

# Assessing Temporal Changes in Global Population Exposure and Impacts from Earthquakes

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## ABSTRACT

It is frequently conveyed, especially in the media, an idea of “increasing impact of natural hazards” typically attributed to their rising frequency and/or growing vulnerability of populations. However, for certain hazard types, this may be mostly a result of increasing population exposure due to phenomenal global population growth, especially in the most hazardous areas.

We investigate temporal changes in potential global population exposure and impacts from earthquakes in the XXth century. Spatial analysis is used to combine historical population distributions with a seismic intensity map. Changes in number of victims were also analyzed, while controlling for the progress in frequency and magnitude of hazard events. There is also a focus on mega-cities and implications of fast urbanization for exposure and risk.

Results illustrate the relevance of population growth and exposure for risk assessment and disaster outcome, and underline the need for conducting detailed global mapping of settlements and population distribution.

## Keywords

Population distribution, earthquakes, spatio-temporal analysis, cities

## INTRODUCTION

Disaster risk, understood as the potential for loss and damage, results from the combination of three main components: hazard, exposure, and vulnerability (UNDP, 2004). Today, a major driver of growing disaster risk is the rapid increase in exposure of population and assets (UNISDR, 2013).

It is frequently conveyed, in mass media but also in the disaster-related scientific literature, an idea of “increasing impact of natural hazards” typically attributed to their rising frequency and/or growing vulnerability of populations. However, for many hazard occurrences, especially those above a certain magnitude or intensity, population exposure is arguably the greatest determinant of resulting human losses and impacts (Freire and Aubrecht, 2012). If this is confirmed, then the ongoing phenomenal global population growth and urbanization (especially in the most hazardous areas), is the main driver of these mounting impacts, since the frequency of events has remained relatively constant (Cutter and Emrich, 2005). In fact, for a number of low-income countries the rapid population growth outpaces any disaster risk mitigation and vulnerability reduction activities, resulting in a net disaster risk increase (UNISDR, 2009).

Evaluating human exposure for global disaster risk assessment is challenging, being limited by the availability and quality of geophysical and socio-economic data (Lerner-Lam, 2007; Peduzzi et al., 2009). Therefore estimations of human exposure are usually conducted for small areas and without a temporal dimension.

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Earthquakes may provide a case-study that allows advancing these analyses. For support to seismic risk assessment, there is availability of digital data on spatial distribution of global seismic hazard. This zonation can be considered relatively stable in time, since it's due to slow-changing tectonics. Earthquake catalogs and databases provide data on their frequency and impacts. Although the randomness in the occurrence of these events complicates testing of scientific hypotheses about earthquakes (Sornette and Werner, 2005), this problem might be mitigated by analyzing a sufficiently long and complete temporal series.

The United States Geological Survey (USGS) already estimates population exposure to significant global earthquakes which occurred since 1973 (Allen et al., 2009), yet departing from a single date of population distribution data. The availability of spatially-explicit surfaces of global population distribution at decadal intervals, despite their still coarse resolution, offers the opportunity to extend the temporal depth of such analyses.

This work is an exploratory analysis of temporal changes in potential population exposure to seismic hazard, at global scale (period 1900-2000) and for selected cities (period 1950-2010). The ultimate goal is to study earthquake impacts and their frequency in relation to the spatio-temporal variation of the potentially-affected population.

## DATA SETS

Data used for analysis included both spatial and tabular global sets related to seismic risk (Table 1).

Risk component	Data set	Source	Spatial Resolution/Scale	Temporal Coverage/Resolution
Hazard	Seismic Intensity Zones	UNEP/GRID World Map of Natural Hazards	1:34,000,000	-
Hazard occurrence and impacts	Catalog of earthquakes	USGS PAGER-CAT, V. 2008_06.1	-	1900-2008, by event day
Exposure	Population distribution grids	HYDE 3.1	5'	(10,000BC-) 1700-2005, by decade

**Table 1. Data sets used and respective characteristics**

The global map of hazard zoning was obtained by using the "EQUAGEO" coverage, which was produced by UNEP/GRID on the basis of the World Map of Natural Hazards (MunichRe, 1988). This map shows earthquake intensity zones in accordance with the 1956 version of the Modified Mercalli Intensity Scale (MMI). Since the intensity describes exclusively the effects of an earthquake, it is the preferred scale to assess population exposure (USGS PAGER - Prompt Assessment of Global Earthquakes for Response).

