- A Technical report for the 2011 Global Assessment Report on Disaster Risk Reduction -

Testing the GAR risk methodology at the national level : the case of earthquakes in Indonesia

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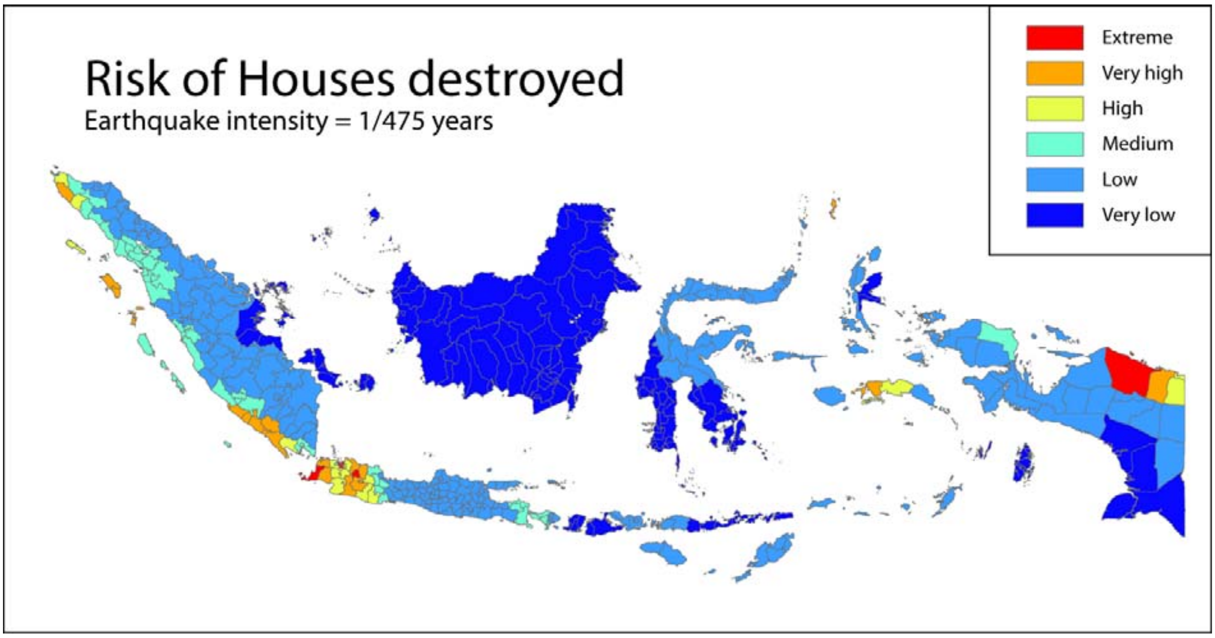

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Abstract

According to the 2009 Global Assessment Report on Disaster Risk Reduction (GAR 2009), Indonesia is one of the countries in the highest category of risk (top five). It has the highest world exposure to tsunamis and landslides, the third exposure to earthquakes and is ranking 6 exposed to floods. There is a need to disaggregate the information on risk within the national level, in order to highlight wich regions should get priority attention to implement disaster risk reduction measures. The idea of this project was to test whether the methodology used at the global level for the 2009 GAR, could be used at the Indonesian National level. A first attempt was made using earthquakes hazard. A large database linking exposure to different intensity of past hazardous earthquakes with losses and contextual vulnerability parameters was created and a multiple regression analysis was run. This study provides the results of the multiple regression, but also provides recommendation on what is needed to improved so that further risk analysis.

1. Introduction

According to the 2009 Global Assessment Report on Disaster Risk Reduction (UN, 2009), Indonesia is one of the countries in the highest category of risk (top five). It has the highest world exposure to tsunamis and landslides, the third exposure to earthquakes and is ranking 6 exposed to floods. There is a need to disaggregate the information on risk within the national level, in order to highlight wich regions should get priority attention to implement disaster risk reduction measures.

In the context of the analysis for the 2011 Global Assessment Report on Disaster Risk Reduction, one of the activities was to test whether the methodology developed at the global level can be used at national level. To this end a collaboration with the Crisis Prevention and Recovery Unit of UNDP Country Office was initiated. A two weeks mission to Jakarta was carried out in January 2010 in order to identify the existing data at the Indonesian national level. This is also the occasion to test the methodology with database from DesInventar, which may offer more detailed information as compared with global loss database such as EM-Dat which was the one used up to now.

