masonry constructions which are vulnerable to shaking. Most of the buildings constructed after 1960s are concrete and steel moment frame constructions.
12. Eastern Europe	Czech Republic, Slovenia, Slovakia, Hungary, Bosnia and Herzegovina, Croatia, Serbia, Montenegro, Romania, Albania, Former Yugoslav Republic of Macedonia,	**HDI:** Mostly high, in the range of 0.8–0.9 with higher in Slovenia. No HDI data is available for Serbia and Montenegro. HDI is 0.8 in Macedonia, Bulgaria and Albania.	This group of countries which have experienced deadly earthquakes in the past. Block masonry, rubble/dressed stone masonry, and concrete framed constructions

	Bulgaria, Republic of Moldova	Medium in the range of 0.7 for Moldova. **Climate:** Snow climate, fully humid precipitation with warm summer temperatures throughout Eastern European countries.	are common in this group of countries; they also share similarities in terms of geography and socio-economic characteristics. Both Spain and Portugal have experienced significant earthquakes in the past but they do not have enough earthquakes to develop country-specific models.
13. Baltic States and Russia	Estonia, Latvia, Lithuania, Belarus, Ukraine, Russian Federation, Georgia, Armenia, Azerbaijan	**HDI:** Mostly high, in the range of 0.8–0.85. It varies slightly within the Baltic states with the upper end in Russia and the lower end for Ukraine in the range of 0.75–0.8. **Climate:** The main climate within the Baltic states is snow with fully humid precipitation; temperature that varies from warm summer in Ukraine and Belarus to cool summer in the northern and central Russian Federation, with the Polar Tundra temperature in parts of northern Russia close to the north pole.	These countries that have experienced fatal earthquakes during the last few centuries and have similar building stock. Some of the building stock is extremely vulnerable to earthquake shaking. The region is part of former Soviet Union and has vulnerable construction (particularly, precast concrete framed and block masonry construction which performed poorly in the 1988 Spitak, Armenia earthquake).
14. Central Asia	Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, Tajikistan	**HDI:** Medium to high index, in the range of 0.67–0.71with lowest in Tajikistan and highest in Turkmenistan. **Climate:** Arid Steppe climate with cold arid temperature throughout the region and desert precipitation in central part. Warm temperate with summer dry conditions in the pockets of southeastern parts of Tajikistan and Kyrgyzstan.	Common buildings types in this group consist of precast concrete, stone/concrete block masonry construction and steel moment frame with infill masonry construction. Construction practices were strongly influenced during the former Soviet Union era. Rural area consists of predominant adobe and wood construction.
15. Arabian Peninsula	Turkey, Oman, United Arab Emirates, Qatar, Saudi Arabia, Bahrain, Kuwait, Lebanon, Jordan, Palestinian Territory, Syrian Arab Republic, Israel, Cyprus, Libyan Arab Jamahiriya	**HDI:** Mostly high, in the range of 0.8 in Libya with higher end in Saudi Arabia. Medium in Syria and high in Israel. HDI is in the range of 0.7–0.8 for other countries. **Climate:** Arid, desert and hot arid and slightly cold arid temperature. Warm temperate with steppe and hot summer condition in northern pockets of Libya. Arid climate with steppe and cold arid temperatures in eastern part of the countries.	This group consists of countries which potentially have low seismic hazard and have experienced very few fatal earthquakes during the catalog period. The most common building construction is adobe, brick, and stone masonry construction for residential and reinforced concrete construction for workplaces. With low seismic hazard, the building stock is generally not considered to be designed for earthquake resistant characteristics (Petrovski, 1983).
16. Iran & Iraq	Iran, Iraq, Afghanistan and Pakistan	**HDI:** Lowest in Afghanistan, Iraq and	Predominantly vulnerable construction

		Pakistan in the range of 0.5–0.6 and 0.76 in Iran. **Climate:** Arid climate with desert precipitation through the region with hot arid temperatures. The northern parts of these countries have mostly cold arid temperatures.	includes traditional adobe, unburnt brick, and block-masonry constructions which have experienced severe damage during past earthquakes. About 70-80% of rural building stock is made of traditional constructions in these countries.
17. Chinese Peninsula	Brunei Darussalam, China, North Korea, S. Korea, Macao, Mongolia	**HDI:** High in the range of 0.75–0.8 with medium (0.7–0.75) for Mongolia. **Climate:** Mixed climate zone within countries. In China, it varies from arid desert to polar tundra climate in the central and southern part and warm temperate climate with humid and hot summer temperature in southern and eastern Coast of China. In Southern Mongolia, the climate is mostly arid with winter dry precipitation to snow climate with cool summers in the northern part of the country. Central parts of S. Korea have snow climate with winter dry precipitation and hot summer temperature.	During the catalog period only a few deadly earthquakes occurred in one or two countries in this group. These countries have significant vulnerable building stock.
18. Philippines and Malaysian Peninsula	Singapore, Thailand, Hong Kong, Malaysia, Philippines	**HDI:** Mostly high 0.82–0.92 in Malaysia and Singapore and medium in the range of 0.75–0.78 in Philippines and Thailand respectively. **Climate:** In Thailand, Malaysia, and Philippines, the main climate is mostly equatorial but the precipitation varies from winter dry to fully humid in Malaysia.	This region consists of a group of countries that are relatively similar in terms of their urban building stock, but rural areas may have variable construction practices.
19. Indian Peninsula	India, Sri Lanka, Bangladesh, Nepal, Bhutan, Myanmar	**HDI:** Varies from 0.62 in India to 0.74 in Sri Lanka. **Climate:** Mixed climatic condition within a country. Polar tundra climate in northern Nepal and equatorial climate with winter dry precipitation . In India, it is mostly warm temperate in central India to equatorial southern India and arid in western parts of northern India. In Sri Lanka, it is equatorial with winter dry precipitation in north to fully humid condition in southern Sri Lanka.	Most of the buildings in Nepal, Bhutan and Myanmar are constructed using adobe, rubble stones, and clay burnt bricks. Countries in this group have experienced several fatal earthquakes during the last few decades and are believed to be similar in terms of their susceptibility to earthquake losses.
20. Indonesian	Cambodia, Laos, Timor-Leste Viet Nam,	**HDI:** Mostly medium range but lowest in	Countries in this group have experienced

Peninsula	Papua New Guinea, American Samoa, Samoa, Tokelau, Tuvalu, Fiji, Tonga, Vanuatu, Wallis and Futuna, Niue, Nauru, New Caledonia, Solomon Islands, Palau, Guam, Northern Mariana Islands, Marshall Islands, Federated States of Micronesia, Kiribati, Cook Islands, French Polynesia, Norfolk Island, Pitcairn, British Indian Ocean Territory, Christmas Island, Cocos (Keeling) Islands, French Southern Territories, Heard Island and McDonald Islands, Maldives, Comoros, Mauritius, Mayotte, Reunion, Seychelles, Bermuda, Antarctica, Indonesia	Laos, Timor in the range of 0.5–0.55 and in the range of 0.72–0.75 in other countries. **Climate:** Mostly equatorial and varies within a country. In Indonesia, it is fully humid precipitation in the central islands of Indonesia, and winter dry to monsoonal precipitation in Cambodia and Viet Nam.	numerous deadly earthquakes in the past. They share analogous construction practices (predominant clay brick masonry, wood, and block masonry constructions) and have vulnerable building stock prone to earthquake damage.
21. Japan & South Korea	Japan, Taiwan	**HDI:** Mostly high index ranges from 0.92–0.95. **Climate:** Main climate is a warm temperate condition with fully humid precipitation and hot summer. The northern tip of the Japanese islands has snow climate with fully humid condition and warm summer.	Traditional as well as modern wood-frame constructions are the most common forms of residential construction in both rural as well as urban areas. However most recent buildings (constructed after 1980s) in urban areas are generally either concrete shear wall or steel moment-frame constructions.

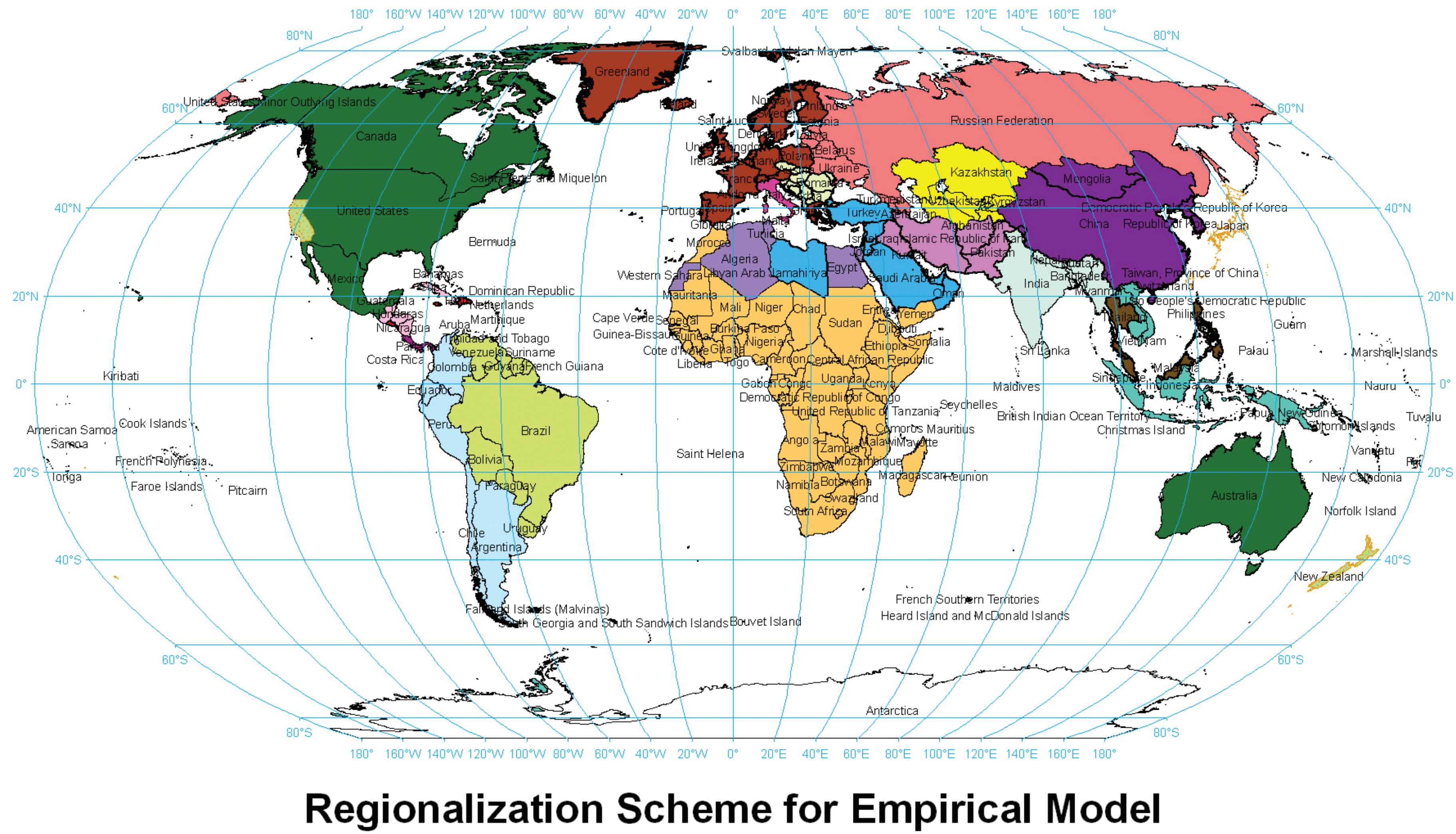


Figure Ia. Proposed regionalization scheme (groups shown with different colors) for empirical loss modeling.

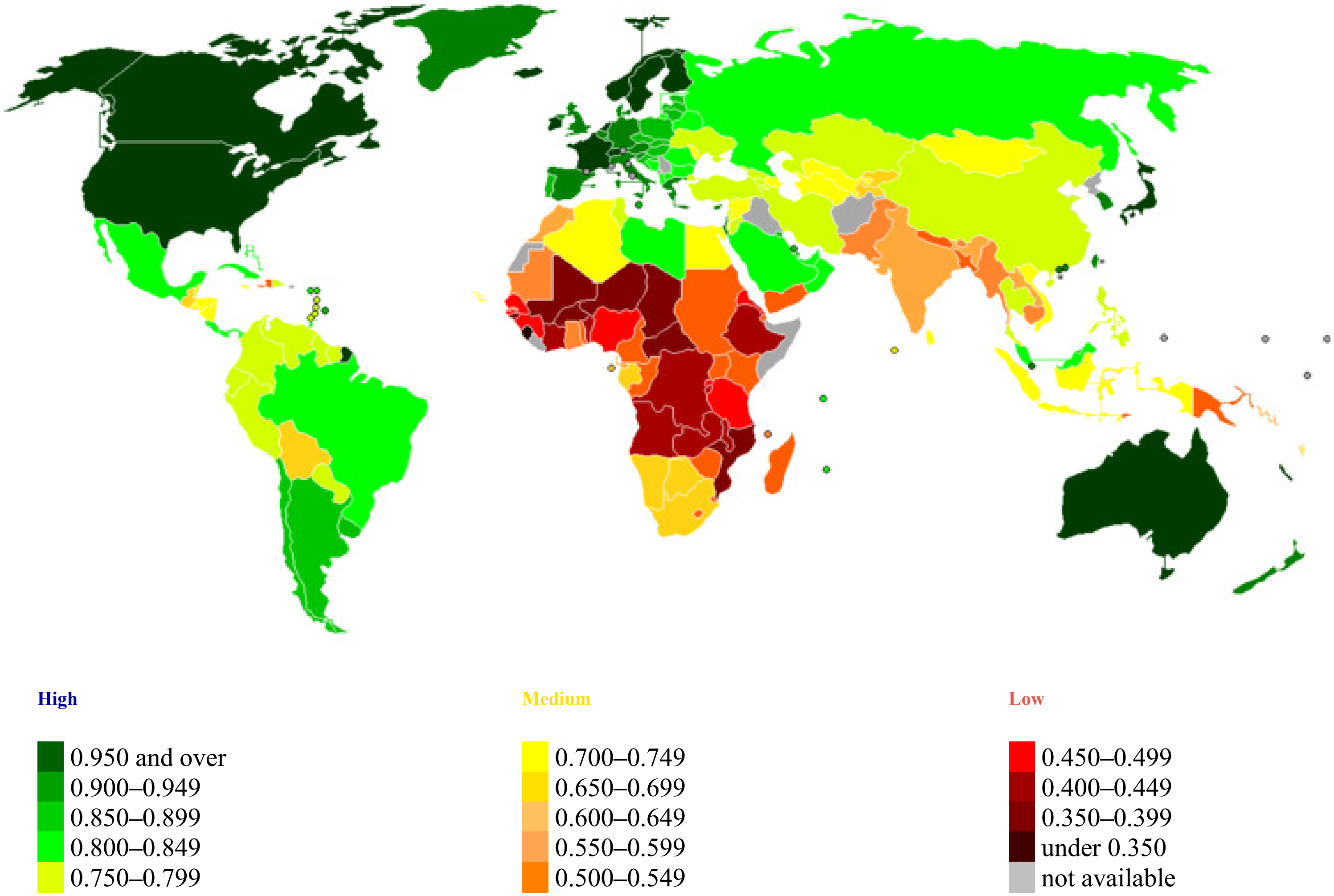


Figure Ib. Map showing spatial variation of Human Development Index (HDI) (Source: http://hdrstats.undp.org/indicators/1.html and http://en.wikipedia.org/wiki/List_of_countries_by_Human_Development_Index).