Data on actual earthquake events was obtained from the USGS earthquake catalog (USGS PAGER-CAT), a composite global register of significant events for the period 1900-2008 (Allen et al., 2009b).

To analyze human exposure, we used data from History Database of the Global Environment - HYDE 3.1 (Goldewijk et al., 2010). HYDE provides spatially-explicit global raster surfaces of population counts for various time steps, since 10,000BC (by decade since 1700AD).

## ANALYSIS

The analysis was carried out in a Geographic Information System (GIS) and addressed temporal changes in potential population exposure and impacts from earthquakes at (a) global level and (b) for selected cities.

### Temporal changes in potential global population exposure to seismic hazard, 1900-2000

Potential population exposure was quantified for each seismic zone and decade from 1900 to 2000. This was accomplished by conducting zonal analyses of the population surfaces and the seismic hazard map in a GIS. Results are presented in Table 2 and Figure 1.

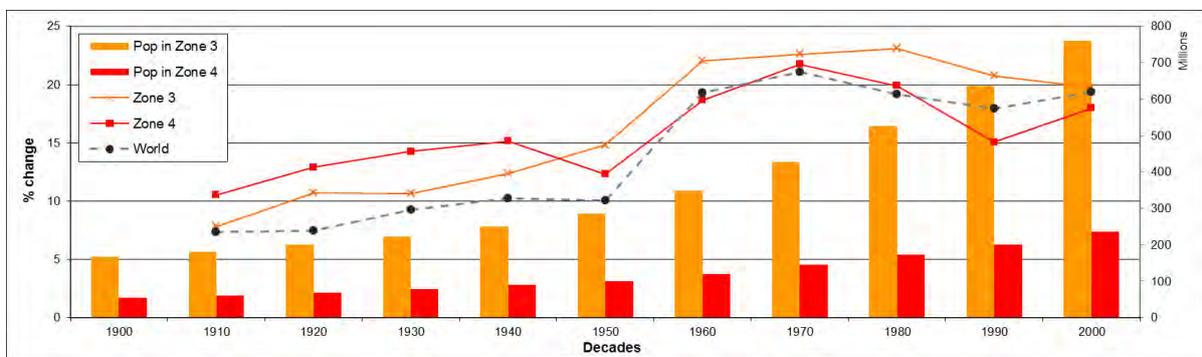
Table 2 shows that population potentially exposed to severe ground shaking (MMI  $\geq$  VIII) had the highest

relative increase from 1900 to 2000 (300%+), with more than 200 million people now living in the highest hazard zone. Although this zone accounts for only 1.5% of the total surface, it now includes 4% of the world's population. This is especially dangerous since earthquake mortality appears to be more systematically linked to the population exposed to severe ground shaking (Modified Mercalli Intensity VIII+) (Allen et al., 2009).

Zone	MMI	Area*		Exposure 1900		Exposure 2000		Change 1900-2000	
		Km <sup>2</sup> [10 <sup>6</sup> ]	%	Pop. [10 <sup>6</sup> ]	%	Pop. [10 <sup>6</sup> ]	%	Pop. [10 <sup>6</sup> ]	%
0	I - V	76.1	57.1	528.7	32.8	1735.2	29.0	1206.5	228.2
1	VI	30.5	22.9	522.1	32.4	1870.6	31.3	1348.5	258.3
2	VII	15.2	11.4	337.9	21.0	1371.2	22.9	1033.3	305.7
3	VIII	9.6	7.2	167.6	10.4	760.0	12.7	593.4	354.0
4	IX - XII	2	1.5	54.4	3.4	235.9	3.9	181.5	333.7
All		133.4	100.0	1610.8	100.0	5974.0	100.0	4363.2	270.9