The UNDP/Indonesia expressed the need for the development of a simple and robust risk Index at the district level.

The methodology applied at the global level uses past hazardous events and related losses to identify best contextual vulnerability parameters. Through a multiple regression analysis it is possible to allocate weights to the different component of risk. The first step is to model (or take existing) footprint of past hazardous events. In this case we used the earthquakes, as the footprints of past earthquakes events were available (see data sources), for other hazards this would have request to be modelled.

2. Risk and earthquake hazard maps

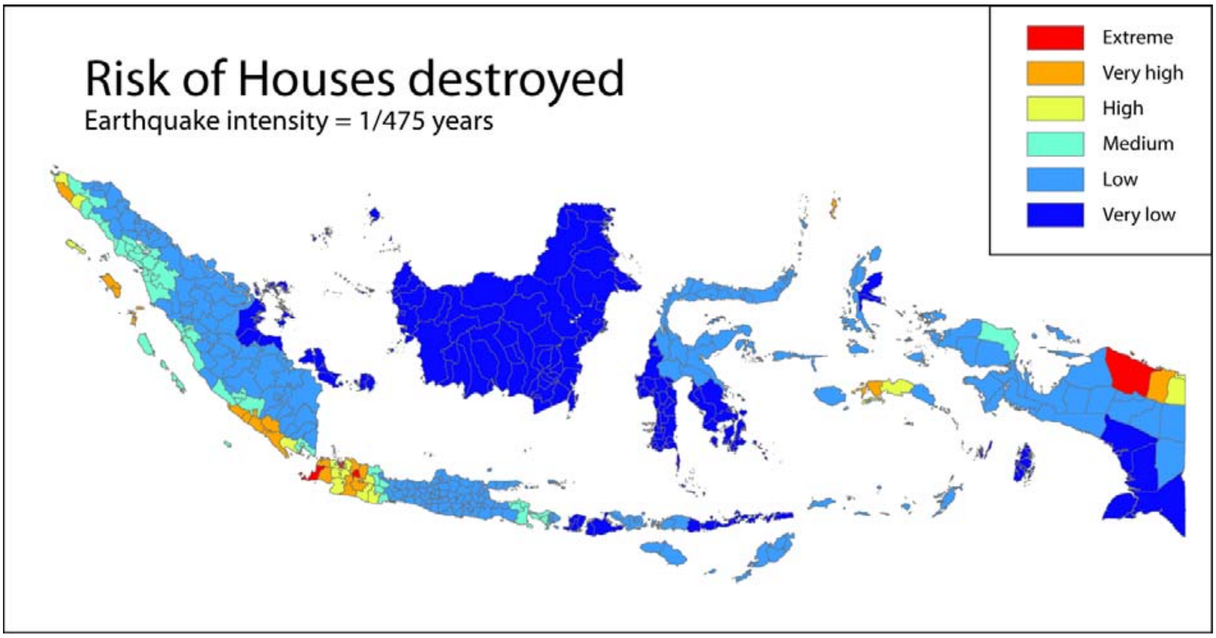
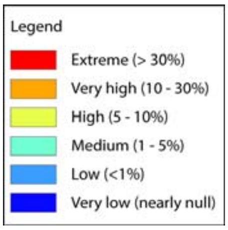


Figure 1 Map of Risk model for Percentage of Houses Destroyed



<u>NOTE:</u> Given the analysis based on transformed logarithmic regression, the values should not be taken as exact value, this is why only classes ranging from very low to extreme are provided.
For information
For internal discussion here is the corresponding table.