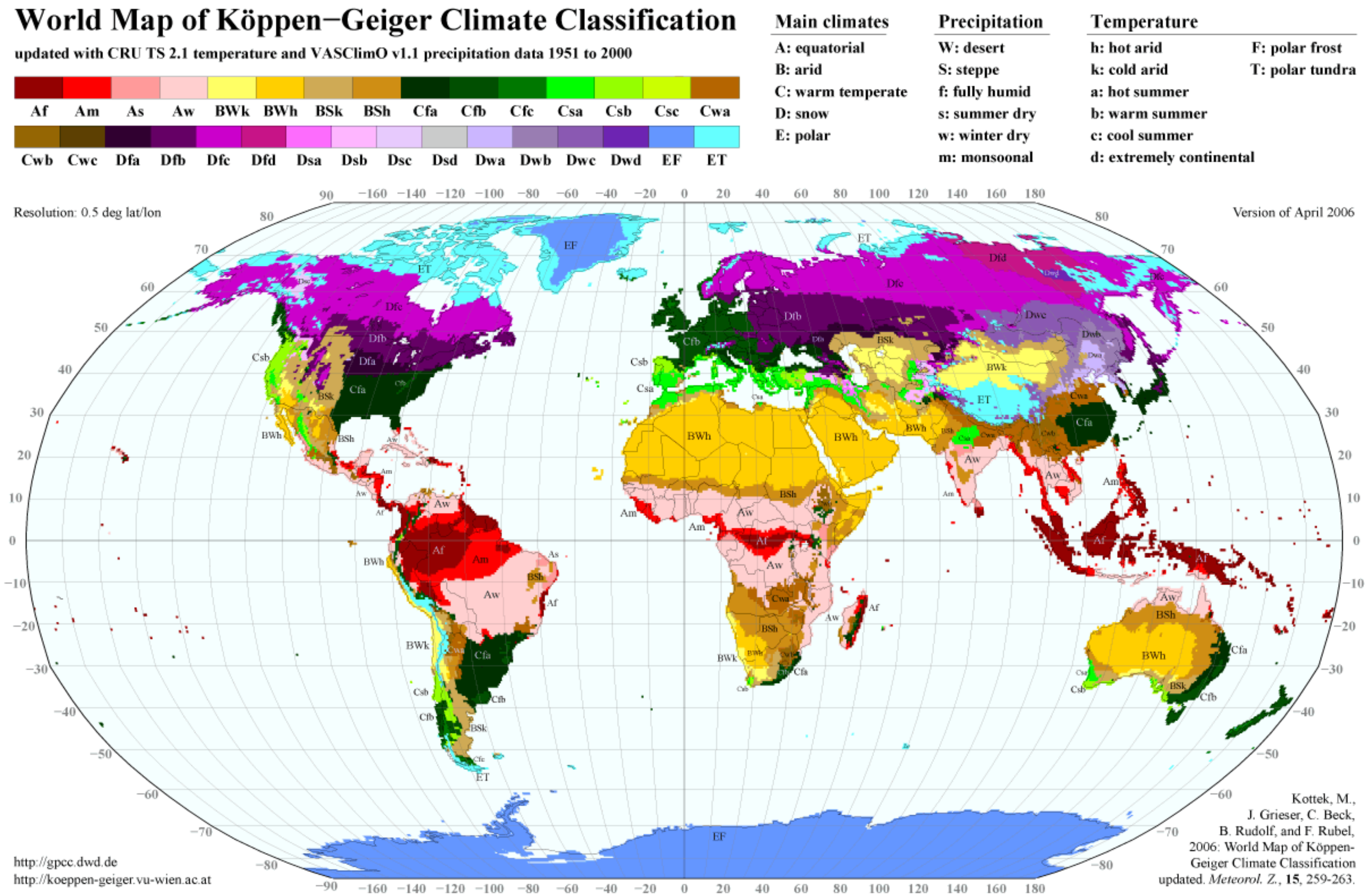


Figure Ic. Map showing Koppen-Geiger climatic classification.

Appendix II. PAGER Implementation of Empirical Model*

Country Name	ISO code	Theta	Beta	ζ (residual error)	Number of earthquakes	Status
Afghanistan	AF	31.44	0.43	2.24	26	Country
Aland Islands	AX	18.63	0.24	1.41	47	Group
Albania	AL	16.47	0.22	1.82	29	Group
Algeria	DZ	15.91	0.22	2.17	18	Country
American Samoa	AS	13.71	0.16	1.89	110	Group
Andorra	AD	18.63	0.24	1.41	47	Group
Angola	AO	15.05	0.19	2.18	29	Group
Anguilla	AI	12.56	0.13	1.52	29	Group
Antarctica	AQ	13.71	0.16	1.89	110	Group
Antigua and Barbuda	AG	12.56	0.13	1.52	29	Group
Argentina	AR	75.99	0.57	1.71	97	Group
Armenia	AM	29.74	0.36	2.43	21	Group
Aruba	AW	12.56	0.13	1.52	29	Group
Australia	AU	100.00	0.61	1.63	49	Group
Austria	AT	18.63	0.24	1.41	47	Group
Azerbaijan	AZ	29.74	0.36	2.43	21	Group
Bahamas	BS	12.56	0.13	1.52	29	Group
Bahrain	BH	11.05	0.10	1.61	87	Group
Bangladesh	BD	11.01	0.11	2.38	44	Group
Barbados	BB	12.56	0.13	1.52	29	Group
Belarus	BY	29.74	0.36	2.43	21	Group
Belgium	BE	18.63	0.24	1.41	47	Group
Belize	BZ	12.56	0.13	1.52	29	Group
Benin	BJ	15.05	0.19	2.18	29	Group
Bermuda	BM	13.71	0.16	1.89	110	Group
Bhutan	BT	11.01	0.11	2.38	44	Group
Bolivia	BO	100.00	0.63	1.83	13	Group
Bosnia and Herzegovina	BA	16.47	0.22	1.82	29	Group
Botswana	BW	15.05	0.19	2.18	29	Group
Bouvet Island	BV	18.63	0.24	1.41	47	Group
Brazil	BR	100.00	0.63	1.83	13	Group
British Indian Ocean Territory	IO	13.71	0.16	1.89	110	Group
Brunei Darussalam	BN	10.40	0.10	2.03	119	Group
Bulgaria	BG	16.47	0.22	1.82	29	Group
Burkina Faso	BF	15.05	0.19	2.18	29	Group
Burundi	BI	15.05	0.19	2.18	29	Group

Cambodia	KH	13.71	0.16	1.89	110	Group
Cameroon	CM	15.05	0.19	2.18	29	Group
Canada	CA	100.00	0.61	1.63	49	Group
Cape Verde	CV	18.63	0.24	1.41	47	Group
Cayman Islands	KY	12.56	0.13	1.52	29	Group
Central African Republic	CF	15.05	0.19	2.18	29	Group
Chad	TD	15.05	0.19	2.18	29	Group
Chile	CL	40.93	0.44	1.77	26	Country
China	CN	10.40	0.10	2.03	119	Country
Christmas Island	CX	13.71	0.16	1.89	110	Group
Cocos (Keeling) Islands	CC	13.71	0.16	1.89	110	Group
Colombia	CO	48.07	0.47	2.29	22	Country
Comoros	KM	13.71	0.16	1.89	110	Group
Congo	CG	15.05	0.19	2.18	29	Group
Democratic Republic of the Congo	CD	15.05	0.19	2.18	29	Group
Cook Islands	CK	13.71	0.16	1.89	110	Group
Costa Rica	CR	27.61	0.36	1.62	3	Country
Cote d'Ivoire	CI	15.05	0.19	2.18	29	Group
Croatia	HR	16.47	0.22	1.82	29	Group
Cuba	CU	12.56	0.13	1.52	29	Group
Cyprus	CY	11.05	0.10	1.61	87	Group
Czech Republic	CZ	16.47	0.22	1.82	29	Group
Denmark	DK	18.63	0.24	1.41	47	Group
Djibouti	DJ	15.05	0.19	2.18	29	Group
Dominica	DM	12.56	0.13	1.52	29	Group
Dominican Republic	DO	33.77	0.37	1.86	13	Group
Ecuador	EC	100.00	0.64	1.74	12	Country
Egypt	EG	16.16	0.23	1.99	22	Group
El Salvador	SV	26.62	0.32	1.95	7	Country
Equatorial Guinea	GQ	15.05	0.19	2.18	29	Group
Eritrea	ER	15.05	0.19	2.18	29	Group
Estonia	EE	29.74	0.36	2.43	21	Group
Ethiopia	ET	15.05	0.19	2.18	29	Group
Falkland Islands (Malvinas)	FK	18.63	0.24	1.41	47	Group
Faroe Islands	FO	18.63	0.24	1.41	47	Group
Fiji	FJ	13.71	0.16	1.89	110	Group
Finland	FI	18.63	0.24	1.41	47	Group
France	FR	18.63	0.24	1.41	47	Group
French Guiana	GF	100.00	0.63	1.83	13	Group
French Polynesia	PF	13.71	0.16	1.89	110	Group
French Southern Territories	TF	13.71	0.16	1.89	110	Group
Gabon	GA	15.05	0.19	2.18	29	Group
Gambia	GM	15.05	0.19	2.18	29	Group

Georgia	GE	26.49	0.33	0.74	7	Country
Germany	DE	18.63	0.24	1.41	47	Group
Ghana	GH	15.05	0.19	2.18	29	Group
Gibraltar	GI	18.63	0.24	1.41	47	Group
Greece	GR	21.48	0.28	1.43	30	Country
Greenland	GL	18.63	0.24	1.41	47	Group
Grenada	GD	12.56	0.13	1.52	29	Group
Guadeloupe	GP	33.77	0.37	1.86	13	Group
Guam	GU	13.71	0.16	1.89	110	Group
Guatemala	GT	12.25	0.13	1.83	15	Country
Guernsey	GG	18.63	0.24	1.41	47	Group
Guinea	GN	15.05	0.19	2.18	29	Group
Guinea-Bissau	GW	15.05	0.19	2.18	29	Group
Guyana	GY	100.00	0.63	1.83	13	Group
Haiti	HT	12.56	0.13	1.52	29	Group
Heard Island and McDonald Islands	HM	13.71	0.16	1.89	110	Group
Holy See (Vatican City State)	VA	13.23	0.18	1.6	43	Group
Honduras	HN	12.56	0.13	1.52	29	Group
Hong Kong	HK	16.04	0.18	1.51	32	Group
Hungary	HU	16.47	0.22	1.82	29	Group
Iceland	IS	18.63	0.24	1.41	47	Group
India	IN	11.53	0.14	1.93	28	Country
Indonesia	ID	14.05	0.17	1.74	78	Country
Islamic Republic of Iran	IR	9.58	0.10	2.71	93	Country
Iraq	IQ	9.70	0.10	2.46	143	Group
Ireland	IE	18.63	0.24	1.41	47	Group
Isle of Man	IM	18.63	0.24	1.41	47	Group
Israel	IL	11.05	0.10	1.61	87	Group
Italy	IT	13.23	0.18	1.6	43	Country
Jamaica	JM	33.77	0.37	1.86	13	Group
Japan	JP	11.93	0.10	1.49	108	Country
Jersey	JE	18.63	0.24	1.41	47	Group
Jordan	JO	11.05	0.10	1.61	87	Group
Kazakhstan	KZ	16.37	0.2	1.63	15	Group
Kenya	KE	15.05	0.19	2.18	29	Group
Kiribati	KI	13.71	0.16	1.89	110	Group
D. People's Republic of Korea	KP	10.40	0.10	2.03	119	Group
Republic of Korea	KR	10.40	0.10	2.03	119	Group
Kuwait	KW	11.05	0.10	1.61	87	Group
Kyrgyzstan	KG	16.37	0.20	1.63	15	Group
Lao People's Democratic Republic	LA	13.71	0.16	1.89	110	Group
Latvia	LV	29.74	0.36	2.43	21	Group

Lebanon	LB	11.05	0.10	1.61	87	Group
Lesotho	LS	15.05	0.19	2.18	29	Group
Liberia	LR	15.05	0.19	2.18	29	Group
Libyan Arab Jamahiriya	LY	11.05	0.10	1.61	87	Group
Liechtenstein	LI	18.63	0.24	1.41	47	Group
Lithuania	LT	29.74	0.36	2.43	21	Group
Luxembourg	LU	18.63	0.24	1.41	47	Group
Macao	MO	10.40	0.10	2.03	119	Group
Former Yugoslav R. of Macedonia	MK	16.47	0.22	1.82	29	Group
Madagascar	MG	15.05	0.19	2.18	29	Group
Malawi	MW	15.05	0.19	2.18	29	Group
Malaysia	MY	16.04	0.18	1.51	32	Group
Maldives	MV	13.71	0.16	1.89	110	Group
Mali	ML	15.05	0.19	2.18	29	Group
Malta	MT	13.23	0.18	1.6	43	Group
Marshall Islands	MH	13.71	0.16	1.89	110	Group
Martinique	MQ	12.56	0.13	1.52	29	Group
Mauritania	MR	15.05	0.19	2.18	29	Group
Mauritius	MU	13.71	0.16	1.89	110	Group
Mayotte	YT	13.71	0.16	1.89	110	Group
Mexico	MX	100.00	0.72	2.73	5	Country
Federated States of Micronesia	FM	13.71	0.16	1.89	110	Group
Republic of Moldova	MD	16.47	0.22	1.82	29	Group
Monaco	MC	18.63	0.24	1.41	47	Group
Mongolia	MN	10.40	0.10	2.03	119	Group
Montenegro	ME	16.47	0.22	1.82	29	Group
Montserrat	MS	12.56	0.13	1.52	29	Group
Morocco	MA	10.04	0.10	2.43	3	Country
Mozambique	MZ	15.05	0.19	2.18	29	Group
Myanmar	MM	11.01	0.11	2.38	44	Group
Namibia	NA	15.05	0.19	2.18	29	Group
Nauru	NR	13.71	0.16	1.89	110	Group
Nepal	NP	11.01	0.11	2.38	44	Group
Netherlands	NL	18.63	0.24	1.41	47	Group
Netherlands Antilles	AN	12.56	0.13	1.52	29	Group
New Caledonia	NC	13.71	0.16	1.89	110	Group
New Zealand	NZ	38.33	0.36	0.8	41	Group
Nicaragua	NI	12.56	0.13	1.52	29	Group
Niger	NE	15.05	0.19	2.18	29	Group
Nigeria	NG	15.05	0.19	2.18	29	Group
Niue	NU	13.71	0.16	1.89	110	Group
Norfolk Island	NF	13.71	0.16	1.89	110	Group
Northern Mariana Islands	MP	13.71	0.16	1.89	110	Group

