Towards reliable recurrent disaster forecasting methods: Peruvian earthquake case

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ABSTRACT

We are interested in recurrent disaster forecasts; these are events such as annual cyclones in the Caribbean, earthquakes along the Ring of Fire and so on. These crises, even small- or medium-sized, are, in fact, critical for the emergency response of humanitarian organizations inasmuch as the sum of casualties and losses attained are as deadly as those that are considered exceptional. The aim of our research is to show that it is possible to use traditional forecasting methods such as: causal methods (which include the use of linear regression functions, non-linear, multivariate, etc.), time series (which include simple moving average, weighted moving average, exponential smoothing, trend-adjusted exponential smoothing, etc.) and so on, if the historical data keeps, among other criteria, its patterns, frequency, and magnitude, in a sustainable manner. Finally, an example to forecast recurrent earthquakes in Peru is presented.

Keywords

Recurrent disasters, forecast, earthquake, frost, El Niño.

INTRODUCTION

The eruption of Mount Pinatubo in June 1991 illustrates the complexity of disaster forecasting. Earthquakes in the month preceding the eruption led some scientists to say that seismic activity could be a sign of an increase in volcanic activity, or that perhaps these have contributed to the eruption of the volcano. The eruption was the second strongest of the century and had global effects, causing an increase in ozone levels worldwide and a global decrease in temperature of 0,5°C. The effects of the volcano were intensified by the fact that typhoon Yunya struck the Philippines on the same day of the eruption, 45 miles away from the volcano. The ensuing rains from the typhoon, mixed with the ashes of the volcanic eruption, created massive lahars which destroyed the communitarian harvest. Moreover, the long-term effects of lahars, ashes and pollution, consequence of the eruption, contributed to the impacted region for them to have a poor crop and food insecurity. All of these events could have been predicted, by integrating tools to monitor and control databases about the updated state of the atmospheric phenomena. This paper is arranged as follows; the first chapter presents recurrent disaster frames which had been analyzed: landslides, frost, El Niño and earthquakes. The next chapter presents in focus recurrent disasters in relation to Peru's historical events. After the paper's approach is presented, it considers using traditional forecasting tools like simple moving averages to estimate recurrent disaster triggering or magnitude. Finally, conclusion and future research works are remarked.

RECURRENT DISASTERS

The media mostly speaks of major disasters involving many victims: a tsunami in the Indian Ocean in 2004, an earthquake in Haiti in 2010, a tsunami in Japan in 2011, a typhoon in the Philippines in 2013 and so forth. Though, since the year 2000, more than 400 natural disasters have been recorded each year worldwide. In many parts of the world, disasters occur repeatedly, such as droughts in the Sahel, hurricanes in the Caribbean, floods in Southeast Asia and earthquakes along the Pacific Ring of Fire. The general opinion is that the number of natural disasters, even of small or medium scale, is increasing throughout the world and will continue to increase due to the Climate Change.

Ferris and al. (2013), say the term “recurrent catastrophe" is used to denote the arrival of a single repeated natural hazard in the same geographical region. In 2008, Haiti was hit by four hurricanes throughout the year. Pakistan has experienced floods in 2010, 2011 and 2012. In some regions, droughts occur regularly, with more or less long pauses between them. Therefore, if disaster events return frequently enough, we can speak of recurrent disasters (IFRC, 2007; IPCC, 2007; Charles, 2010).

Recurrent Landslides

The occurrence of a landslide is described as "the movement of a mass of rock, debris or earth down a slope" (Cruden, 1991), in Peru it is called a *Huaico*. Due to the overflowing during the rainy months in the Peruvian highlands, the *Huaicos* occur in most of its 159 watersheds -- they are critical to local transport and supply because routes are damaged by mixed debris, mud and rocks (PNUD, 2009).

This hazard is essentially analyzed by the recurrence and spatial predominant location (DIPECHO, 2012):

1. Recurrence. Landslides can be periodic, occasional and exceptional. The periodic ones in Peru occur more frequently and during the rainy season between December and April; the occasional ones may or may not be caused by seasonal rains, rather deforestation, illegal construction, etc. could be causal. The exceptional landslides have a higher impact and a longer return; they are related to severe weather crisis as *El Niño* during 1997-1998 in the central area of Peru.
2. Predominant space location. The periodic and occasional landslides occur in the canyons of mountain ranges, in the slopes of ravines confined to mountain valleys and effluents of the main valleys, with extensive reception areas, in places with high rainfall rates and where there is erosion of slopes and steep relieves. However, exceptional ones may occur in flatter terrain relief, in the slope of streams with moderate to soft slopes, with deforested areas where exceptional rainfalls may occur, washing and transporting sediments in wide channels or dry ravines.