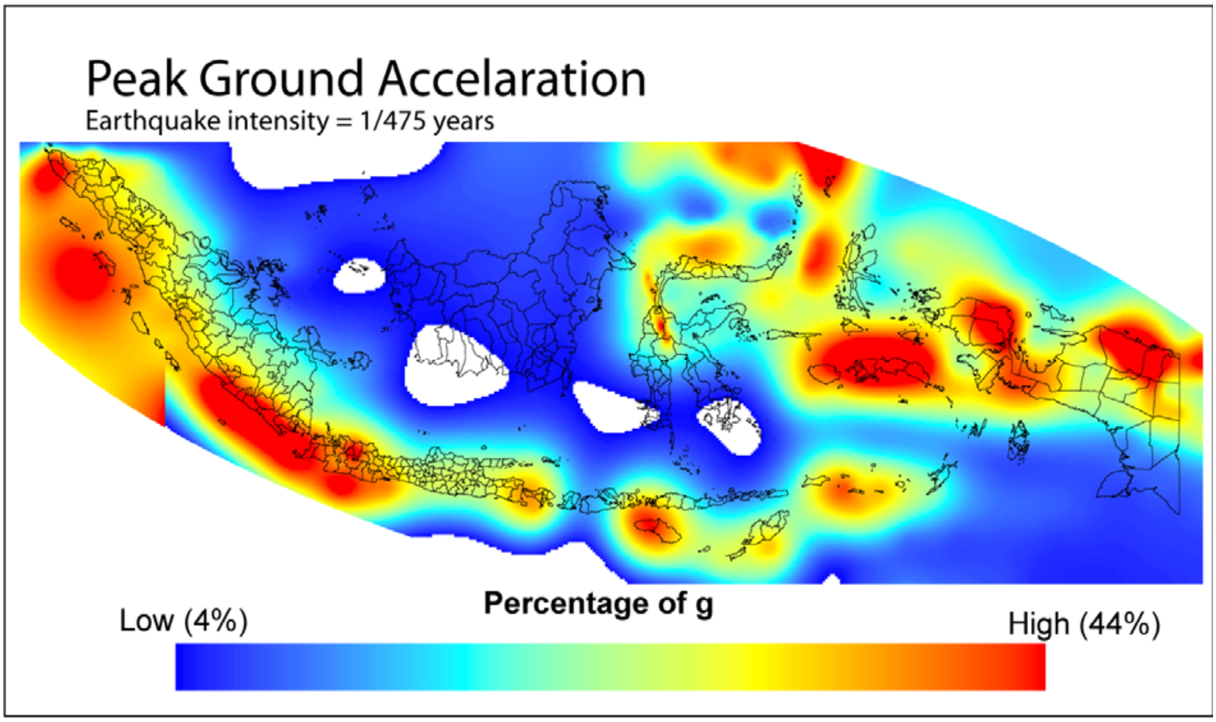


Figure 2 Map of Peak Ground Accelaration (data sources GSHAP)

3. Data sources

Name	Description	Sources	Link
ShakeMaps	Past Earthquakes events footprints	USGS	http://earthquake.usgs.gov/earthquakes/shakemap/atlas.php
Global Seismic Hazard Map	Seismic hazard map	GSHAP	http://www.seismo.ethz.ch/gshap/
Hazard Map for Indonesia with a Return Period of 500 Years	Seismic hazard map of PGA with a Return Period of 500 Years	Department of Public Works, Indonesia	http://www.pu.go.id/
Hazard Map for Indonesia with a Return Period of 2500 Years	Seismic hazard map of PGA with a Return Period of 2500 Years	Faculty of Mining and Petroleum Engineering, ITB, Bandung	http://www.fttm.itb.ac.id/en/
DIBI	Indonesian Losses Database	Data dan Informasi Bencana Indonesia BNPB	http://dibi.bnpb.go.id/DesInventar/main.jsp?countrycode=id&lang=EN
PODES	BPS Village Potential Statistics	Badan Pusat Statistik Republik Indonesia	http://dds.bps.go.id/eng/aboutus.php?tabel=1&id_subyek=04
BPS Statistics by Subjects	BPS Population Census	Badan Pusat Statistik Republik Indonesia	http://dds.bps.go.id/eng/aboutus.php?glos=1
Administrative Boundaries of Indonesia	GIS file for the four levels of administrative boundaries	Badan Nasional Penanggulangan Bencana	http://www.bakornaspb.go.id/website/index.php?option=com_content&task=view&id=1712&Itemid=120
Port and Airport Facilities	GIS file of Port and Airport for Indonesia	Badan Nasional Penanggulangan Bencana	http://www.bakornaspb.go.id/website/index.php?option=com_content&task=view&id=1712&Itemid=120

4. Methodology

4.1. General approach

This study is based on an "event per event" methodology, similar to the one which was used for the 2009 Global Assessment Report (UN, 2009).

The equation of risk used in the Global risk Analysis is as follows:

Risk = Hazards x Exposure x Vulnerability

<u>Where</u>:

Risk is the expected losses for a specific hazards, time and place

Hazards is the probability of occurrence of a hazardous event at a specific intensity (severity)

Exposure is the number of people, object or asset present in a given location potentially affected by the selected hazard.