Norway	NO	18.63	0.24	1.41	47	Group
Oman	OM	11.05	0.10	1.61	87	Group
Pakistan	PK	9.71	0.10	2.34	23	Country
Palau	PW	13.71	0.16	1.89	110	Group
Occupied Palestinian Territory	PS	11.05	0.1	1.61	87	Group
Panama	PA	29.45	0.38	1.14	4	Group
Papua New Guinea	PG	13.71	0.16	1.89	110	Group
Paraguay	PY	100.00	0.63	1.83	13	Group
Peru	PE	51.50	0.50	1.62	33	Country
Philippines	PH	15.95	0.18	1.53	31	Country
Pitcairn	PN	13.71	0.16	1.89	110	Group
Poland	PL	18.63	0.24	1.41	47	Group
Portugal	PT	18.84	0.30	0.6	4	Country
Puerto Rico	PR	12.56	0.13	1.52	29	Group
Qatar	QA	11.05	0.10	1.61	87	Group
Reunion	RE	13.71	0.16	1.89	110	Group
Romania	RO	17.50	0.24	2.6	6	Country
Russian Federation	RU	29.74	0.36	2.43	21	Group
Rwanda	RW	15.05	0.19	2.18	29	Group
Saint Helena	SH	18.63	0.24	1.41	47	Group
Saint Kitts and Nevis	KN	12.56	0.13	1.52	29	Group
Saint Lucia	LC	12.56	0.13	1.52	29	Group
Saint Pierre and Miquelon	PM	100.00	0.61	1.63	49	Group
Saint Vincent and the Grenadines	VC	12.56	0.13	1.52	29	Group
Samoa	WS	13.71	0.16	1.89	110	Group
San Marino	SM	13.23	0.18	1.6	43	Group
Sao Tome and Principe	ST	15.05	0.19	2.18	29	Group
Saudi Arabia	SA	11.05	0.10	1.61	87	Group
Senegal	SN	15.05	0.19	2.18	29	Group
Serbia	RS	16.47	0.22	1.82	29	Group
Seychelles	SC	13.71	0.16	1.89	110	Group
Sierra Leone	SL	15.05	0.19	2.18	29	Group
Singapore	SG	16.04	0.18	1.51	32	Group
Slovakia	SK	16.47	0.22	1.82	29	Group
Slovenia	SI	16.47	0.22	1.82	29	Group
Solomon Islands	SB	13.71	0.16	1.89	110	Group
Somalia	SO	15.05	0.19	2.18	29	Group
South Africa	ZA	15.05	0.19	2.18	29	Group
South Georgia and the South Sandwich Islands	GS	18.63	0.24	1.41	47	Group
Spain	ES	18.63	0.24	1.41	47	Group
Sri Lanka	LK	11.01	0.11	2.38	44	Group
Sudan	SD	15.05	0.19	2.18	29	Group

Suriname	SR	100.00	0.63	1.83	13	Group
Svalbard and Jan Mayen	SJ	18.63	0.24	1.41	47	Group
Swaziland	SZ	15.05	0.19	2.18	29	Group
Sweden	SE	18.63	0.24	1.41	47	Group
Switzerland	CH	18.63	0.24	1.41	47	Group
Syrian Arab Republic	SY	11.05	0.10	1.61	87	Group
Taiwan	TW	12.54	0.10	1.36	27	Country
Tajikistan	TJ	16.37	0.20	1.63	15	Group
United Republic of Tanzania	TZ	15.05	0.19	2.18	29	Group
Thailand	TH	16.04	0.18	1.51	32	Group
Timor-Leste	TL	13.71	0.16	1.89	110	Group
Togo	TG	15.05	0.19	2.18	29	Group
Tokelau	TK	13.71	0.16	1.89	110	Group
Tonga	TO	13.71	0.16	1.89	110	Group
Trinidad and Tobago	TT	12.56	0.13	1.52	29	Group
Tunisia	TN	16.16	0.23	1.99	22	Group
Turkey	TR	10.97	0.10	1.52	81	Country
Turkmenistan	TM	16.37	0.20	1.63	15	Group
Turks and Caicos Islands	TC	12.56	0.13	1.52	29	Group
Tuvalu	TV	13.71	0.16	1.89	110	Group
Uganda	UG	15.05	0.19	2.18	29	Group
Ukraine	UA	29.74	0.36	2.43	21	Group
United Arab Emirates	AE	11.05	0.10	1.61	87	Group
United Kingdom	GB	18.63	0.24	1.41	47	Group
United States	US	100.00	0.61	1.63	49	Group
United States Minor Outlying Islands	UM	100.00	0.61	1.63	49	Group
Uruguay	UY	100.00	0.63	1.83	13	Group
Uzbekistan	UZ	16.37	0.20	1.63	15	Group
Vanuatu	VU	13.71	0.16	1.89	110	Group
Venezuela	VE	100.00	0.67	1.89	8	Group
Viet Nam	VN	13.71	0.16	1.89	110	Group
British Virgin Islands	VG	12.56	0.13	1.52	29	Group
U.S. Virgin Islands	VI	12.56	0.13	1.52	29	Group
Wallis and Futuna	WF	13.71	0.16	1.89	110	Group
Western Sahara	EH	16.16	0.23	1.99	22	Group
Yemen	YE	15.05	0.19	2.18	29	Group
Zambia	ZM	15.05	0.19	2.18	29	Group
Zimbabwe	ZW	15.05	0.19	2.18	29	Group
Saint Barthelemy	BL	12.56	0.13	1.52	29	Group
Saint Martin (France)	MF	12.56	0.13	1.52	29	Group
U.S. Earthquake Region California	XF	38.53	0.36	0.80	39	Country

* Refer to the PAGER website (http://earthquake.usgs.gov/eqcenter/pager/) for the most recent version of appendix II.

Appendix III. An Automated Alerts and Comments Development Methodology for the lossPAGER System

The USGS PAGER system currently provides the estimates of total population exposed to different levels of shaking intensity along with maps presented in an expanded form on the USGS Earthquake Hazards Program website (http://earthquake.usgs.gov/pager/). Although the population exposure estimates provide a useful indicator of an earthquake's potential impact, adding the fatality estimate based alert would provide more actionable information for emergency response. In order to provide this information, we propose the development of alert schema as described below. The uncertainty associated with median fatality estimates is represented in terms of probabilistic assessment of the fatalities being in different alert threshold on a global scale. We propose the color schema in terms of Green, Yellow, Orange and Red which are also commonly used for other natural perils. In addition to alert levels which are assigned based on median fatality deaths, we also suggest confidence levels denoting the level of uncertainty associated with the model's fatality estimates. The uncertainty estimates are presented using a bar scale of Green, Yellow, Orange and Red alerts indicating the probability of different alerts for a given earthquake.

G	Green	No deaths
Y	Yellow	1 to 100 deaths
O	Orange	100 to 1,000 deaths
R	Red	> 1,000 deaths

While developing the comments for internal lossPAGER system, we propose a combination of alert levels and confidence levels to generate automated comments. These comments will be based on a range of factors apart from the fatality estimates obtained using the empirical model. These factors include population exposure, country or group based model, and fatality estimates from other models. The comment development algorithm is flexible; including accommodating results from the other two PAGER loss models (semi-empirical and analytical) when applicable.

- **<u>Uncertainty Estimation and illustration:</u>**

a) Estimating upper and lower bound ranges for actual deaths

If Ω = median estimated deaths from the model and 'ξ' is the standard deviation of log-residual error (logarithmic ratio of estimated death and recorded deaths) which is normally distributed, then the probability of actual deaths *d* being less than certain bound *b* is

$$P(d \leq b) = \Phi\left[\frac{\log(b) - \log(\Omega)}{\xi}\right]$$

<u>Implementation:</u>

Probability P of actual death 'd' is

P = Φ *((log(D)-log(*Ω*))/* ξ*)*

If D = Upperbound deaths, then we get P= Probability of upper bound deaths

If D = Lowerbound deaths, then we get P= Probability of lower bound deaths

It is desirable to allow D to span an order of magnitude. We can estimate the probability associated with one order of magnitude above or below for the median estimate of Ω*= 500, by substituting D(lower) =* Ω */10 = 50, and D(higher)=* Ω **10= 5000.*

b) Estimating the probability of actual deaths being in different thresholds:

Probability that the actual death *d* may be between *a* and *b* is given as

$$P(a < d \leq b) = \Phi\left[\frac{\log(b) - \log(\Omega)}{\xi}\right] - \Phi\left[\frac{\log(a) - \log(\Omega)}{\xi}\right]$$

Implementation:

For alert level purposes, we can use the predefined alert threshold and estimate the probability of being in different alert levels using the following-

deathrange = [1 10 100 1000 10000 100000] is the range to be used for defining the alert levels then,

P(k) = Φ ((log(deathrange(k+1))-log(Ω))/ ξ) - Φ ((log(deathrange(k))-log(Ω))/ ξ);

The median death estimate Ω will determine the alert symbol and we can choose two alert thresholds (one above and one below, based on Ω) to estimate the probability of actual deaths being in those (upper and lower) alert thresholds. We illustrate the impact level assessment using the median fatality estimate and associated uncertainty in Figure III. The plot shows an alert symbol with color indicating level of impact along the vertical scale showing 0 to 1,000,000+ fatality range with green, yellow, orange and red levels. On the left hand side of scale, we show the probability of deaths being in a given alert threshold. For example, for an earthquake with zero median estimated deaths, there is 64% likelihood that the earthquake will have green alert diminishing to 36% for yellow alert. Figure III (a to d) shows different alert thresholds and demonstrate the likelihood estimates. The definition of alert thresholds used herein (0 deaths for green level; 1 to 10 & 10 to 100 for yellow; 100 to 1,000 for orange level, and 1,000 or greater for red alert level) are preliminary. Marano et al.(2009) are using past fatal earthquake data to investigate the development of alert thresholds that are not just limited to the fatality ranges but rather provide a more comprehensive assessment including exposure and financial losses. The development of such alert schema applicable at a global scale is not only crucial for future PAGER alerts and associated uncertainty estimation but also for the international disaster response agencies for their response planning.

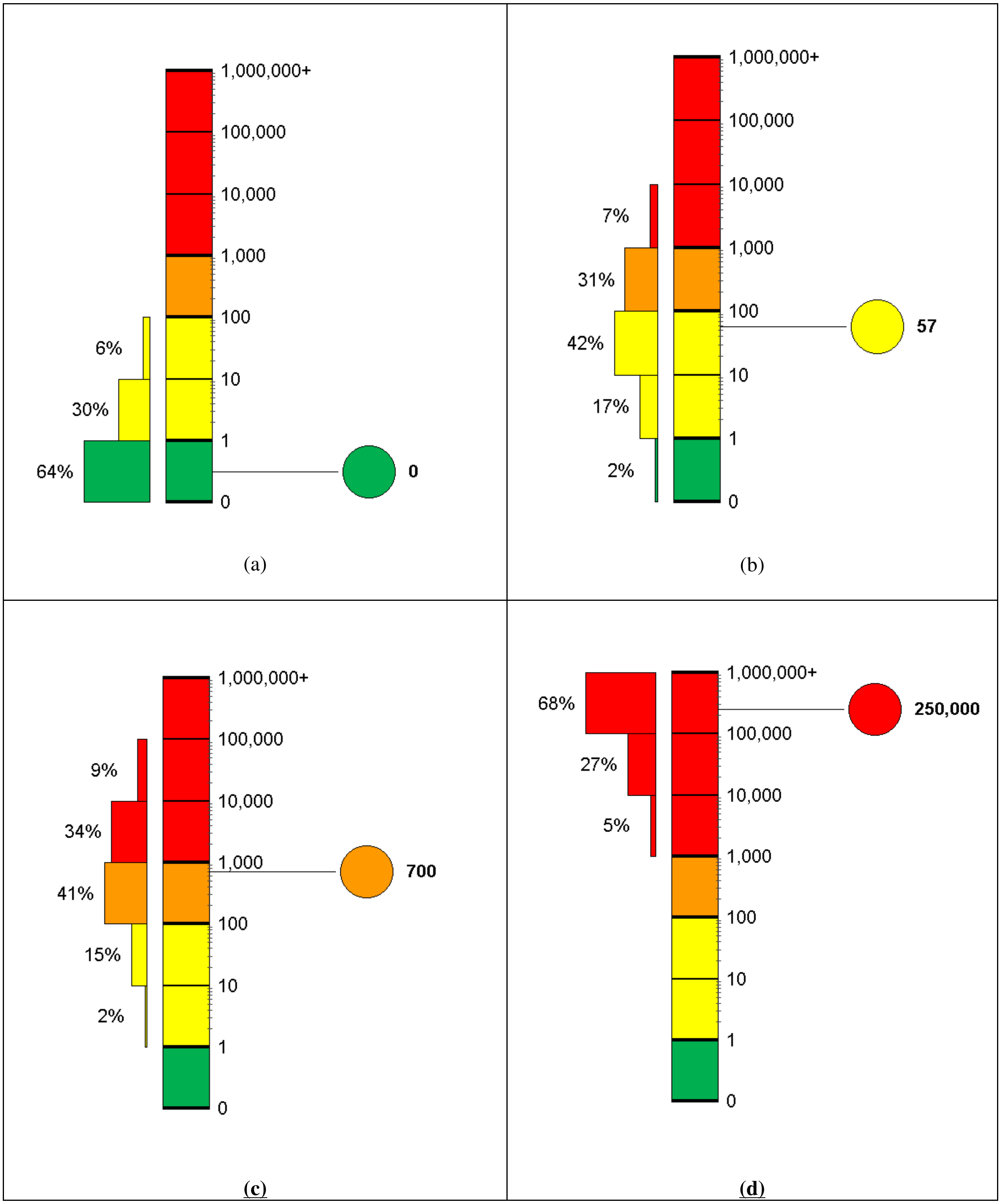


Figure III. Illustration of various impact levels and associated uncertainty depiction for hypothetical scenarios.

Table 1. List of countries with 10 or more fatalities due to any single earthquake since 1900. For each country, it also shows the total number of earthquake shaking-related fatalities and the number of fatal earthquakes since 1900.