Recurrent Frost

The occurrence of frost is technically defined as the formation of ice crystals on surfaces; this involves freezing dew and the change of steam to ice phase (Blanc and al., 1963; Bettencourt, 1980; Speck, 1981; Cunha, 1982). However, the term "frost" is colloquially used to describe the meteorological event when crops and plants experience a freezing damage, in addition to posing a risk to human health. Katz, Murphy and Winkler (1982) indicate that for the frost analysis it is necessary to consider the minimum temperature and the perceived damage to life such as health, education, agriculture, livestock, and infrastructure. In a period of frosts, the temperature varies and results in critical moments of exposition. The factors that determine the intensity of a frost are multiple, such as the cloudiness, wind speed, humidity, tillage of the soil, slope of the site and height above the ground.

According to Bravo (1992), to estimate the frost period there are two methods: The Thorm Methodology and the Box- Jenkins methodology. They estimate the forecast of minimum temperatures for one year. The first method considers the concepts of early frost (date in which the first frost of the year occurs), and late frost (date in which the last frost of the year occurs). The second method requires that the data (time series) which it will work with, be stationary and invertible in time.

Recurrent "El Niño"

Formally, "El Niño Southern Oscillation" (ENSO) is defined by NWS (2006) as the coupled ocean-atmosphere phenomenon characterized by: (i) abnormally warm sea surface temperatures from the date line the East of the South American coast, (ii) changes in the distribution of tropical rainfall from the Eastern Indian Ocean east to the tropical Atlantic, (iii) changes in sea level pressure throughout global Tropics (low-index phase of the Southern oscillation) and (iv) large-scale atmospheric circulation changes in the Tropics and portions of the extra-Tropics in both hemispheres.

For Latif and Keenlyside (2009), the ENSO phenomenon originating in the Tropical Pacific is the strongest natural inter-annual climate signal and has widespread effects on the global climate system and ecology of the Tropical Pacific. Veldkamp and al. (2015) explain that ENSO is the result of a coupled climate variability system in which ocean dynamics and sea level pressure interact with atmospheric convection and winds.

According to Bates et al. (2008), ENSO is associated with wave-like disturbances to the atmospheric circulation outside the tropics, such as the Pacific–North American (PNA) and Pacific–South American (PSA) patterns, which have major regional climate effects. The strength and frequency of ENSO events vary on the decadal scale, in association with the Pacific Decadal Oscillation (PDO, also known as the Inter-Decadal Pacific Oscillation or IPO), which modulates the average state of the ocean surface temperatures and the tropical atmospheric circulation on time-scales of 20 years and longer.

Recurrent Earthqukes

Burbank and Anderson (2011) mention current tectonic plates model was developed by William Morris in 1899, Walther Penck in 1953 and John T. Hack in 1975. They conclude that there is a certain tendency of seismic forces to distort progressively the landscape during long intervals of time; this is called a balance state between distortion and erosion. Apparently, earthquakes have a cyclical nature when geomorphological conditions are present; pressure, elasticity, tension, speed and composition of motion-mass ground. Earthquakes happen when this balance system break down at an unknown time. The existence of this cyclical behavior could have timescales of 100 000 or more years, as is the case of glacial cycles (Burbank and Anderson, 2011). Therefore, a classification of major disasters versus recurrent disasters makes sense in the determination of frequency occurrence.

Konşuk and Aktaş (2013) say that when earthquakes are analyzed, four questions must be answered: Where? Size? Frequency? and When?

1. Where. McCaffrey (2008) says that most large earthquakes occur in underwater subduction zones where a tectonic plate slides over another one. There are seven major crustal plates, subdivided into a number of small plates. In Peru, the seismic activity is associated with the subduction of The Nazca under the South American plate; this stress zone is called "the Pacific Ring".
2. Magnitude. McCaffrey (2008) shows main world subduction zones and tectonic plate boundaries. He says that due to the great subduction, the database on earthquakes is incomplete; we cannot predict which subduction zones will be capable of generating an earthquake of magnitude 9 M. However, simulations of recurrent tremors suggest the occurrence of global 9 M earthquakes is 1 to 3 per century.
3. Frequency. Ambraseys (2006) said that for short-term observations, regional seismicity is well described by cumulative frequency-magnitude relation of Gutenberg and Richter proposed in 1935;

   $$\log(N) = \alpha - \beta x M$$

   N: is the annual number of earthquakes with magnitude equal to or greater than M in a given territory. Delic and Radojicic (2005) state that the parameters α and β are determined by using a regression data analysis on earthquakes which have already taken place in a specific area.
4. When. Sgrigna and Conti (2012) state that a deterministic forecast method to know the earthquake hypocenter location and its magnitude is an open scientific problem. Suzuki (1988), states that stochastic approach allows us to understand better the ground motion, but the lack of knowledge, data and random-fracture process hinders to predict issues around earthquakes.