Vulnerability is the expected percentage of loss of the exposure, should an event of a specific intensity occur. To ease the computation, in this case vulnerability includes coping capacity and resilience.

The application of the risk model involved the following seven steps for each hazard type (see Peduzzi et al., 2009a and Peduzzi et al. 2010 for more details):

1. Compile geographical and physical information on specific past hazard events such as tropical cyclone track data, areas of flood extent, or earthquake location and magnitude.

2. For each hazardous event, we determine the footprint of impacted areas using GIS models.

3. For each impacted area, we compute the exposure (number of people and economic assets within that area), by overlaying the event footprint on population, house and GDP distribution models.

4. We link available loss information (killed, economic loss) for each hazardous event (sourced from DesInventar Indonesia) to the hazard event information (hazard severity and exposure). This link is made using the dates and the district code, further automation were also applied for special cases. This allows a georeferencing of the loss database. It draws from previous methodologies applied to generate the Disaster Risk Index (Peduzzi et al. 2005, Peduzzi et al. 2009b).

5. By intersecting the shakeMaps with a vector map of Indonesian district, it is possible to extract the district affected by each past hazardous event. Link with information on vulnerability is made by creating a database links based on date of the event and ID of the districts affected. This creates a databased were exposure of population, houses and other object for different classes of severity of earthquakes can be linked with contextual parameters such as percentage of permanent houses, GDP per capita, … It also provided links with recorded losses (killed, missing, injured, houses destroyed,…).

6. Estimate empirical loss functions that relate event mortality or economic losses to risk factors (hazard characteristics, exposure and vulnerability) using statistical regression techniques. The socio-economical parameters are separated in different groups (hypothesis) of uncorrelated variables. Each hypothesis is then tested and best models are selected using statistical tests (e.g. percentage of variance explained, significance of the variable selected).

7. For each district and class of Peak Ground Acceleration, a risk can be computed by running the equation from the multiple regression analysis.

4.2. Data preparation

Considering expected timelines for results, we decided to realize this risk analysis considering first seismic hazard. Indeed, earthquake event footprint database is the most accessible and complete one (see USGS ShakeMaps in data sources). Time-window for statistical analysis has been fixed to 11 years (1998-2008). This choice is mainly due to the spatiotemporal complexity induced by the changes of coding system for administrative boundaries over the years. But it also allows considering a pertinent range of socio-economic indicators over the time. Nevertheless, the recurrent creation of new administrative units and changes of coding system is adding time consuming processes at many steps of such an analysis, especially because table of correspondence is available only for the district level. The best way to effectively solve this issue in the future would be to georeference statistics at the village level.

4.3. Earthquake events footprints

Individual earthquake events footprints are available through the Shakemap Atlas version 1.0, provided by the Earthquake Hazard Program at USGS. We use Peak Ground Acceleration (PGA) maps corresponding to the mentioned time-window.

Link between individual PGA shakemap and DIBI events was achieved using specific thresholds on dates, and then processing to spatial intersection between polygons of shakemap and event district. Precedence was given to highest PGA when various shakemap were selected. Following this procedure, we could georeference about 80% of the DIBI events. Visual check of spatial correspondence between PGA maps and affected districts was performed. It generally show reliable pattern, confirming that DIBI data collection process is probably not affected by changes in district coding system. On the other hand, it highlights some cases where, among the districts affected by the same earthquake and a similar level of PGA, some were not recorded in DIBI especially for the period prior 2000.

4.4. Losses

DIBI national database is used as a reference for quantitative information about houses and population losses at district level. Excluding the records that are missing essential information, it totalizes 218 records over the considered 11 years time-window. A few portion of this subset is again excluded during further statistical analysis. It corresponds to district affected by both tsunamis and earthquakes. In terms of losses from earthquakes, the number of houses destroyed was used and the number of people killed (i.e. killed was computed as killed + missing).

4.5. Exposure

Exposure raster have been generated for population and houses from 1998 to 2008, both at the sub-district level.

Population raster is based on values produced by BPS (PODES) for year 2006 and 2008, and the shapefile of sub-district boundaries corresponding to coding system ID440 (12/2003-07/2007).

First, sub-district population values of year 2006 were joined to the administrative boundaries using coding system. In few districts, some sub-districts were missing values. In these cases, when district value obtained by spatial summation was equal to official district value, the district density was applied to missing sub-district. When this value was lower, the difference was used to calculate density for missing sub-district. When these two district values were different, but no sub-district missing, the ratio between them was used to adjust sub-district values. Finally, when district value itself were missing (two cases), it was implemented by density value available at the province level.