Serial no.	Country	Maximum shaking deaths (10 or more) due to any single earthquake since 1900	Total shaking deaths by all earthquakes since 1900	Total fatal (one or more deaths) earthquakes since 1900	Average shaking deaths per earthquake since 1900
1	China	242,800	604,330	122	4,954
2	Pakistan	87,351	153,586	21	7,314
3	Iran	45,000	161,215	75	2,150
4	Turkey	32,968	85,182	64	1,331
5	Italy	32,610	36,169	18	2,009
6	Chile	28,000	28,718	24	1,197
7	Armenia	25,000	25,000	1	25,000
8	India	20,023	52,189	17	3,070
9	Tajikistan	15,000	27,050	7	3,864
10	Nepal	10,700	12,330	4	3,083
11	Nicaragua	10,000	10,017	3	3,339
12	Mexico	9,500	11,941	33	362
13	Argentina	8,000	8,147	8	1,018
14	Ecuador	6,000	7,269	15	485
15	Indonesia	5,749	10,870	62	175
16	Japan	5,502	6,499	43	151
17	Afghanistan	4,000	8,404	27	311
18	Algeria	3,500	7,422	14	530
19	Taiwan	3,276	7,850	38	207
20	Turkmenistan	3,257	3,668	3	1,223
21	Yemen	2,800	2,811	2	1,406
22	Guatemala	2,000	25,103	12	2,092
23	Russian Federation	1,989	1,997	3	666
24	Philippines	1,621	2,980	27	110
25	Romania	1,581	2,598	5	520
26	Peru	1,400	2,566	41	63
27	Colombia	1,185	2,643	19	139
28	El Salvador	950	1,584	7	226
29	Greece	800	1,313	25	53
30	Morocco	631	635	3	212
31	Egypt	552	576	4	144
32	Bulgaria	500	713	4	178
33	Kazakhstan	450	467	4	117
34	Guinea	443	443	1	443
35	Venezuela	240	340	8	43
36	Congo; DR	200	210	3	70
37	Serbia	156	157	2	79

38	Georgia	114	132	6	22
39	Bolivia	105	108	3	36
40	Costa Rica	75	114	7	16
41	United States	65	270	18	15
42	Kyrgyzstan	61	102	2	51
43	Portugal	56	80	4	20
44	Bangladesh	50	61	5	12
45	Ethiopia	40	70	2	35
46	Myanmar	38	81	7	12
47	Macedonia	35	35	1	35
48	Bosnia and Herzegovina	20	29	2	15
49	Iraq	20	20	1	20
50	Albania	18	19	2	10
51	Papua New Guinea	15	37	9	4
52	Australia	12	12	1	12
53	South Africa	12	18	3	6
54	Panama	11	15	3	5

Table 2. Fatality estimation using empirical model for earthquakes since January 2008.

Date/time	Country	Magnitude	Highest intensity	Total exposure (>VI)	Recorded total deaths	Estimated shaking deaths
Jan 01, 2008 at 06:32:33	Kyrgyzstan	5.7	VI	1,184,285	0	0
Jan 01, 2008 at 18:55:03	Papua New Guinea	6.3	VII	60,745	0	0
Jan 01, 2008 at 19:13:08	Papua New Guinea	5.8	VI	9,360	0	0
Jan 03, 2008 at 11:15:48	Indonesia	5.5	VI	257	Unknown*	0
Jan 04, 2008 at 07:29:18	Indonesia	6	VII	209,263	0	2
Jan 06, 2008 at 05:14:17	Greece	6.1	VII	108,533	0	0
Jan 07, 2008 at 03:12:26	Indonesia	5.9	VIII	86,940	Unknown	1
Jan 08, 2008 at 19:23:37	Indonesia	5.8	VIII	5,392	Unknown	0
Jan 09, 2008 at 08:26:45	China	6.4	IX	2,303	Unknown	1
Jan 13, 2008 at 12:15:40	Philippines	5.7	VII	247,585	Unknown	0
Jan 14, 2008 at 13:38:38	India	5.8	VI	2,263	0	0
Jan 16, 2008 at 11:54:44	China	5.9	VII	666	0	0
Jan 22, 2008 at 07:55:53	Wallis and Futuna	6	VII	189	Unknown	0
Jan 22, 2008 at 10:49:26	Wallis and Futuna	6.1	VII	189	Unknown	0
Jan 22, 2008 at 17:14:57	Indonesia	6.2	VIII	343,275	1	11
Jan 22, 2008 at 18:43:33	China	5.4	VII	174	Unknown	0
Jan 24, 2008 at 22:29:52	Papua New Guinea	5.9	VII	103,954	Unknown	0
Jan 30, 2008 at 07:32:47	Indonesia	6.2	VII	3,796	Unknown	0
Feb 03, 2008 at 07:34:12	Congo, D.R.	5.9	VIII	1,051,474	44	5
Feb 04, 2008 at 17:01:29	Chile	6.3	VII	222,838	Unknown	2
Feb 07, 2008 at 07:50:55	Indonesia	5.8	VII	40,084	Unknown	0
Feb 09, 2008 at 07:12:06	Mexico	5.1	VII	104,068	Unknown	1
Feb 11, 2008 at 18:29:30	Mexico	5.1	VII	76,664	Unknown	1
Feb 12, 2008 at 01:29:40	Indonesia	5.5	VI	30,939	Unknown	0
Feb 12, 2008 at 04:32:39	Mexico	5	VII	44,605	0	1
Feb 12, 2008 at 12:50:20	Mexico	6.4	VII	179,622	0	2
Feb 13, 2008 at 19:58:44	Indonesia	6.2	IX	1,241	Unknown	0
Feb 14, 2008 at 10:09:23	Greece	6.9	VII	46,340	Unknown	0

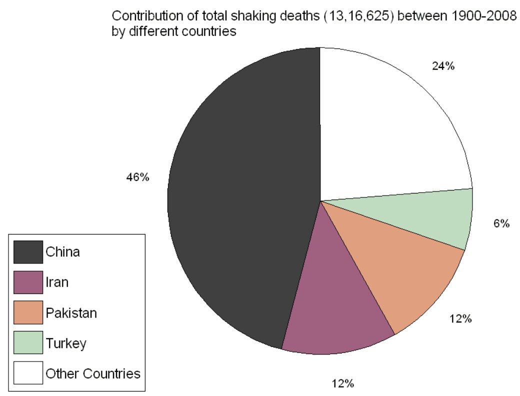
Feb 14, 2008 at 12:08:56	Greece	6.2	VIII	100,050	Unknown	0
Feb 15, 2008 at 10:36:19	Lebanon	5	VI	93,474	Unknown	0
Feb 19, 2008 at 17:01:29	Indonesia	5.3	VII	11,026	Unknown	0
Feb 20, 2008 at 08:08:32	Indonesia	7.4	VIII	105,679	3	18
Feb 20, 2008 at 18:27:11	Greece	6.2	VII	28,742	Unknown	0
Feb 21, 2008 at 21:41:41	Indonesia	5.6	VII	53,959	Unknown	0
Feb 21, 2008 at 23:55:36	Indonesia	5.7	VIII	33,506	Unknown	1
Feb 23, 2008 at 07:17:09	Indonesia	5.4	VI	10,073	Unknown	0
Feb 24, 2008 at 04:36:28	Indonesia	5.5	VI	284,588	Unknown	0
Feb 24, 2008 at 08:53:38	Indonesia	5.4	VII	29,974	Unknown	0
Feb 24, 2008 at 14:46:23	Indonesia	6.4	VIII	63,342	Unknown	4
Feb 24, 2008 at 14:57:31	Indonesia	5.5	VII	42,711	Unknown	0
Feb 25, 2008 at 08:36:35	Indonesia	7	VIII	338,143	0	11
Feb 25, 2008 at 18:06:05	Indonesia	6.4	VIII	60,821	Unknown	3
Feb 25, 2008 at 21:02:20	Indonesia	6.6	VIII	68,502	Unknown	7
Feb 26, 2008 at 18:18:31	Indonesia	5.8	VI	110	Unknown	0
Mar 01, 2008 at 19:51:59	Chile	5.7	VII	119,991	Unknown	1
Mar 03, 2008 at 02:37:27	Indonesia	6.1	VIII	41,409	Unknown	4
Mar 12, 2008 at 11:23:34	Vanuatu	6.4	VIII	10,273	Unknown	0
Mar 12, 2008 at 11:36:55	Vanuatu	6.3	VII	11,001	Unknown	0
Mar 20, 2008 at 14:10:39	Philippines	6	VI	4,365	Unknown	0
Mar 20, 2008 at 22:33:01	China	7.2	VII	32,165	Unknown	0
Mar 20, 2008 at 23:12:02	China	5.5	VII	3,618	Unknown	0
Mar 26, 2008 at 20:06:05	Guam	5.6	VI	6,670	Unknown	0
Mar 28, 2008 at 22:41:32	Philippines	5.8	VIII	7,254	Unknown	0
Mar 29, 2008 at 08:09:46	Philippines	5.5	VII	4,745	0	0
Mar 29, 2008 at 17:30:51	Indonesia	6.3	VIII	28,506	Unknown	0
Apr 02, 2008 at 08:48:49	Indonesia	5.7	VI	51,895	Unknown	0
Apr 09, 2008 at 11:13:20	Vanuatu	6.4	VI	11,918	Unknown	0
Apr 09, 2008 at 11:23:40	Vanuatu	6.3	VI	5,272	Unknown	0
Apr 09, 2008 at 12:46:12	Vanuatu	7.3	VII	26,470	0	0
Apr 09, 2008 at 14:47:50	Vanuatu	6.3	VI	20,277	Unknown	0
Apr 15, 2008 at 03:03:10	Guatemala	6.1	VI	107,135	Unknown	0
Apr 19, 2008 at 03:12:28	Indonesia	6.1	VIII	31,538	Unknown	0

Apr 19, 2008 at 10:21:12	Indonesia	6	VII	14,155	Unknown	0
Apr 20, 2008 at 13:01:21	Indonesia	5.6	VI	4,844	Unknown	0
Apr 23, 2008 at 18:28:42	Taiwan	6	VI	11,372	Unknown	0
Apr 23, 2008 at 14:05:42	Indonesia	5.5	VI	3,768	Unknown	0
Apr 28, 2008 at 18:33:30	Vanuatu	6.4	VI	5,992	0	0
Apr 29, 2008 at 05:26:04	Japan	5.8	VI	3,223	Unknown	0
May 03, 2008 at 03:53:34	Indonesia	5.3	VI	19,421	Unknown	0
May 03, 2008 at 19:01:46	Papua New Guinea	5.8	VII	13,239	Unknown	0
May 07, 2008 at 16:45:19	Japan	6.8	VI	24,199	0	0
May 12, 2008 at 06:28:01	China	7.9	X	33,506,961	87,652	66,191
May 12, 2008 at 06:43:14	China	6	VIII	752,642	Unknown	3
May 12, 2008 at 09:42:25	China	5.5	VII	410,714	Unknown	0
May 12, 2008 at 06:54:18	China	5.7	VII	1,145,759	Unknown	3
May 12, 2008 at 11:11:02	China	5.8	VIII	392,136	Unknown	0
May 12, 2008 at 20:08:48	China	5.6	VII	116,642	Unknown	0
May 13, 2008 at 07:07:08	China	5.8	VIII	63,284	Unknown	0
May 13, 2008 at 10:29:19	Indonesia	5.4	VI	2,740	Unknown	0
May 14, 2008 at 02:54:38	China	5.5	VII	27,598	Unknown	0
May 16, 2008 at 05:25:47	China	5.6	VII	28,997	Unknown	0
May 17, 2008 at 17:08:25	China	5.7	VII	152,591	Unknown	0
May 18, 2008 at 12:17:23	Indonesia	5.7	VII	117,664	Unknown	0
May 19, 2008 at 14:26:45	Indonesia	6	VIII	246,257	Unknown	2
May 20, 2008 at 17:08:00	Indonesia	5.7	VII	145,628	Unknown	1
May 24, 2008 at 13:24:06	Solomon Islands	5.9	VIII	4,880	Unknown	0
May 24, 2008 at 19:20:47	Colombia	5.9	VII	998,171	6	14
May 25, 2008 at 08:21:49	China	6	VIII	273,213	6	32
May 27, 2008 at 08:37:51	China	5.7	VII	109,024	Unknown	0
May 26, 2008 at 15:01:36	Costa Rica	5.6	VII	251,273	Unknown	0
May 29, 2008 at 15:46:00	Iceland	6.3	VIII	12,155	0	0
Jun 01, 2008 at 01:57:23	Philippines	6.3	VII	10,295	0	0
Jun 01, 2008 at 09:42:32	Indonesia	5.5	VI	198	Unknown	0
Jun 01, 2008 at 10:33:28	Indonesia	5.8	VIII	5,574	Unknown	0
Jun 03, 2008 at 16:20:51	Solomon Islands	6.2	VI	14,545	0	0
Jun 03, 2008 at 17:31:31	Indonesia	5.9	VI	25,197	Unknown	0

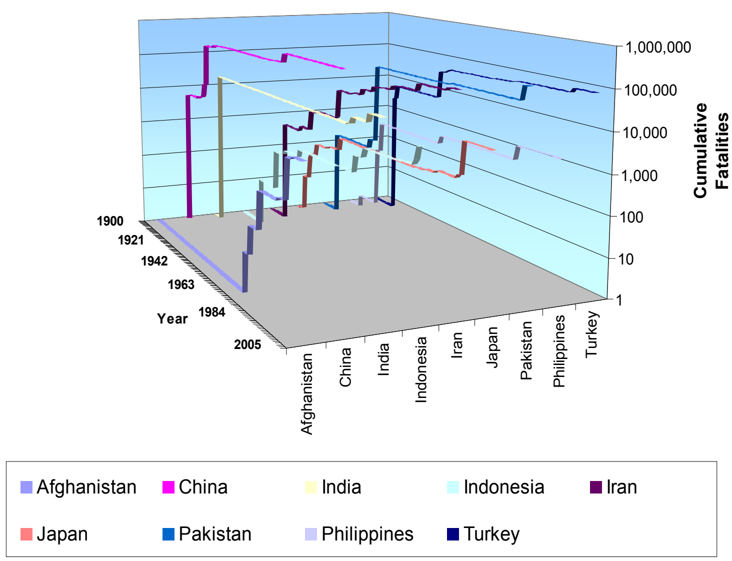
Jun 03, 2008 at 21:03:46	Indonesia	5.8	VI	4,412	Unknown	0
Jun 03, 2008 at 22:04:27	Indonesia	6	VI	6,970	Unknown	0
Jun 03, 2008 at 22:49:57	Indonesia	5.5	VII	15,034	Unknown	0
Jun 06, 2008 at 20:02:57	Algeria	5.5	VI	897,210	Unknown	5
Jun 08, 2008 at 12:25:30	Greece	6.3	IX	504,061	2	11
Jun 13, 2008 at 23:43:46	Japan	6.9	IX	2,083,576	13	22
Jun 14, 2008 at 00:20:13	Japan	5.5	VII	73,871	Unknown	0
Jun 18, 2008 at 13:13:08	Indonesia	5.4	VI	1,375	Unknown	0
Jun 22, 2008 at 07:22:06	Solomon Islands	5.8	VIII	7,485	Unknown	0
Jun 25, 2008 at 02:53:29	Indonesia	5.6	VII	120,301	Unknown	0
Jun 25, 2008 at 15:41:27	Papua New Guinea	5.7	VI	5,840	Unknown	0
Jul 01, 2008 at 00:17:29	Peru	5.5	VII	6,597	Unknown	0
Jul 08, 2008 at 07:42:10	Japan	6	VI	15,391	6	0
Jul 14, 2008 at 04:44:55	Indonesia	5.5	VI	10,348	Unknown	0
Jul 15, 2008 at 03:26:36	Greece	6.4	VI	14,271	Unknown	0
Jul 23, 2008 at 15:26:19	Japan	6.8	VII	3,861,300	1	0
Jul 23, 2008 at 19:54:45	China	5.5	VII	78,854	Unknown	0
Jul 24, 2008 at 01:43:17	Russian Federation	6.2	VII	455	Unknown	0
Jul 24, 2008 at 07:09:30	China	5.7	VII	95,969	1	0
Jul 29, 2008 at 18:42:15	U.S. Earthquake Region California	5.4	VI	1,172,066	Unknown	0
Aug 01, 2008 at 08:32:43	China	5.7	VII	209,503	2	1
Aug 04, 2008 at 15:16:53	Papua New Guinea	5.5	VI	3,361	Unknown	0
Aug 05, 2008 at 09:49:17	China	6	VIII	171,069	3	15
Aug 06, 2008 at 22:41:01	Indonesia	5.9	VIII	14,352	0	0
Aug 12, 2008 at 05:25:58	Solomon Islands	5.9	VII	1,260	Unknown	0
Aug 15, 2008 at 10:25:16	Philippines	6	VII	154,743	Unknown	0
Aug 16, 2008 at 04:01:10	Russian Federation	5.7	VII	495	Unknown	0
Aug 21, 2008 at 12:24:31	China	6	VIII	45,499	3	1
Aug 25, 2008 at 13:21:59	China	6.7	IX	3,657	Unknown	4
Aug 26, 2008 at 03:07:30	Indonesia	5.7	VI	852	Unknown	0
Aug 25, 2008 at 02:43:09	Philippines	5.8	VI	526,993	0	0
Aug 25, 2008 at 11:25:16	New Zealand	5.5	VII	15,630	0	0
Aug 27, 2008 at 01:35:32	Russian Federation	6.2	VIII	44,829	0	3

