

Global Assessment Report on Disaster Risk Reduction



Landslide risk in Indonesia

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October 2010



Landslides

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1.2. Introduction

The term landslide in this study refers to events involving rapid downslope mass movement, like rockslides and debris flows, which pose a threat to human life. Slow moving slides have significant economic consequences for constructions and infrastructure, but rarely cause any fatalities. The focus of this study was on landslides induced by heavy precipitation or by earthquakes. Rock avalanches, lateral spreads and submarine slides are also classified as rapid mass movement events, but are not covered in this study.

Statistics from the Centre for Research on the Epidemiology of Disasters (CRED) show that, on average, landslides are responsible for a small fraction of all fatalities from natural hazards worldwide. However, both the socio-economic impact and the human impact of landslides are greatly underestimated in these statistics because landslides are usually not separated from other natural hazard triggers, such as extreme precipitation, earthquakes or floods in the natural disaster databases. This underestimation contributes to reducing the awareness and concern of both authorities and general public about landslide risk.

Indonesia is frequently affected by landslides induced by both rainfall and earthquakes. An annual frequency of 49 landslides per year is reported by Chrisanto et al. (2008) during the period 1981-2007. The DesInventar inventory for Indonesia covering the period 1998-2009, contains 890 landslide events that killed 1280 persons. The global catalogue presented by Kirschbaum et al. (2009) which spans the years 2003 and from 2007 to 2009, reports 97 landslides in Indonesia, which produced 872 casualties. According to the Geological Agency of Indonesia (Geological Agency, 2006, 2007 & 2008), within the period 2003-2007, rapid landslides caused an average of 32 casualties per event. The majority of victims due to landslides in that period were in the Islands of Java (52%), Sulawesi (24%) and Sumatra (18%). In addition to the impact in terms of loss of lives and damage to buildings, landslides in Indonesia produce significant damage to agricultural land and roads, with the subsequent economic disruption (Kuncoro and Resosudarmo, 2006).

The analyses presented in this study focused on the mortality risk posed by precipitation-induced landslides. The fatalities caused by earthquake-induced landslides are attributed to “earthquakes” in databases, and included in the earthquake risk assessment. Including them again under “landslides” would lead to an overestimation of earthquake risk. The results presented for earthquake-induced landslides are only the hazard and exposure maps.

1.3. Methodology

Landslide hazard, vulnerability and risk assessments were based on the model developed in previous projects (Dilley et al., 2005; UN/ISDR, 2009) and improved in NGI (2009). The schematic approach is shown in Figure 1.

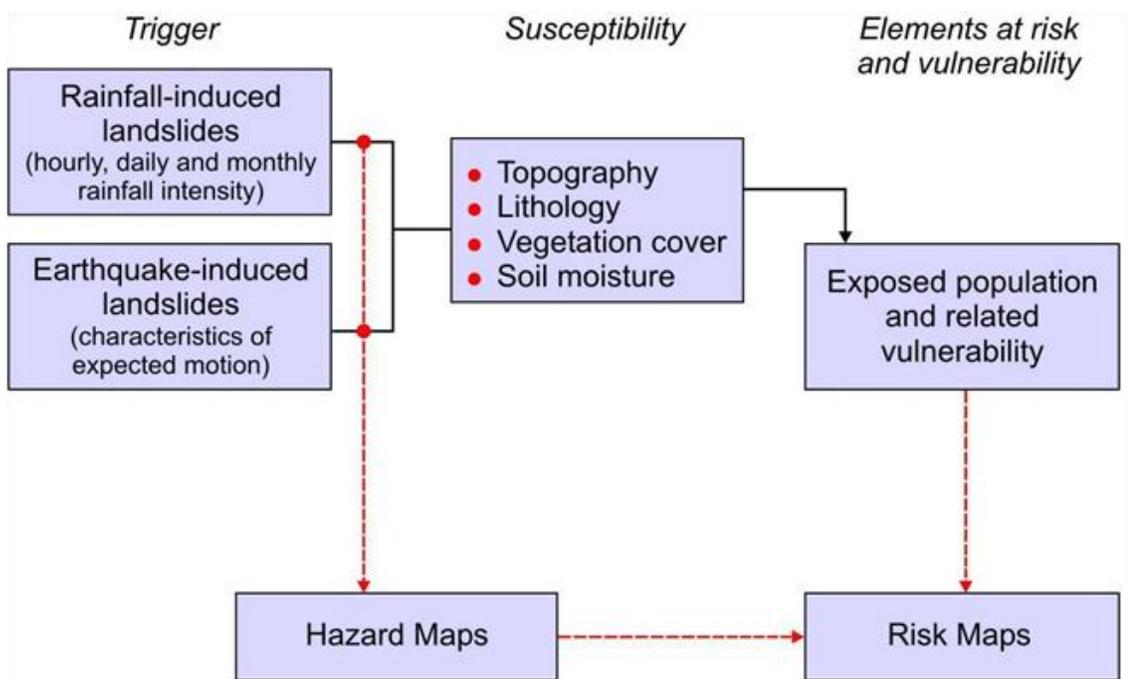


Figure 1. Schematic approach for landslide hazard and risk evaluation. NGI (2009)