As administrative boundaries for year 2008 were not available (system ID465 or ID471), and table of correspondence between successive coding systems were available only at district level, we couldn’t use 2008 population values at sub-district level. So we extrapolated 2006 value until 2008 using value at district level. For this purpose, population 2008 was previously formatted to respect 2006 coding system (ID440). Similarly, we extrapolated 2006 raster until 1998 using value at province level, in order not to reflect district variations occurring between years 2006 and 2008.

Houses raster is based on values produce by BPS (PODES) available only for year 2008. In this case, we had to find how to solve the same issue. It means, how to match sub-district values of year 2008 (system ID465) on the map of year 2006 (system ID440). After joining 2008 houses values to 2006 sub-district boundaries, we only conserved value of district with no changes between these two years, as identified in the correspondence table. As sub-district might be modified even inside unmodified district, we compare district spatial summation with table values. Again, we only conserved districts showing same results. For all other districts, we distributed district values to sub-district based on newly created population raster. Houses values raster for year 2008 was extrapolated until year 1998 following the same method as for population raster. These statistics contain also number of houses of three different building types. These values are used to describe building vulnerability in the model.

4.6. Vulnerability

Socio-economic indicators are used in the model to characterize population vulnerability. Indicators at district level were available for year 2006 and 2008. We first discovered that most of the values that are supposed to increase through time were presenting an important decrease between year 2006 and 2008 for a significant number of districts (30%). As these decreasing trends are obviously not related to the creation of new districts, and no other information was available to explain it, we decided to use indicators available at province level instead of these one. This choice implicated that variability of vulnerability indicators is not represented for district of the same province. Considering the selected time-window of 11 years (1998-2008), we selected indicators presenting a sufficient number of years with values through this period. When needed, values extrapolation were performed over several years to match the required time-window.

The complete list of data is provided in the Annex.

4.7. Assessing DIBI

We found that the distribution of recorded earthquakes events in DIBI is exponential, i.e. there are more records in recent years than in the past. This is more likely due to be driven by a lack of access to past information, rather than a change in the hazard pattern (this could be easily verified by looking at percentage of physical events recorded (we haven’t test this, but it can be done). This is a trend that was also very clear at the global level using EM-Dat, so in this respect DIBI do not appears to correct for this bias. Figure 3 Clearly show a trend in the number of recorded events, most probably linked with access to information. The “unofficial” version of DIBI seems more complete and goes further in the past. However, given that this work was carried out to support the Indonesian government, the decision was to use the official version, with also the expectation that it went to further review and verification.

It is important to note that these events are not the number of physical earthquake events, but the number of Districts affected by earthquake events.

It should also be noted that, in the official version of DIBI, all the losses from the 26.12.2004 tsunami / earthquake event were placed in one district (Banda Aceh). As we know, a majority of the killed were in Banda Aceh, but many losses were recorded in other districts too.

Due to restriction in access to past vulnerability parameters, the period 1998 to 2008 was taken. This is short, but it includes more than 80% of the records (81.7%, 224 events/districts out of 274).

55% of the records report 0 killed. This cannot be used in the logarythmic model. Amongst the rmaining data, 50% have less than 10 killed, 36% less than 100 killed, 12% less than 100 killed and 3% more than 1000 killed. This is the usual distribution for long returning period type of hazards such as earthquakes. In terms of regression, despite transformation of the data using logarythmic regression, the values on killed was not following a normal distribution.