Aug 27, 2008 at 21:52:38	Iran	5.8	VIII	47,534	Unknown	18
Aug 30, 2008 at 06:54:07	Papua New Guinea	6.4	VI	133,825	0	0
Aug 30, 2008 at 08:30:54	China	5.9	VIII	166,839	38	2
Aug 31, 2008 at 08:31:10	China	5.5	VII	103,560	Unknown	0
Sep 08, 2008 at 03:03:16	Vanuatu	6.2	VI	22,582	0	0
Sep 08, 2008 at 18:52:08	Vanuatu	6.9	VI	6,157	0	0
Sep 10, 2008 at 11:00:34	Iran	6.1	IX	43,310	7	295
Sep 10, 2008 at 16:12:04	Chile	5.8	VII	4,346	0	0
Sep 11, 2008 at 00:00:03	Indonesia	6.6	VI	164,487	0	0
Sep 11, 2008 at 00:20:52	Japan	6.9	VI	378	0	0

*Unknown- Referred as unknown fatalities at the time of this investigation.



(*A*)



(*B*)

Figure 1. *A*) Shaking-death distribution for earthquakes, 1900-2008 by country, and *B*) cumulative earthquake mortality recorded since 1900 for selected countries.

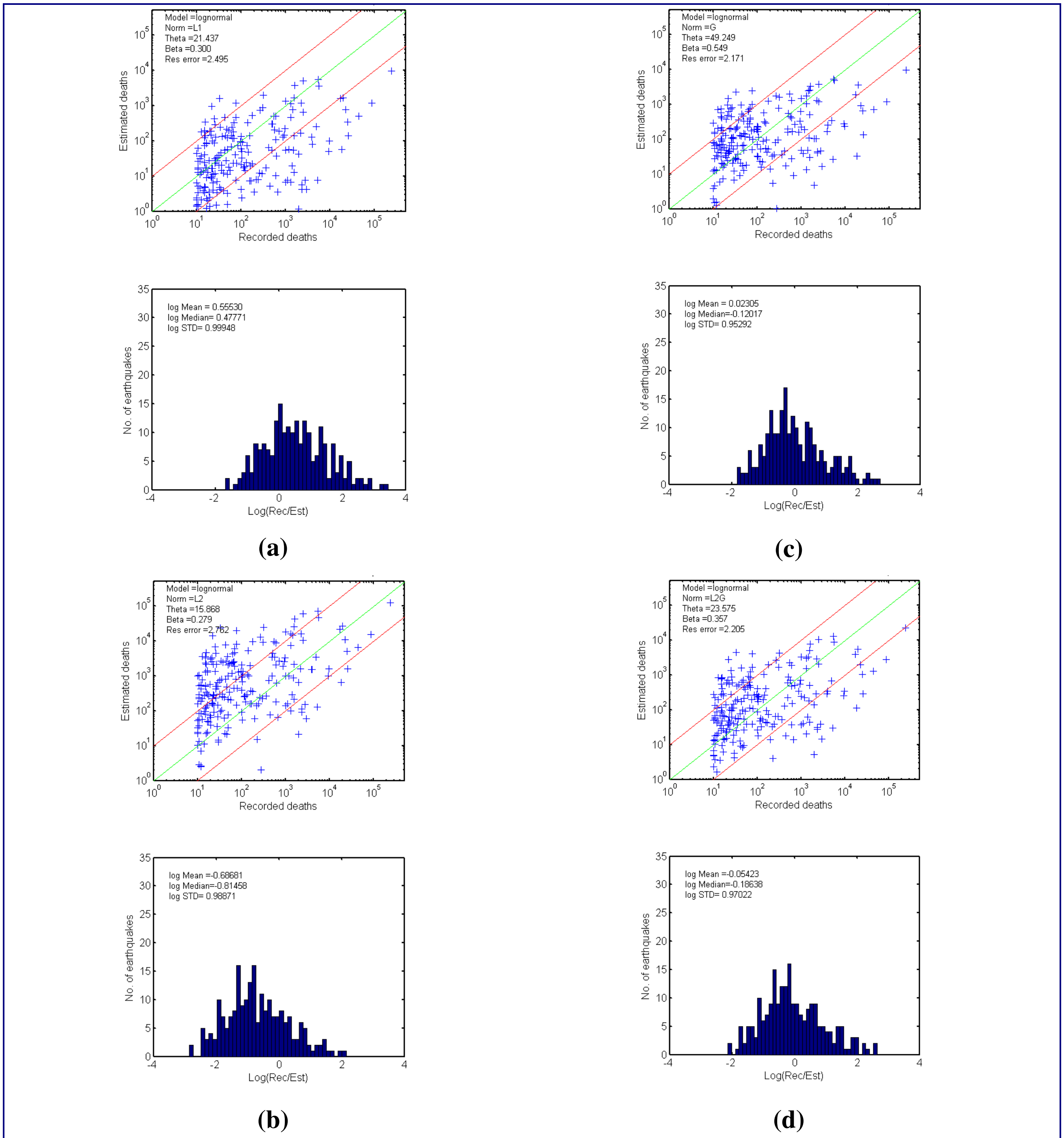


Figure 2. Fatality estimation using lognormal distribution and different norms for global earthquakes with 10 or more deaths recorded between 1973 and 2007.

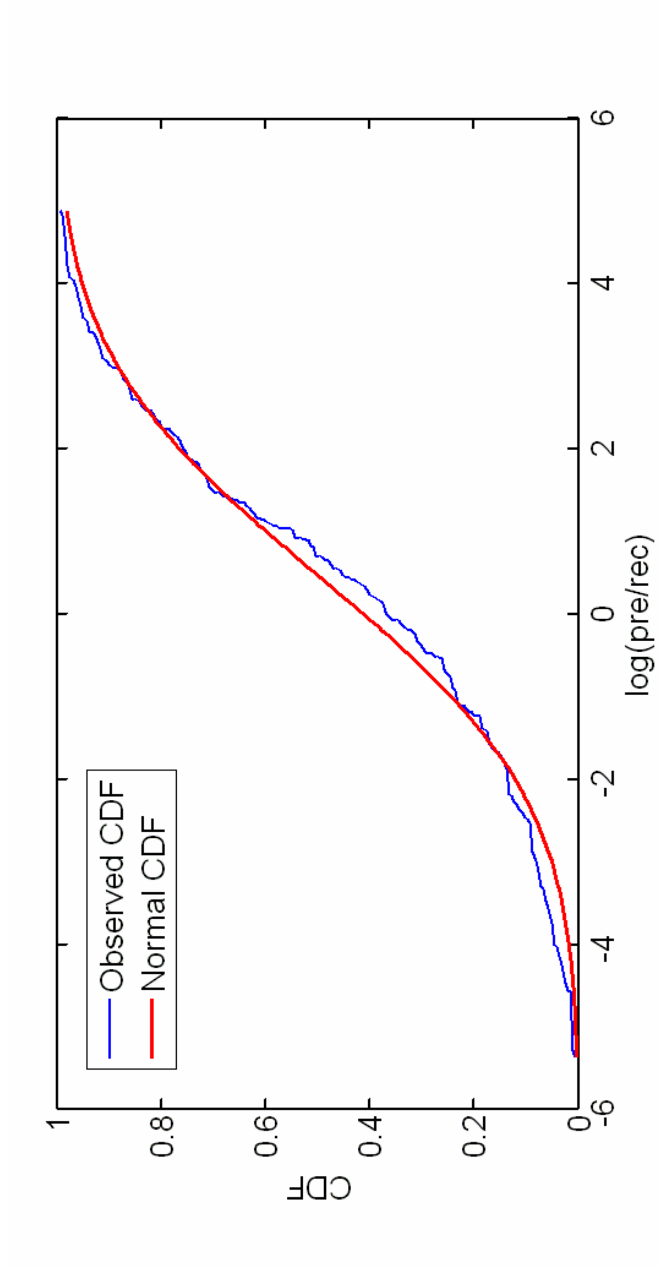


Figure 3. Lilliefors goodness of fit test for lognormal distribution using L2G norm for global earthquakes between 1900 and 2008.

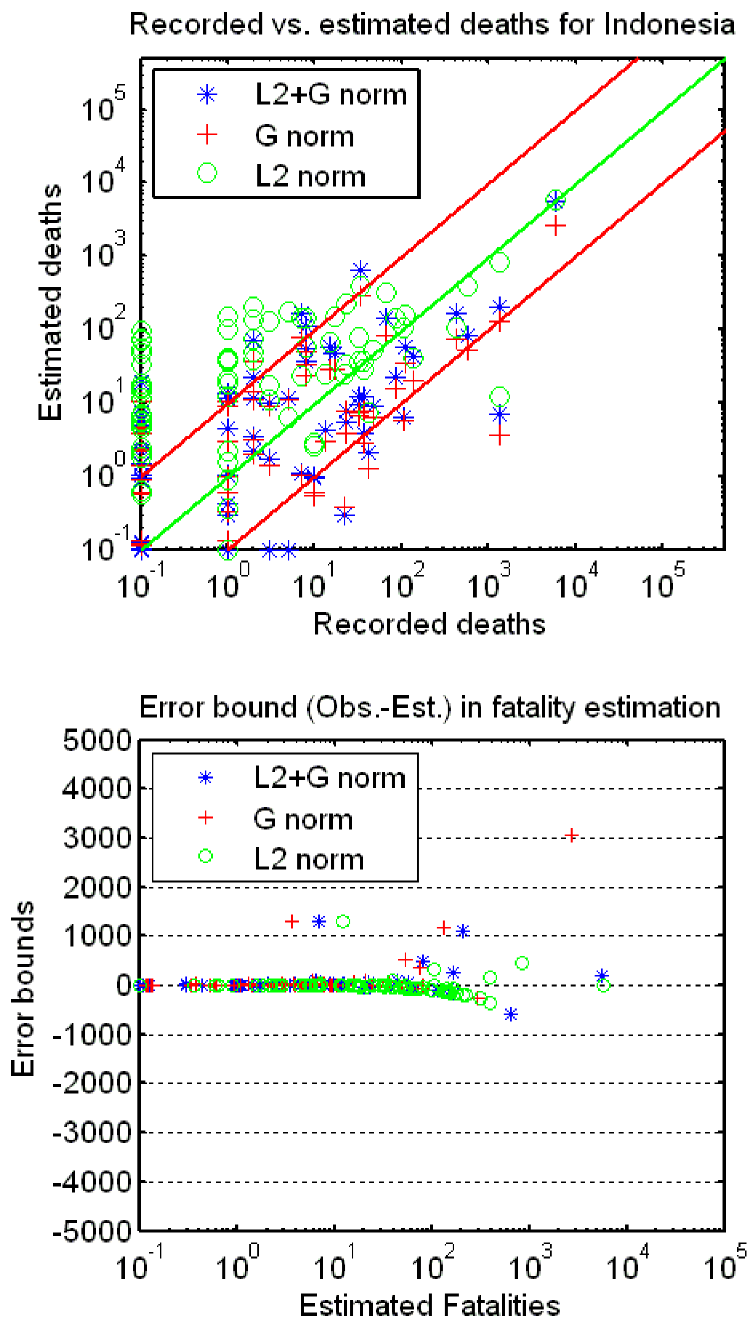


Figure 4. Empirical model derived from fatal earthquakes in Indonesia. Earthquakes with zero recorded deaths were plotted at 0.1 deaths for viewing purposes.

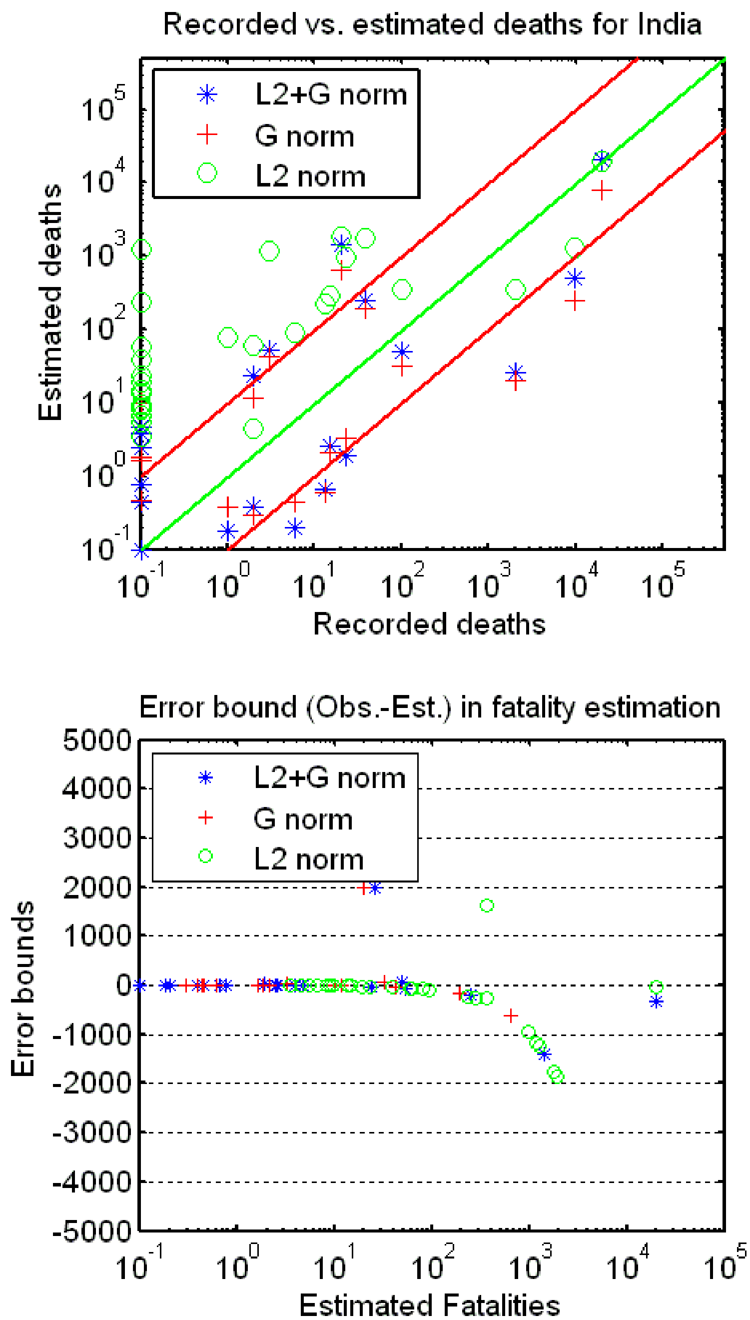


Figure 5. Empirical model derived from fatal earthquakes in India. Earthquakes with zero recorded deaths were plotted at 0.1 deaths for viewing purposes.