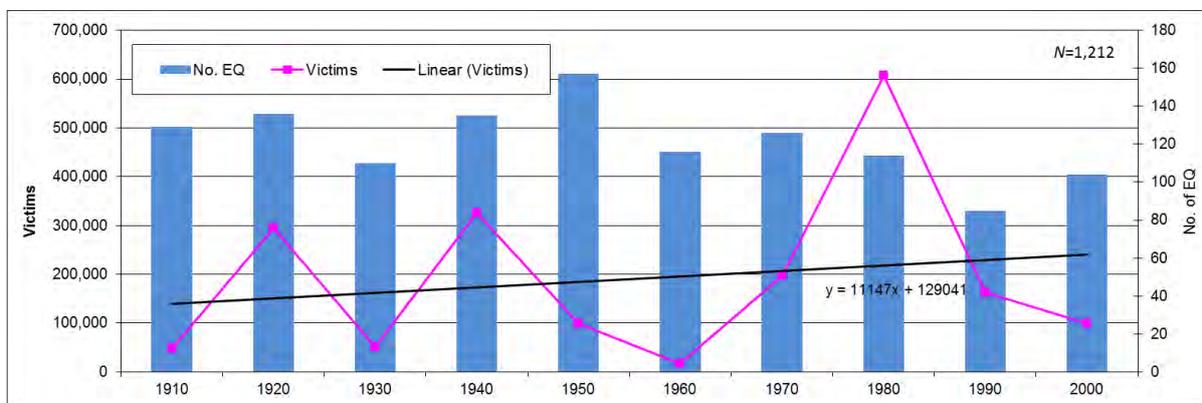
Differences to 100% are due to rounding effects; \*excluding Antarctica

**Table 2. Zones of seismic hazard in the EQUAGEO map, their respective area and potential population exposure in 1900 and 2000**



**Figure 1. Evolution of global population potentially exposed to highest seismic hazard, by decade.**

Figure 1 shows changes in population living within zones 3 and 4. Beyond the continuous increase of total exposure, a finer analysis by decade shows that population growth rate in zone 3 has increased above the global population rate in all periods, while for zone 4 this also occurred in the 1960s and 70s, and especially until 1940, when its increase rate was the highest.



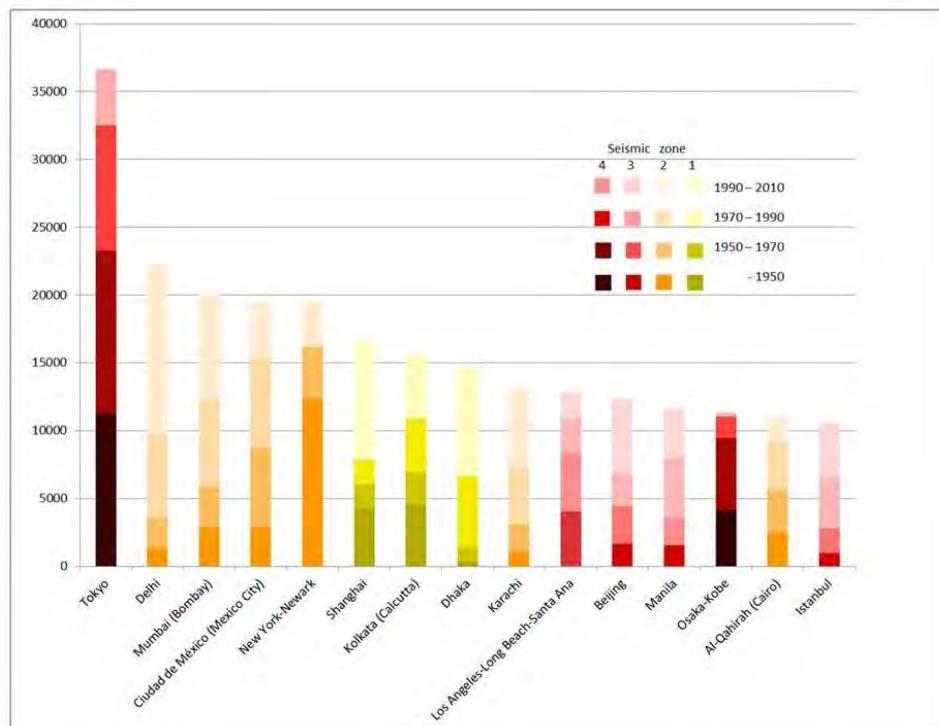
**Figure 2. Number of events and number of victims for large earthquakes (M>7) from USGS PAGER-CAT, by decade.**