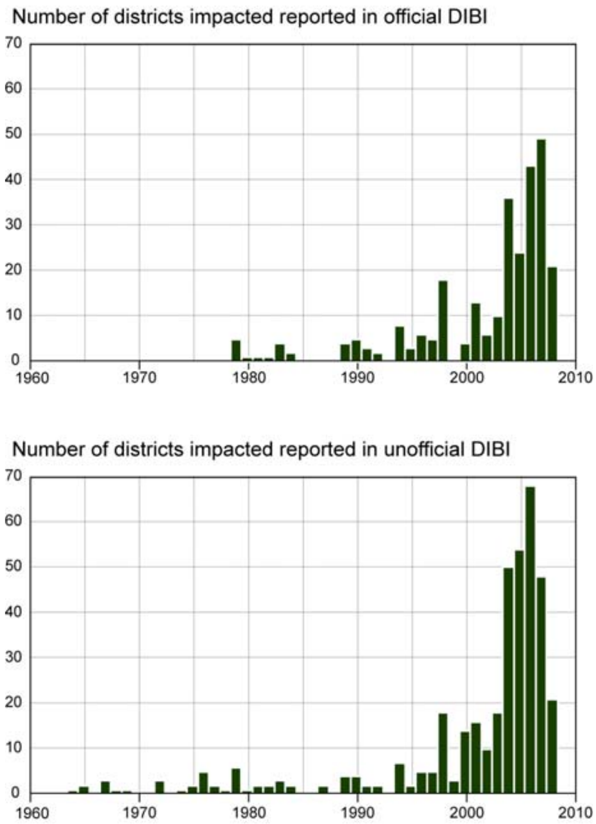


Figure 3 Distribution of number of record of earthquake events in DIBI

The distribution of reported earthquake disasters shows a significant decrease in reporting prior 2000.

The official DIBI includes less records than the unofficial DIBI. Still we stick to the official DIBI as we wanted to produce a methodology based on accepted information.

4.8. Variables extraction

For each of the 218 records selected in DIBI loss database, we generated automatically the variables of hazard, exposure and vulnerability using the above described datasets. They were integrated with specific information on losses in a unique final table described in Annex 1. In order to test statistical analysis using various classes of PGA, we run the extraction process using the two following PGA classifications of the shake map.

Two extractions were used, the first one with three classes on percentage of PGA (see Table 1); the second one using five classes (see Table 2).

1	2	3
4-24	24-52	>52

Table 1 Three classes (in percentage of g)

1	2	3	4	5
4-16	16-28	28-40	40-60	>60

Table 2 Five classes (in percentage of g)

5. Results and discussion

5.1. Results

The modelling concentrated on the percentage of houses Destroyed / houses exposed and the percentage of killed + Missing versus exposed.

Houses destroyed / exposed (HD/Exp)

The ratio houses destroyed by houses exposed (HD/Exp) is positively correlated with the square of Peak Ground Acceleration (PGA). This PGA is ponderated to the population distribution, thus PGA on a population of 1000 inhabitant is counted 500 times more than a PGA on a pixel with 2 inhabitants (see data preparation). HD/Exp is also positively correlated with the Gross Domestic Product per capita (GDPcap).

The model presents a correlation between modelled and observed of r = 0.77. The percentage of HD/Exp explained is 59.4% (R^2 = 0.594). PGA account for 62% of the model, while GDPcap account for 38%. The regression predicted versus observed is provided in Figure 4. This shows a good distribution across the data range.

Distribution of the risk is provided in Figure 1, the legend is based on 6 classes, i.e. 5 and one that is close to null (negligible, but risk = 0 do not exist!). The risk is based on percentage of house destroyed. This can be compared with the probability of GSHAP provided in Figure 2.

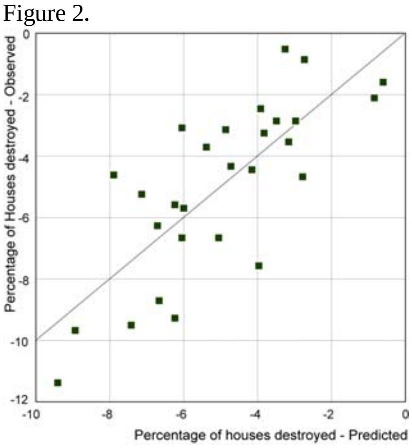


Figure 4 House destroyed, predicted versus observed

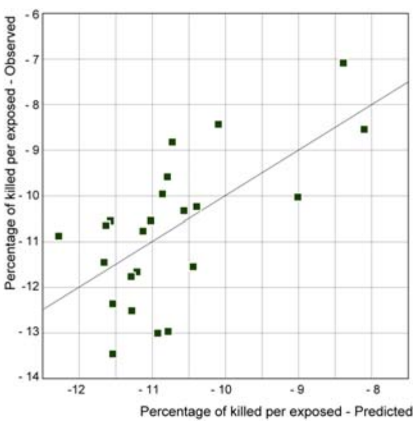


Figure 5 Killed per exposed, predicted versus observed

For the graphs in Figure 4 or Figure 5, it should be noted that the scale are logarythmic and that these low values represent the killed per exposed or the houses destroyed per houses exposed.