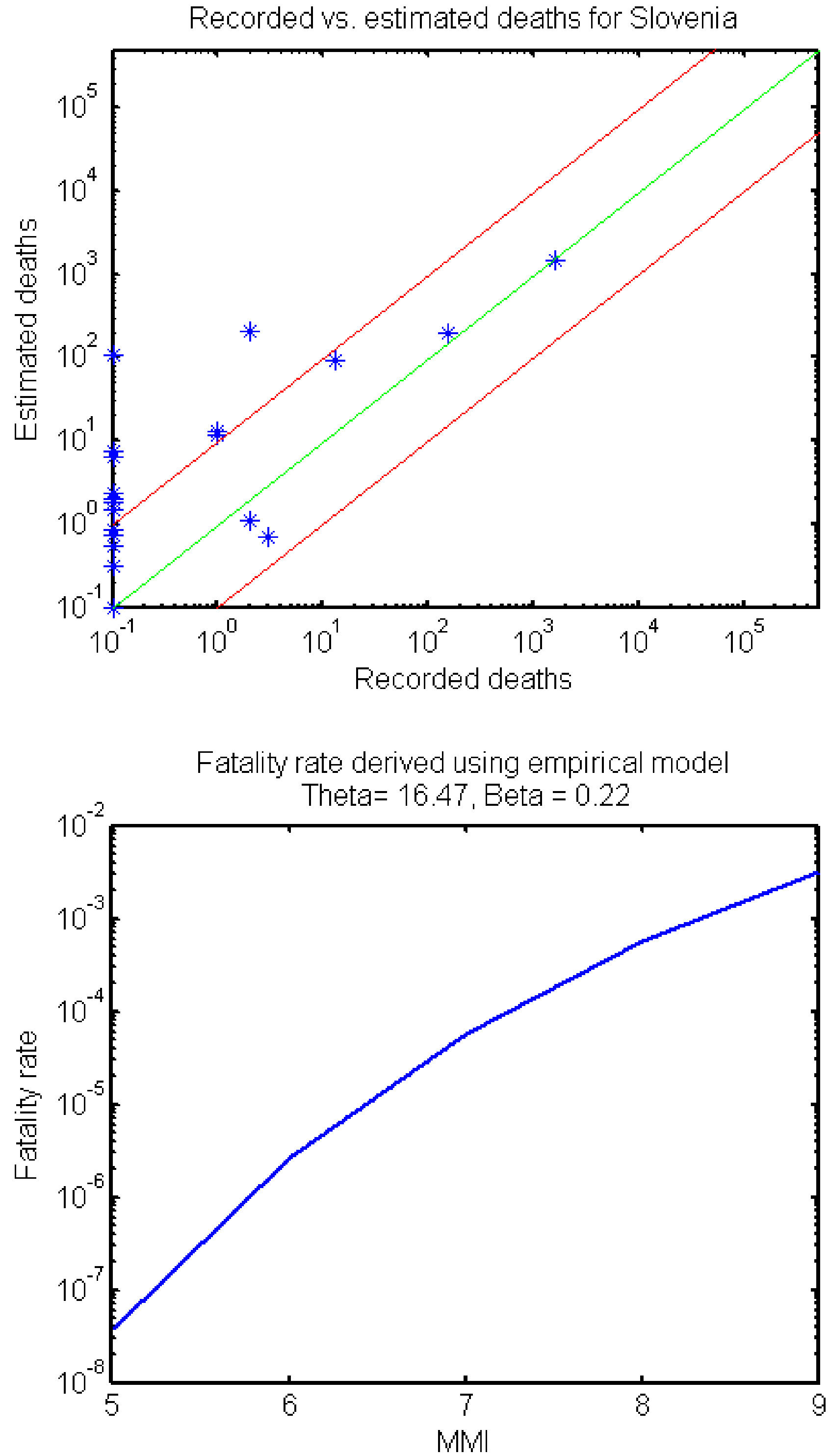


Figure 6. Fatality estimation using empirical loss modeling for Slovenia. Earthquakes with zero recorded deaths were plotted at 0.1 deaths for viewing purposes.

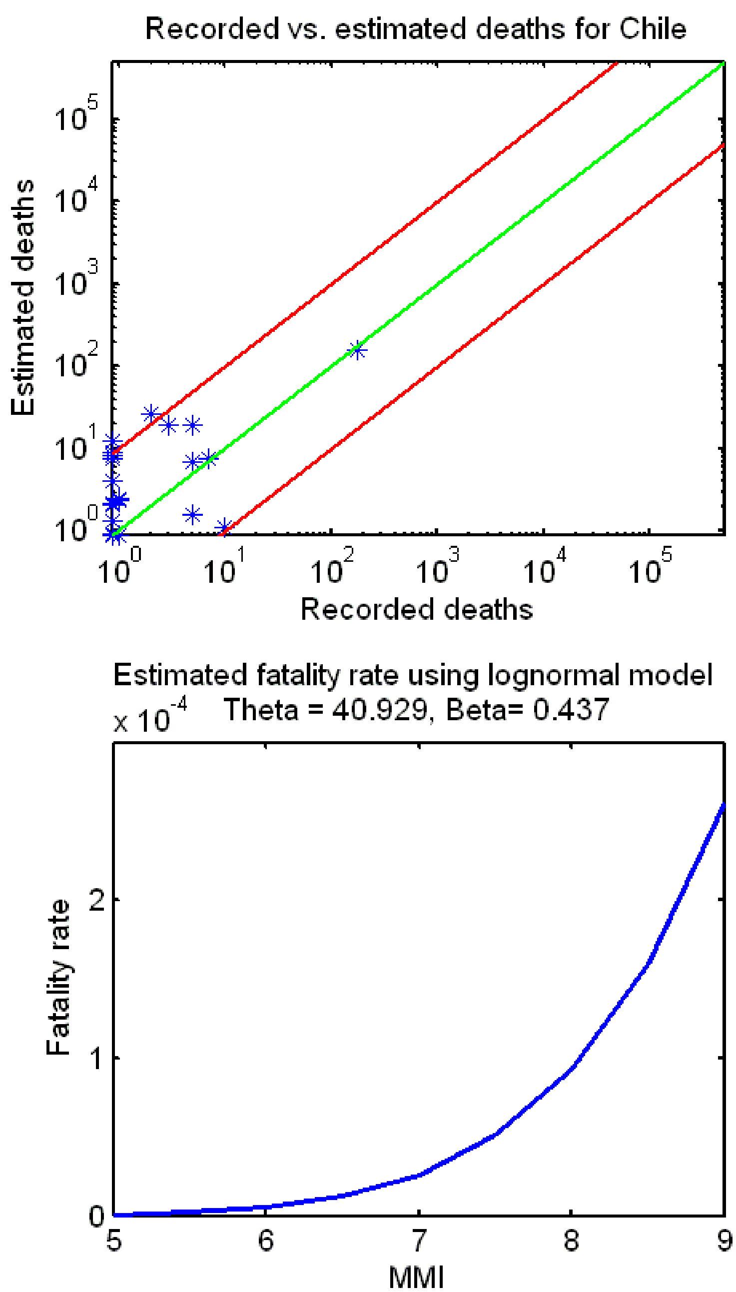


Figure 7. Empirical model derived from fatal earthquakes in Chile. Earthquakes with zero recorded deaths were plotted at 0.1 deaths for viewing purposes.

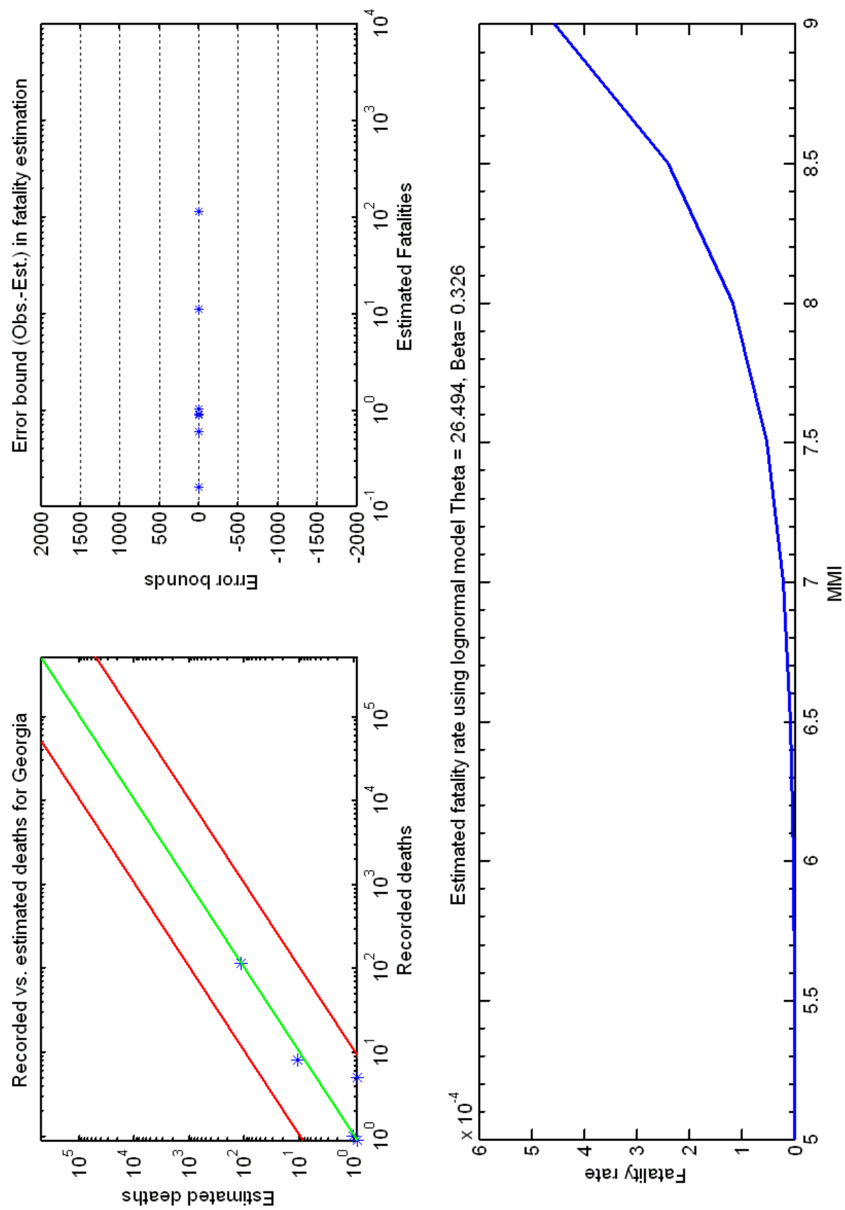


Figure 8. Empirical model derived from fatal earthquakes in Georgia.

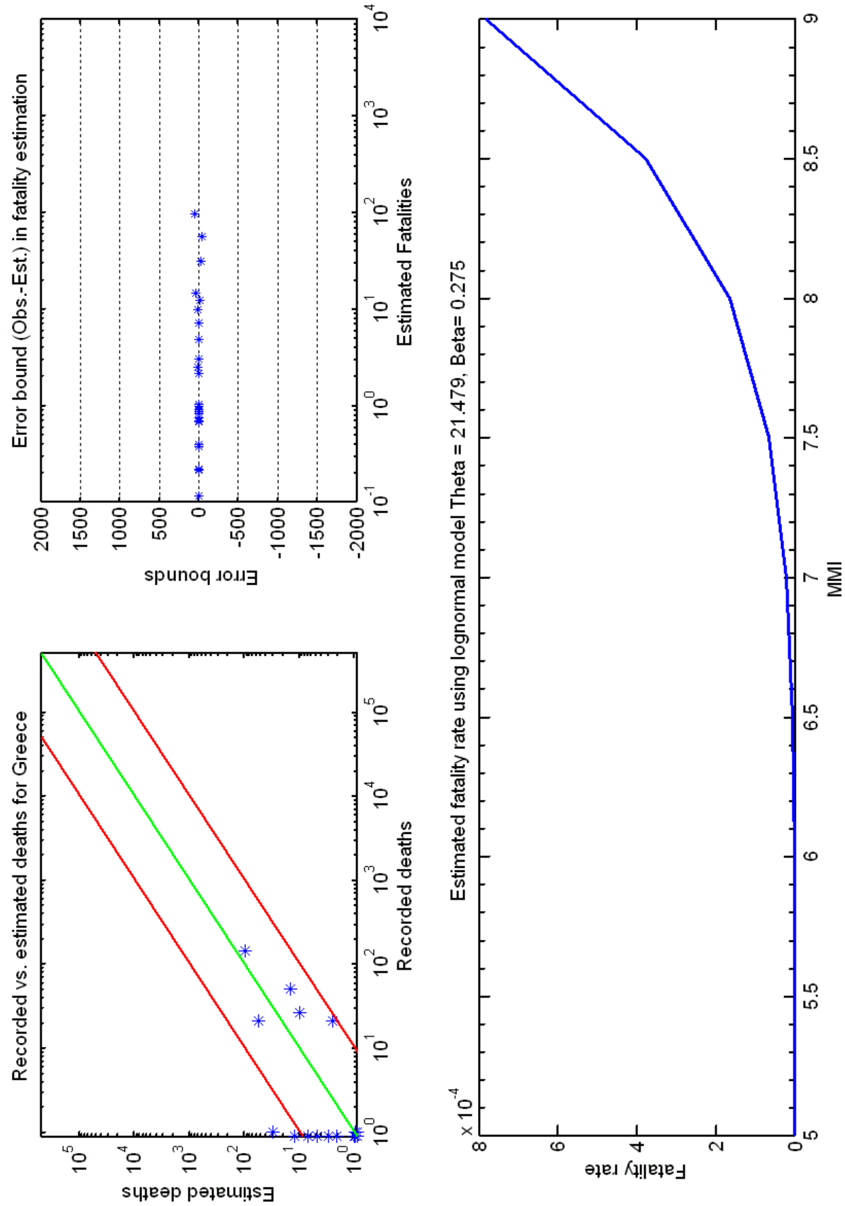


Figure 9. Empirical model derived from fatal earthquakes in Greece.