Landslide hazard, defined as the annual probability of occurrence of a potentially destructive landslide event, depends on the combination of trigger and susceptibility. In the analyses performed in this study, a landslide hazard index was defined using six parameters: slope steepness, lithological (or geological) conditions, soil moisture condition, land cover, and two parameters describing the triggering conditions (extreme precipitation and earthquake). Deforestation was also considered in the study, but, for reasons described later, was not found to be a significant parameter for landslide susceptibility in Indonesia at present.

The methodology was tailored to, and calibrated for Indonesia; and the model has been better linked to risk theory. This was achieved by making the following improvements in the model compared to the 2009 Global Assessment Report (UN/ISDR, 2009):

- Use of the daily precipitation data from a network of 149 rain gauges in all Indonesia (Hamada et al., 2002). The data from these stations span 17 years of observations on average. Estimates of maximum daily and monthly precipitation for a 10-year return period were obtained from the dataset. These estimates were combined with global monthly gridded data for obtaining the triggering factor for precipitation conditions.
- Use of the peak ground acceleration (PGA) for a 475-year return period based on the most recent seismic hazard study for Indonesia (Irsyam et al., 2010).
- Reclassification of the lithological data based on knowledge of local experts. In the global analyses done in the Global Assessment Report (UN/ISDR, 2009), only 2 different classes of lithology were specified for all Indonesia. In the present analyses, the lithology was reclassified into 5 susceptibility levels.
- Use of the following landslide databases for calibration of hazard, exposure and risk:
 - DesInventar database for the period 1998-2009 containing location (district and province) and consequences (damage and casualties). See Figure 2.
 - Global inventory of landslides compiled by NASA for the years 2003, 2007, 2008 and 2009, and containing location, type of landslide and consequences (Kirschbaum et al., 2009). Most of the events in this inventory are rainfall-induced (e.g., 90 of 97 for Indonesia). The spatial distribution of events in this inventory is shown in Figure 2. The majority of sources are international press reports, so the spatial distribution of this catalogue can provide indication of distribution of exposure and risk rather than hazard. This inventory provides an uncertainty associated to the location of each event. This uncertainty varies between 2 and 200 km, with an average of 26 km.
 - West Java database containing location and type of landslide (Hirnawan et al., 2006). Figure 3 shows the distribution of events in this database.
- Use of the following physical and socio-economical parameters for calibration of risk: physical exposure, percent forest cover, percent arable land, Human Development Index (HDI), Gender Development Index (GDI) and Human Poverty Index (HPI). UNDP (2004)

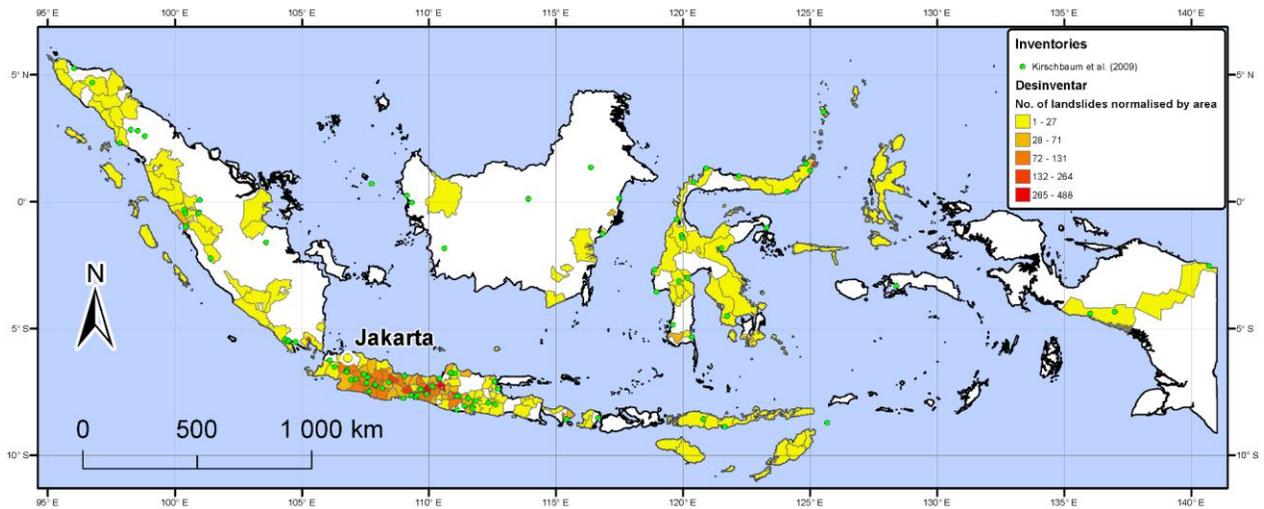


Figure 2. Spatial distribution of landslide inventories from Kirschbaum et al. (2009) and Desinventar.