(Killed + Missing) / Exposed (KM/Exp)

The ratio (Killed + Missing) / Exposed (KM/Exp) was only explained by the square of PGA. Absolutely no other significant correlation with any vulnerability parameters could be found. The model presents a correlation between modelled and observed of r = 0.64. The percentage of KM/Exp explained is 41.6% (R^2 = 0.416).

The regression predicted versus observed is provided in Figure 5. It shows a very mild correlation, lead by few extreme events. The quality of this model is lower than the one on HD/Exp.

5.2. Discussion

The model on percentage of killed (i.e. killed + missing) over exposed is only explained by physical values. The best model is achieved on the number of house destroyed per exposed.

More than 2/3 of the risk is explained by the physical component (PGA) and less than 1/3 is explained by socio-economical parameters (in this case GDPcap). This is fairly usual and is along the values found for analysis at the global level. What is more surprising, is that the GDPcap is positivelly correlated with risk. In theory, the poorest would be more at risk than the wealthier population. Two explainations on this:

In the case of earthquakes, people living in non-permanent houses (slums,…) are actually less at risk. Their houses falling down, being made of light material, inhabitants would be less hurt than people living in permanent houses. Their houses can also be rebuilt in 1-2 days. While people living in more expensive houses are facing higher risk, the concrete building if not designed to stand for high PGA might collapse and those being houses with several floors and built with heavy material, would cause much more arms and casualties as compared with non-permanent houses. Re-building them would take a year or more. While permanent houses would need to be built according to the standard for resisting to earthquakes. Most permanent houses in transition countries, may not be designed for being earthquakes resistant and therefore it is not surprising that an increase in GDP cap translates in higher rate of houses destroyed.

High GDPcap is also connected with urban area. Urban population have higher incomes as compared with rural population. The connexion between higher GDP and higher risk, should also be read as an expression of urban exposure. In this regard the recommandation is to produce separate models for urban and rural area. The datasets we had on population did not allow for qualification of population in terms of urban and rural as it was done at the global level.

These models shows correlation, not causality. Understanding causality would request local case studies.

Given the issues faced in building the dataset on vulnerability, especially regarding the multiplication of new districts, we had often to rely on parameters recorded at the province level. This means that for a given earthquake event affecting several districts located in the same province, the vulnerability parameters will show no variation, despite the variation of losses.

As a consequences of working with transformed variables, the events with 0 losses cannot be used as one cannot compute the logarithm natural of 0. This reduces drastically the number of events available (from 224 to 83). From the remaining 83 events, the intersection with existing data on exposure and vulnerability also reduces the number of records. At the end the models run on 28 events. This is very low for multiple regression analysis.

We did not received distribution of earthquake hazards for multiple returning period. We received a model for 1/475 years retunring period. This one is provided in classes, so the model was built using GSHAP as this one provides PGA in values.

Two other seismic hazard maps of PGA for Indonesia are available: the Peak Ground Acceleration map at bedrock for 500 years return period in the Indonesian Earthquake Code, SNI 03-1726-2002, issued by the Department of Public Works. Map of Peak Ground Acceleration of Indonesia for 2500 years return period, issued by the Faculty of Mining and Petroleum Engineering, ITB, Bandung (Hendriyawan, 2010). They have not been used in this present study, but any further developments of the methodology could greatly benefit from these two hazard maps.

6. Conclusions

We recommand to take this model with caution. The DIBI records need further corrections and, if possible, to complete the period 1970 to 2000. In terms of replicability, until DIBI is further completed, the methodology could be tested in a country with a longer experience with DesInventar, where the database has already gone through several iterations of correction and show less discrepency in number of records through time.

At this stage, it is not possible to say wether it is possible to apply the event per event approach at the national level. The current model being run over very few records.

The issues of increasing districts lead to significant difficulties in building the table of vulnerability parameters. In 1993, there was 290 districts, in 2006 their number increased to 440 and reaches 497 in 2009. This is a 70% increase in 16 years. May be the values from the census should be referred to pixels (e.g. 50 x 50km) and then the values could be aggregated at the district level. This would ensure a constant spatial unit to store the statistics? Here again, the case of Indonesia might be an extreme case interms of district increase. Such issue might not arise in another country. This, however, highlight the difficult for Indonesian government to follow development in their districts, given the issue we observed in dealing with their data.