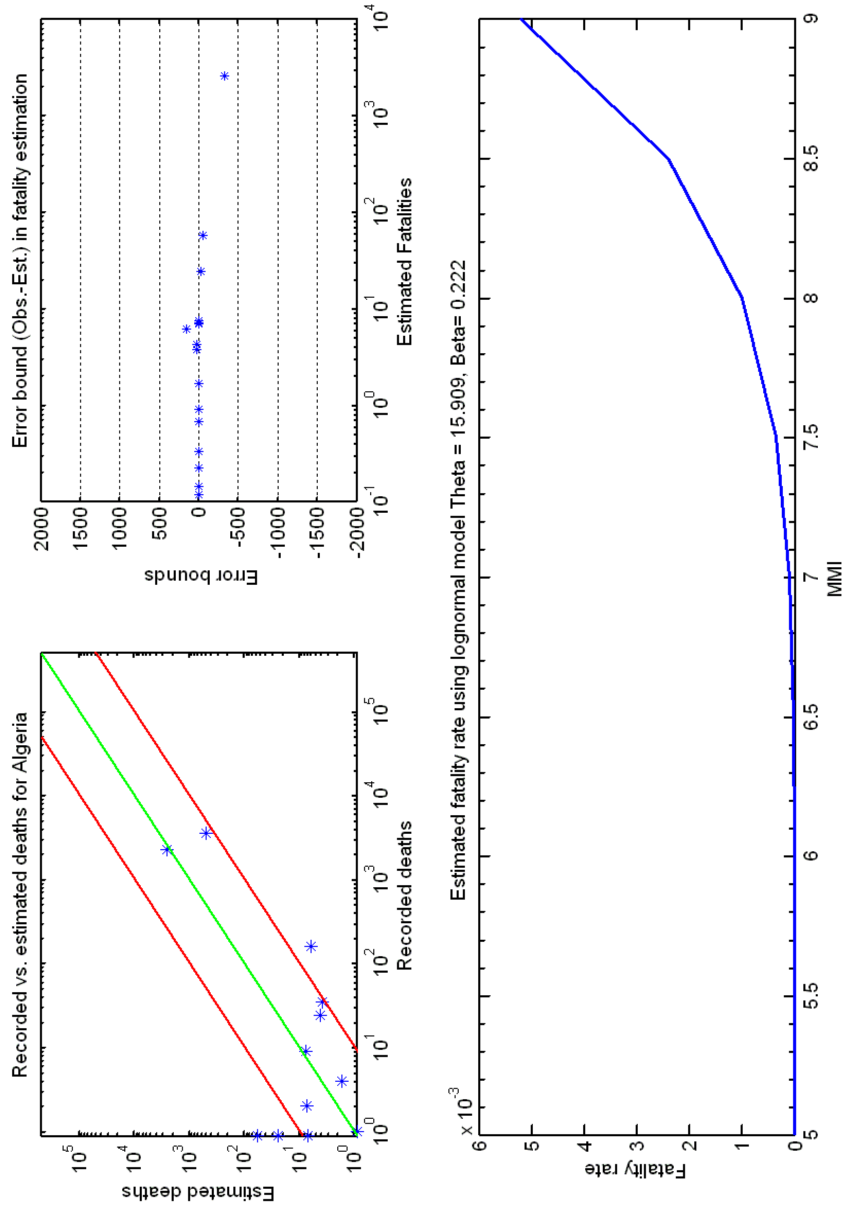


Figure 10. Empirical model derived from fatal earthquakes in Algeria.

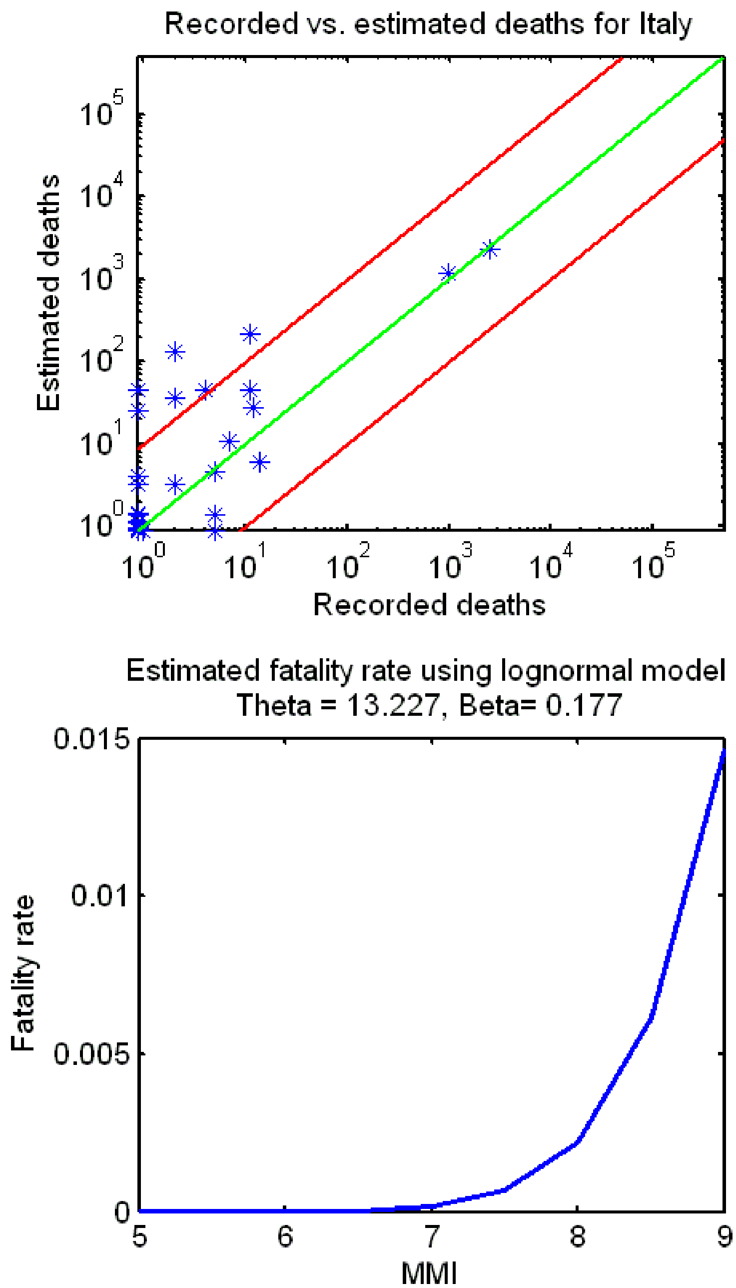


Figure 11. Empirical model derived from fatal earthquakes in Italy.

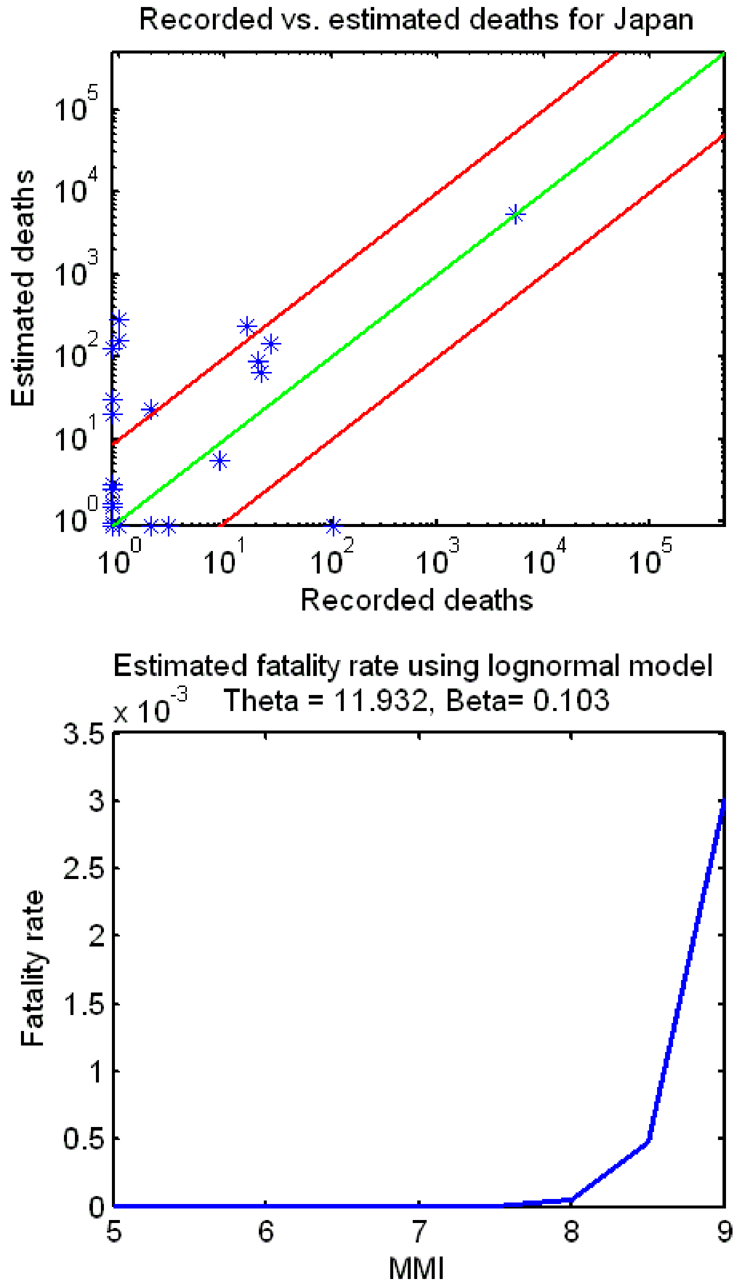


Figure 12. Empirical model derived from fatal earthquakes in Japan.

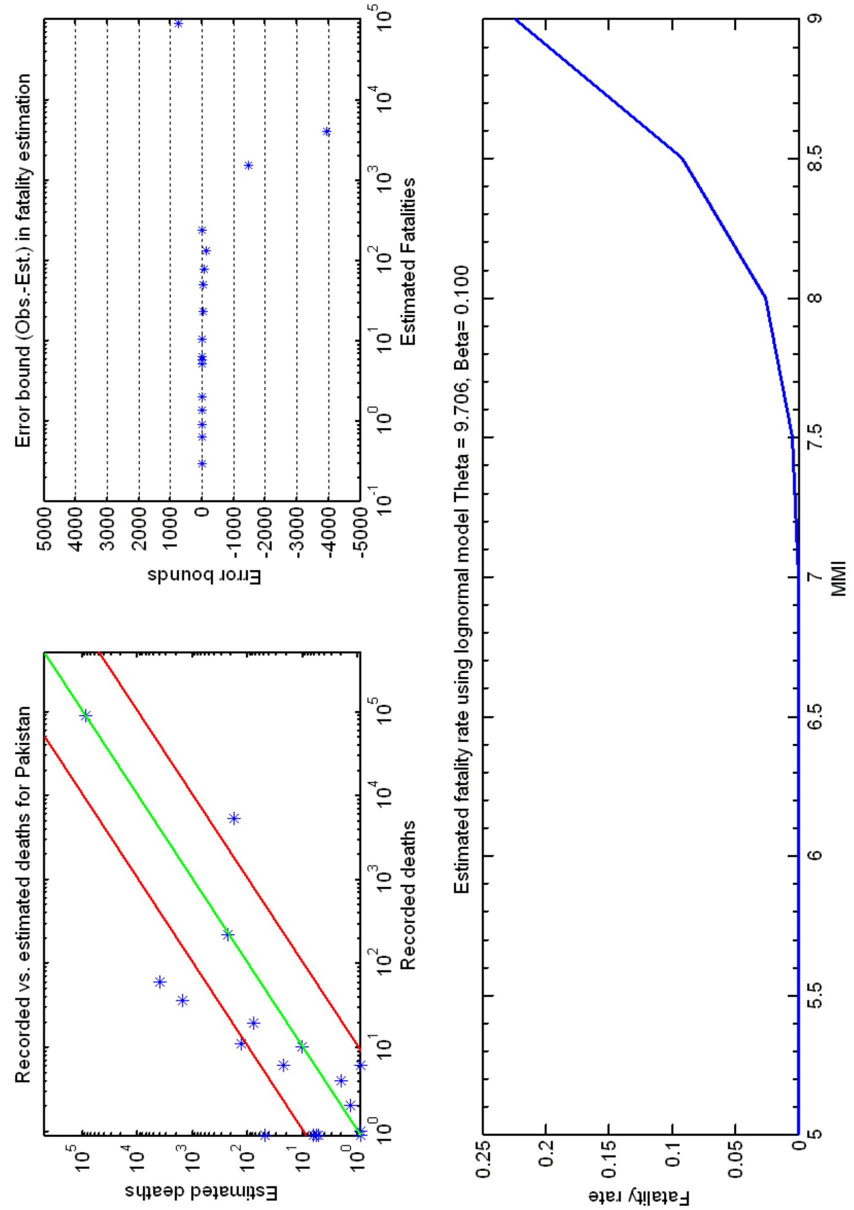


Figure 13. Empirical model derived from fatal earthquakes in Pakistan.

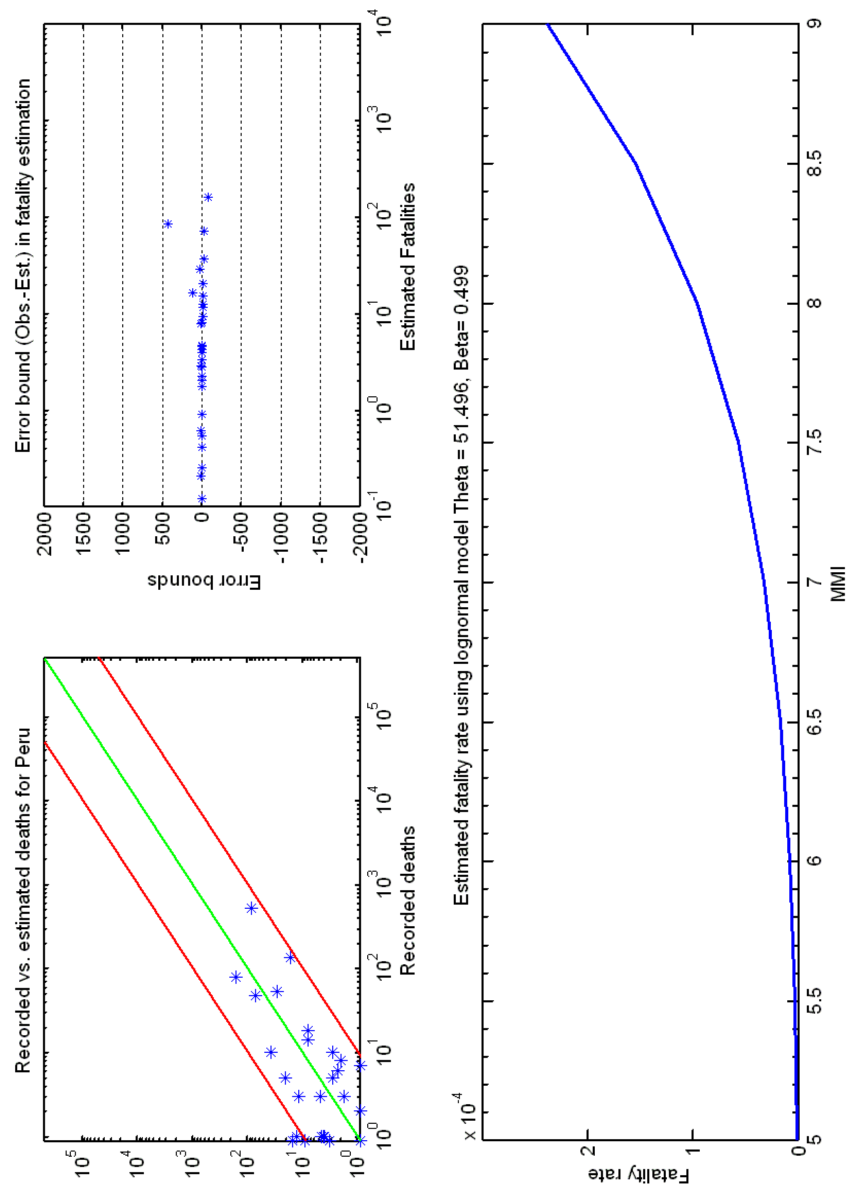


Figure 14. Empirical model derived from fatal earthquakes in Peru.