RECURRENT DISASTERS IN PERU

In the last five centuries, at least 120 “El Niño” episodes have hit Peru according to SENAMHI (2014). Databases indicate that events in 1891 and 1925 were comparable to the events of 1982/83 and 1997/98 (measured by NOAA´s Oceanic Niño Index), these events are recurrent in the central Pacific, and it is expected that they will came back in a middle term.

Landslides and frosts have affected Peru, principally in the Highlands and Forests, respectively and, to a lesser extent, in the Coast, and the latter particularly in the Highlands. Figure 1 indicates that the Cusco and Amazonas regions have been mostly affected by landslides. Regarding frost, in Peru every year during the months of June, July and August, various departments in the high Andean region experience negative effects, Figure 1 points out the Huancavelica, Puno and Apurimac regions regularly have been struck; producing in both cases an increase in the amount of recorded events, because the pattern shown allowed to deduce future occurrences due to those hazards and particularly in the mentioned regions will be hit.

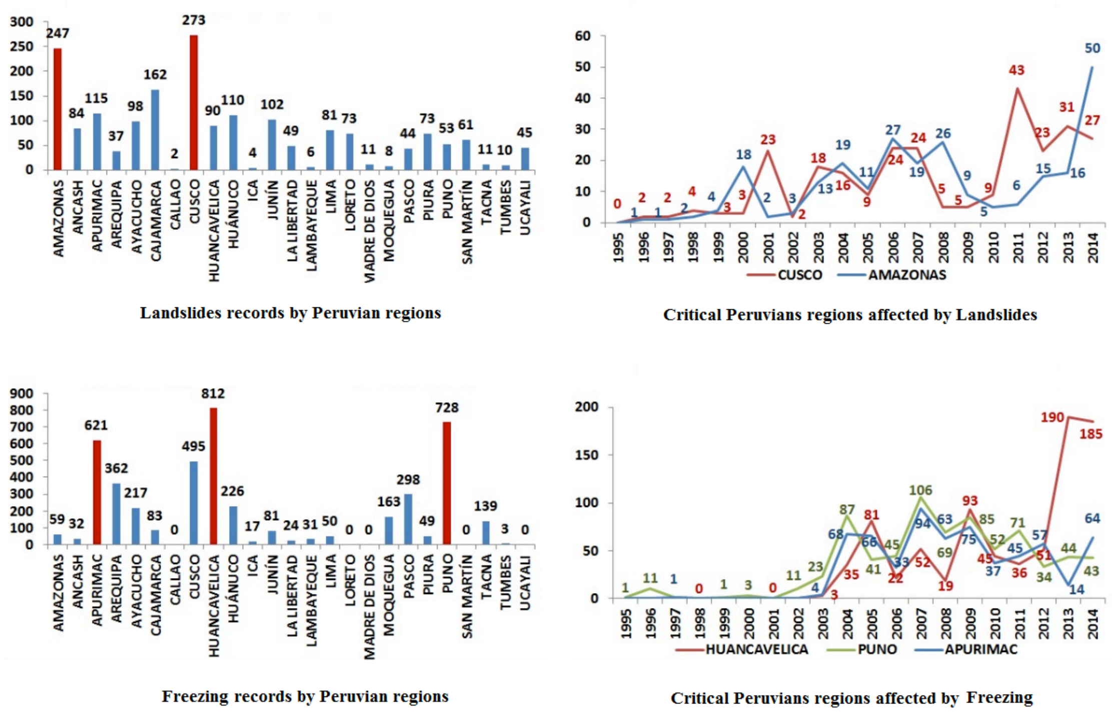

Figure 1: Landslides and freeze records in Peru (1995-2014). Source: INDECI (2014)

APPROACH TO FORECAST RECURRENT DISASTERS

According to the work of IFRC (2007), IPCC (2007), Kovács and Spens (2007), Charles (2010), Peres and al. (2012), Braman and al (2013), can predict recurrent disaster occurrence based on past disasters. Depending on the types of studied phenomena (earthquakes, floods, cyclones, etc.), location and levels of granularity specified (temporal, geographical, etc.), occurrence estimation can vary from simple to complex. The simplest model is often to consider that future developments will resume more or less past events (Charles, 2010; Peres and al. 2012; Galindo and Batta, 2013). In other cases, that require more precision, specialists of a particular geological or climatic phenomenon have the capacity to propose predictive models of specific occurrence in a given application field and over a limited time period. This is particularly the case of the works carried out by Li and al. (2012) and Braman et al. (2013) on floods, WGCEP (2008) on earthquakes and Tatham et al. (2012) on hurricanes. Krajewski et al. (2010) says that criteria used to forecast through time series and causal models using historical data, must analyze trend, seasonality, cycles and randomness. Vargas (2014) achieved a 91,7 % of reliable results to estimate short- and medium-term Peruvian earthquakes using an average time series and causal multivariate models to forecast, respectively.