Figure 2 shows the total number of events and number of victims (deaths + injuries) for magnitudes greater than 7, summarized by decade from the values in the earthquake catalog (PAGER preferred values). While the number (frequency) of large earthquakes is relatively stable (average of 121 per decade) or even shows a tendency to decrease, the number of victims displays a remarkable variation, albeit with a slight rising tendency. If one takes victims as an indication of direct impact on human populations, these impacts may have a tendency for increase.

However, it should be considered that catalogs contain a wide variety of uncertainties and data gaps (Sornette and Werner, 2005) which cannot be easily eliminated. In fact, the absence of reliable data is a major constraint to conducting assessments of disaster risk and losses. Still, loss of life is considered the most consistent and quantifiable measure, despite the recent focus on economic value (NRC, 2006). In this case, thresholding earthquake events by magnitude 7 was also required due to the strong bias present in the number of registered events and associated data below that level. Further research is needed to confirm these results and investigate tendencies in more detail, spatially and temporally.

### Evolution of potential population exposure for cities, 1950 - 2010

Coupled with population growth, a new wave of urbanization is taking place in hazard-exposed countries (UNISDR, 2013). Due to the current extent and pace of urbanization, the analysis of the exposure and risk of cities should increasingly be the focus of research. Of the existing twenty mega-cities – those with more than 10 million inhabitants (UN, 2012) – only 5 are not located in zones of significant seismic hazard ; three cities are located in zone 1, six in zone 2, four in zone 3, and 2 in zone 4 (Tokyo and Osaka) (Figure 3).



**Figure 3. Population growth (in thousands) between 1950 and 2010 in 15 mega-cities, symbolized based on their respective seismic zones.**

The increase in population between 1950 and 2010 is over 30 million people in each of the earthquake intensity zones 1, 3 and 4; and exceeds 80 million for earthquake zone 2. The population growth of mega-cities in the past 60 years has been phenomenal and unprecedented, although varying across countries and continents.

These agglomerations continue to grow in area and number, increasing potential population exposure and disaster risk. However, due to their size and other characteristics, these areas create many challenges for their correct exposure and risk assessment and management. Also, about 75% of the current population is located in centers with less than 750,000 people, and most of future population growth will occur around smaller urban

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centers (UN, 2012), often located in seismic prone areas. This reality calls for new tools and geodata from the DRM community.

## CONCLUSIONS AND OUTLOOK

This paper reports work-in-progress aiming at investigating global temporal trends in potential population exposure to seismic hazard and implications for impacts and losses. Spatial analysis was used to combine historical population distributions with a seismic intensity map to assess human exposure throughout the XX<sup>th</sup> century. The evolution of victims was also analyzed, while controlling for the progress in frequency and magnitude of hazard events.

Results show that population potentially exposed to highest seismic hazard is growing at high rates, eventually increasing the contribution of this component to impacts and losses. Rapid and widespread urbanization poses special challenges for disaster risk management, with emerging cities being difficult to map and monitor, despite being hot-spots of population exposure. This illustrates the relevance of population growth and exposure in risk assessment and disaster outcome, and underlines the need for conducting detailed and updated global mapping of settlements and population distribution.

Future developments should include more spatially detailed analyses (e.g. at continent/regional level) and advance beyond population growth to also investigate changes in densities.

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