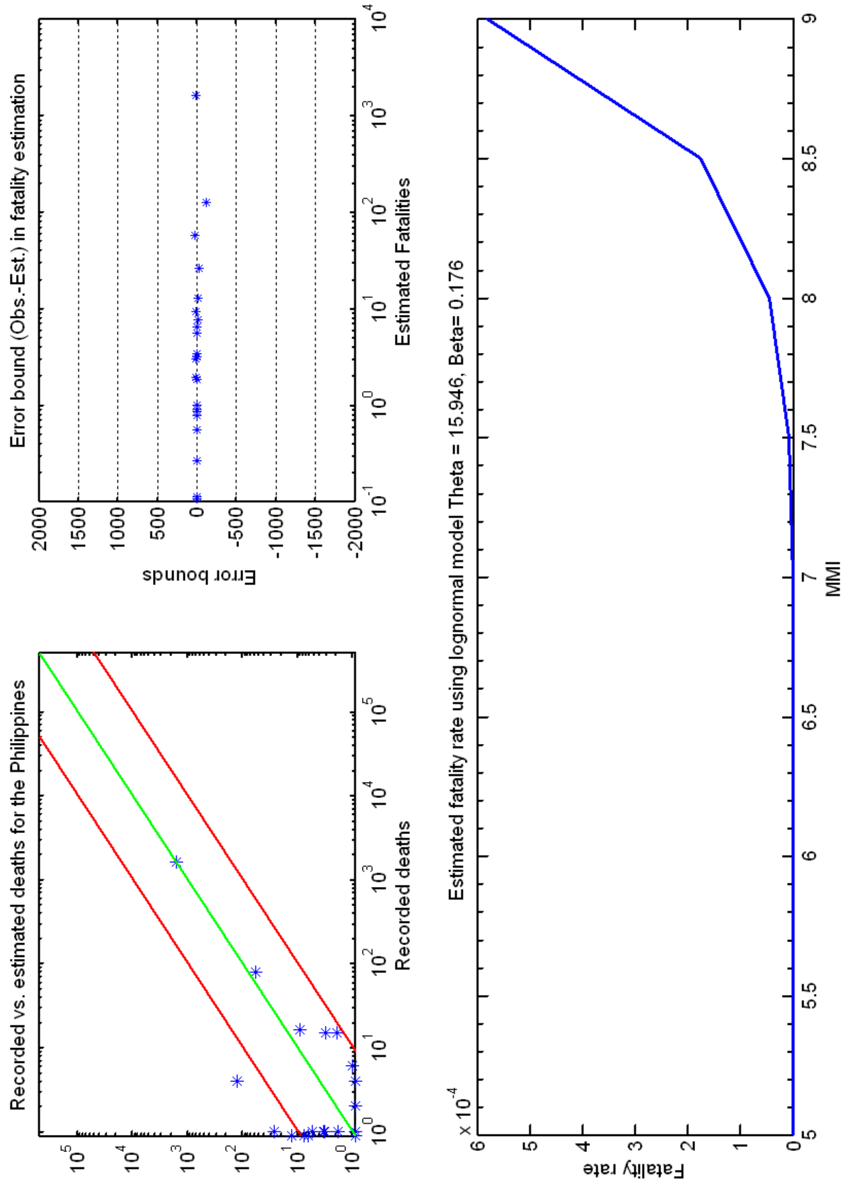


Figure 15. Empirical model derived from fatal earthquakes in Philippines.

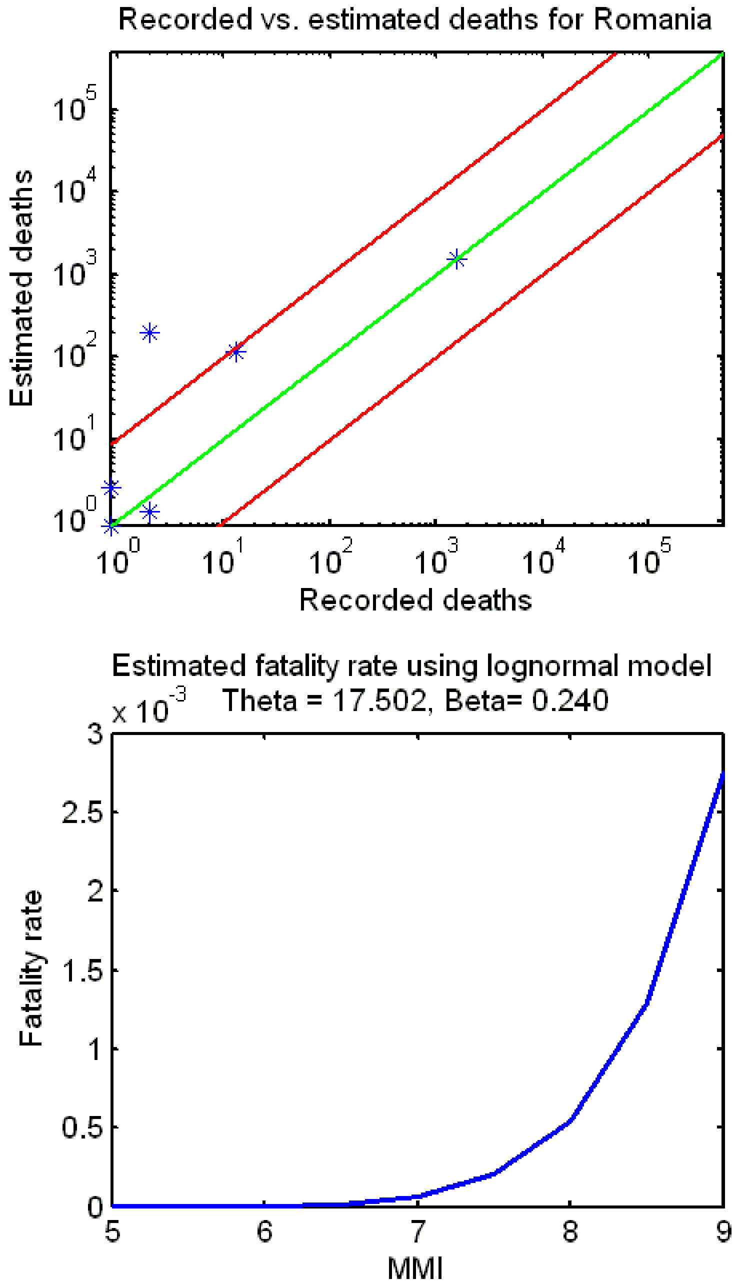


Figure 16. Empirical model derived from fatal earthquakes in Romania.

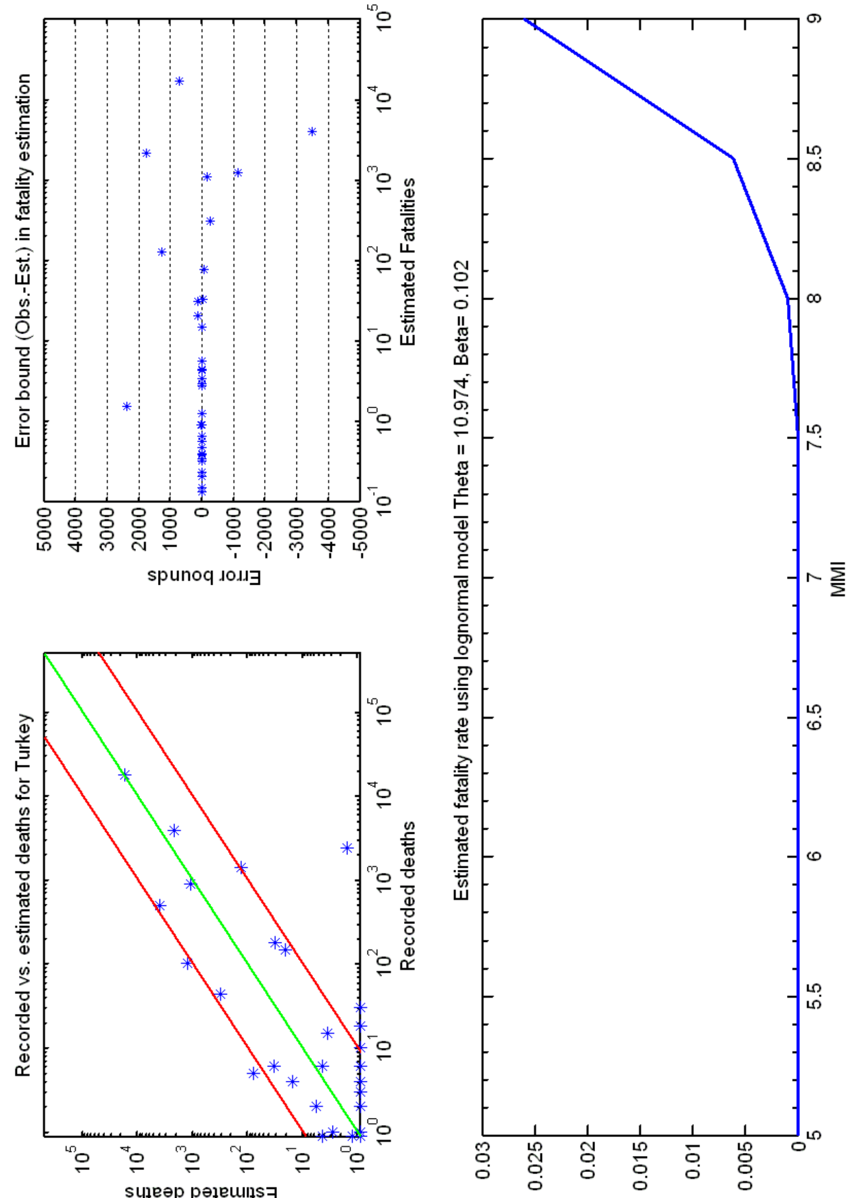


Figure 17. Empirical model derived from fatal earthquakes in Turkey.

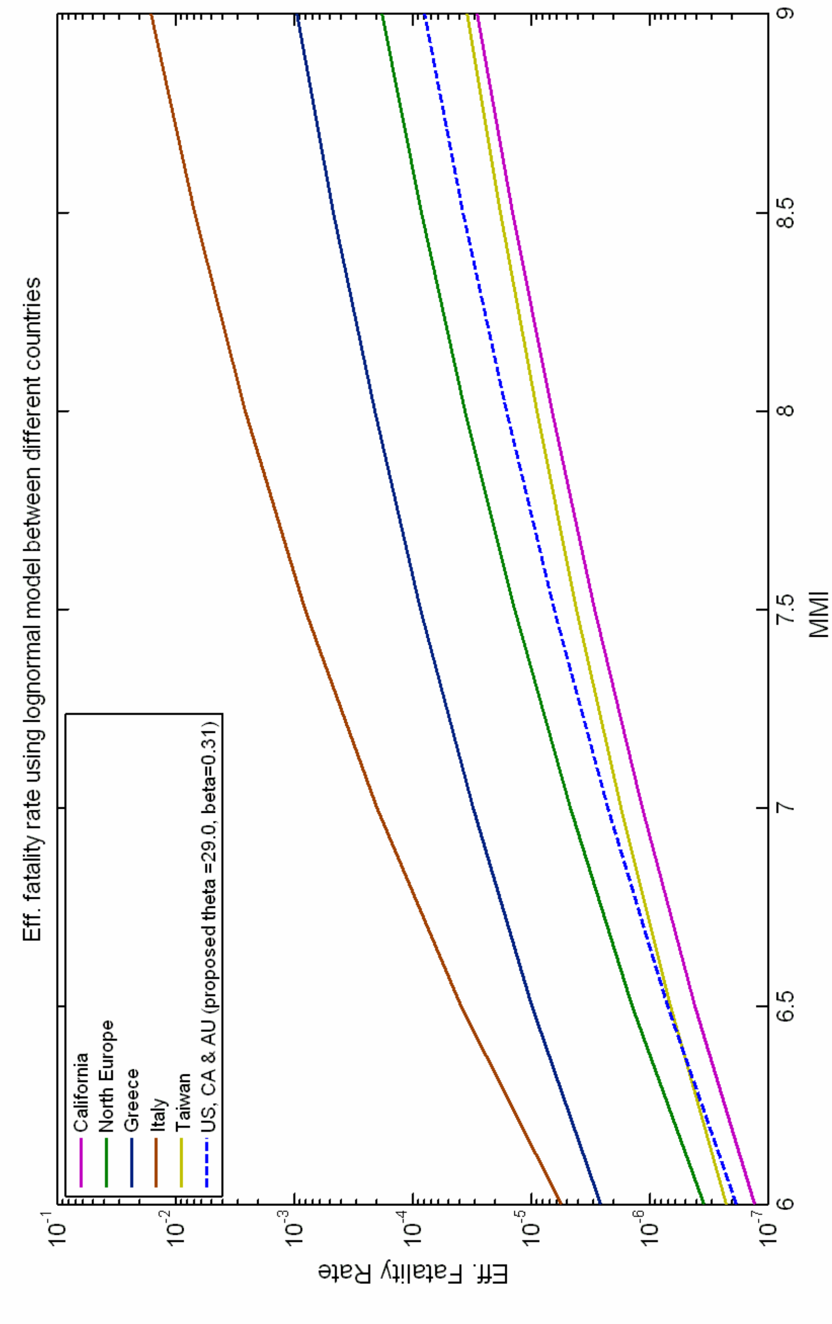


Figure 18. Comparison of fatality rate among different countries including the expert-judgment-based fatality rates (v1.0) for the USA without California, Canada and Australia group.