It reviewed specialized authors’ forecast works such as: Krajewski, Ritzman and Malhotra (2013); Chase, Jacobs and Aquilano (2009); Box and Jenkins (1976); Thom and Shawn (1958). In order to preserve the characteristics of previous data provided in each case for the proper application of traditional forecasting methods; causal, time series and so on, it is proposed to use the following summary table based on previous authors' works to foresee disasters;

Disaster type	Forecasting Method	Quality of historical data	Data pattern	Forecast horizon
"Huayco"	Lineal regression	Over 25 data to validate the regression data	Periodical, occasional (in rainy season) and exceptional	Short term
	Moving Average	Over 6 data.		
Freezing	The Thorm Methodology	More than 25 data to cross several series of time, for another time-series to do the estimation	Seasonal	Short term, medium term
	The Box-Jenkins Methodology			
El Niño	Moving Average	Data from over 20 years of studies	Occasional (every 10 years)	Medium term
Earthquakes	Simple moving Average	Data from over 20 years of studies.	Cyclical and semi periodical (without trend and seasonality)	Long term

Table 1: Summary table on the use of traditional methods for disaster forecasts

CASE: PERUVIAN RECURRENT EARTHQUAKES

Earthquakes between 1582 and 2007 in Peru, set by Silgado (1978), Bernal and Tavera (2002), INDECI (2004) and USGS (2014) allowed us to identify 47 major earthquakes with a magnitude from 6,0 to 8,0 MM, 70 % occurred along the Lima and Ica regions. Moreover, those larger 8,0 MM (see Figure 2) are identified as recurrent, with an average frequency of 132 years (axis X: 142-122-133), magnitudes and dates are 8,4 (1604): 8,4 (1746): 8,6 (1868): 8,4 (2001).

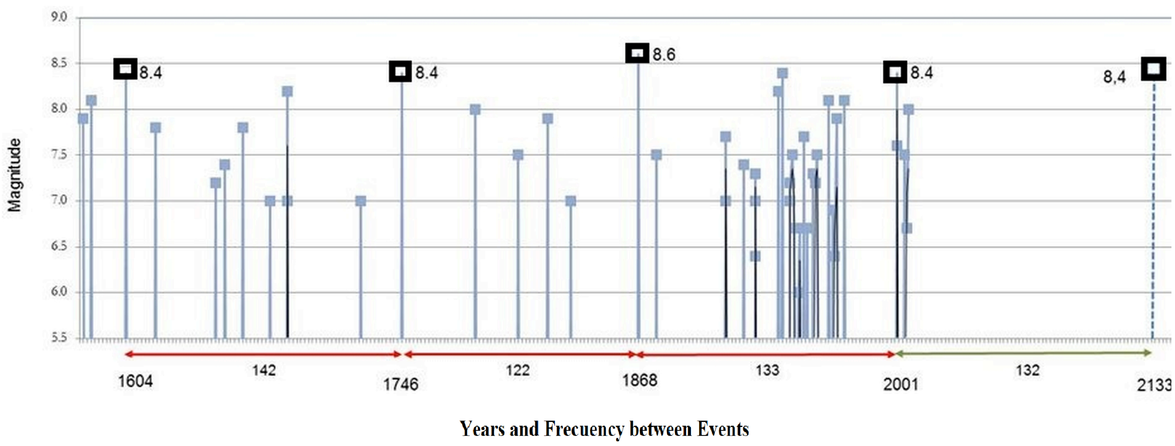

Figure 2: Recurrent large earthquakes in Peru and forecasts using simple moving average

Considering our primary hypothesis that historical events could repeat in a short-medium term, the last record of four earthquakes have the conditions to use a simple moving average forecast method to estimate the next recurrent earthquake to a 132 frequency years; the average result is 8,4 MM to estimated date by 2133, with a high probability of epicenter location between the Lima and Ica regions.

Conclusion

The article demonstrates that in the case of recurrent disasters, forecast calculation can use traditional forecasting tools such as: causal methods (which include the use of linear regression functions, non-linear, multivariate, etc.) and time series (which include submethods as the simple moving average, weighted moving average smoothing exponential, exponential smoothing with trend, etc.). To make this possible, historical data in analysis must demonstrate a consistent database, a sustainable trend and, fundamentally a representative behavior in the time depicted by its frequency, pattern and average magnitude, in a short-and medium-term. Anticipating future recurrent disaster events, we seek to improve the prevention and preparedness humanitarian labor force, reducing material losses and human casualties whenever they take place.

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