The choice of the hazard should be on a short returning period type of hazard (i.e. floods or tropical cyclones). This would ensure a higher number of records. Of course the footprint of the hazardous events need to be available. Maybe the best hazard in this case would be tropical cyclones. The choice of earthquakes was made based on the availability of the footprints, however earthquakes risk the weakest model at the global scale. Earthquakes not only long have a long returning period, they have also a spatio-temporal connection between them: once an earthquake occur, it release the energy, thus another earthquake in the same region is much less likely. As opposed with flood or tropical cyclones. The occurrence of these hydro-meteorological hazard do not preclude the onset of another one.

However, and despite all these limitations it is clear that there is a significant risk of houses destruction by earthquake faced in the urban districts of Indonesia. Particularly in Jakarta districts, but also in Pulao Nias, south of Banda Aceh, southeast of Sumatra, west of Java, western part of Pulao Ceram (Ambon) and centre north of Papua province.

The need to better map this risk is a first compulsory step for this country which is ranked 3rd country at risk from earthquakes in the world. The case of floods should also been looked at.

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Annex 1 Table of vulnerability parameters

FIELD NAME	DESCRIPTION
IDS	GIS Unique ID
SERIAL	DIBI Database event ID
DISTRICT	District Code
DATE_DIBI	Date as recorded in DIBI database
YEAR	Year
MONTH	Month
DAY	Day
EQ_STATUS	Threshold on Date 1=+/-4DAY - 2=+/-1MONTH
SM_ID	Shake Map ID - YYYYMMDDHHMMSS
SM_STIME	Shake Map Standard Time
SM_MAG	Shake Map Magnitude
TSUNAMI	1=Earthquake and Tsunami
COSTAL	1=Costal District
Deaths	Death as recorded in DIBI database
Injured	Injured as recorded in DIBI database
Missing	Missing as recorded in DIBI database
Houses Destroyed	Houses Destroyed as recorded in DIBI database
Houses Damaged	Houses Damaged as recorded in DIBI database
Victims	Victims as recorded in DIBI database
Affected	Affected as recorded in DIBI database
Relocated	Relocated as recorded in DIBI database
Evacuated	Evacuated as recorded in DIBI database
Losses $USD	Losses in $USD as recorded in DIBI database
Losses $Local	Losses in $Local as recorded in DIBI database
Education centers	Education centers Damaged as recorded in DIBI database
Hospitals	Hospitals Damaged as recorded in DIBI database
Damages in crops Ha	Damages in crops Ha as recorded in DIBI database
Lost Cattle	Lost Cattle as recorded in DIBI database
PEXP	Population Exposure
PGA	Mean PGA, weighted by population
PGA2	Mean square PGA, weighted by population
DENS	Population Density in Zone
HEXP	House Exposure
ARPHMEAN	Mean Cost in Hours to Closest Airport
KOTHMEAN	Mean Cost in Hours to Closest Kota
HPRATE	% of Permanent Houses
HSPRATE	% of Semi-Permanent Houses
HNPRATE	% of Non-Permanent Houses
POPD	District Total Population
ENOPLN	Percentage of Households with Electricity Non PLN
FAREA50M	Percentage of Households with Floor Area
ROFLEAVES	Percentage of Households with Roof of Leaves, Sugar Palm Fiber, and Others
WNOBRICK	Percentage of Households with Wall non Bricks
WNOPIPE	Percentage of Households with Source of Water Non Pipe
HDI	Human Development Index
ILLI15+	Percentage of Population who are Illiterate - age >= 15
ILLI1544	Percentage of Population who are Illiterate - age 15 to 44
ILLI45+	Percentage of Population who are Illiterate - age >= 45

Table of vulnerability parameters (continue)

FIELD NAME	DESCRIPTION
NERELEM	Nett Enrollment Ratio - Elementary School
NERJUN	Nett Enrollment Ratio - Junior School
NERSEN	Nett Enrollment Ratio - Senior School
GERELEM	Gross Enrollment Ratio - Elementary School
GERJUN	Gross Enrollment Ratio - Junior School
GERSEN	Gross Enrollment Ratio - Senior School
SEXR	Sex Ratio (Man/Woman)
SEXRD	Sex Ratio (Man/Woman) at District level, unique value for the whole time-window
IMR1	Infant Mortality Rate - age <= 1
IMR5	Infant Mortality Rate - age <= 5
TFR	Total Fertility Rate
GRDPCONM	Gross Regional Domestic Product at 2000 Constant Market Prices (Million Rupiahs)
GRDPPCAP	GRDPCONM per capita