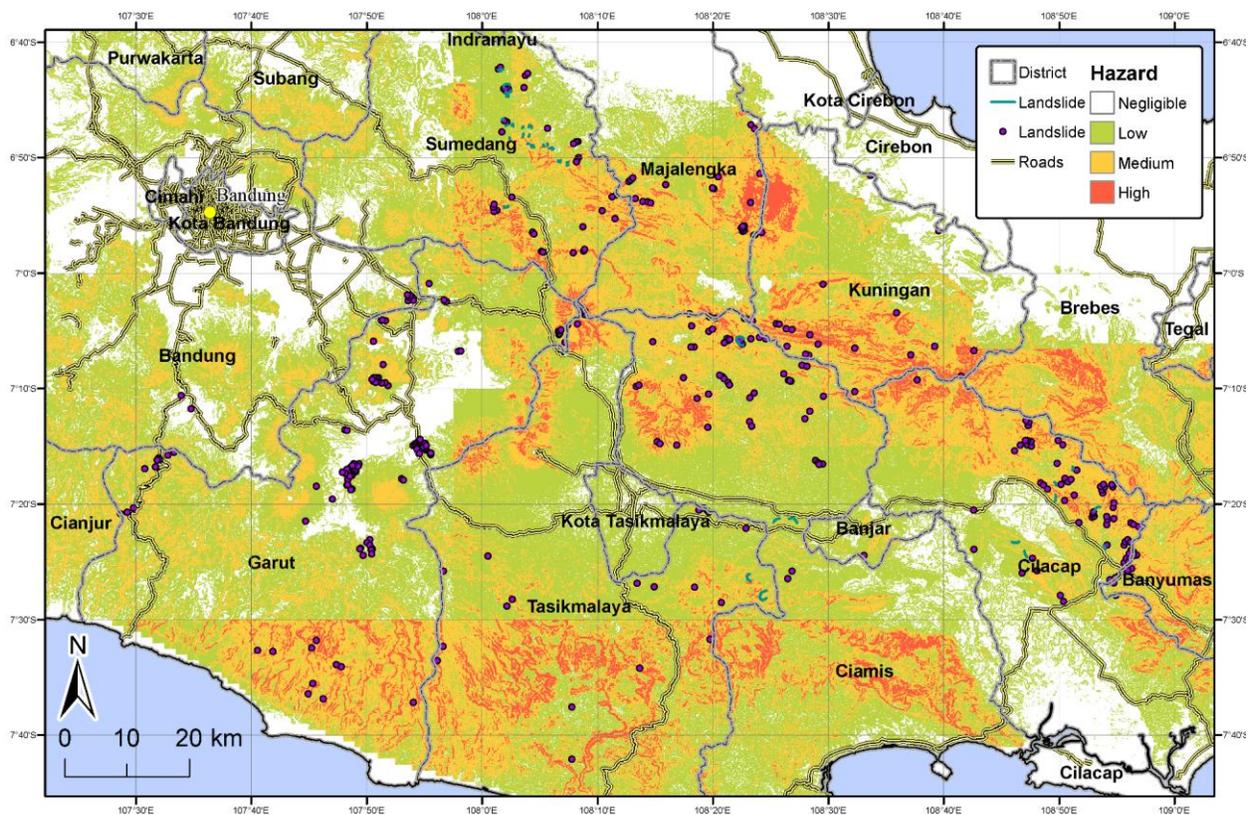


Figure 3. Spatial distribution of landslide inventory from West Java (Hirawan et al., 2006). District boundaries, road network and the hazard for precipitation-induced landslides developed in this study are also shown.

1.4. Summary of procedures and results

The hazard model for precipitation-induced landslides was calibrated using the available inventories. Due to the heterogeneities, incompleteness and uncertainties of the catalogues in space and time, a heuristic approach was followed for calibration.

The hazard due to earthquake-induced landslides was estimated by replacing the precipitation triggering factor by the earthquake triggering factor derived from the reclassification of the Irsyam et al. (2010) map of peak ground acceleration for a 475-year return period. In the DesInventar database, there were only 19 landslides reported as earthquake-induced (about 2% of all the landslide events in the database), some of them lateral spreads in coastal areas or riverbanks, which are outside the scope of this study. Therefore, fine-tuning and calibration of the landslide hazard model for earthquake conditions was not possible.

The results of the hazard model are presented in section 1.5 of this report.

The influence of deforestation on landslide susceptibility was assessed in this study by crossing the slope susceptibility factor and the changes in forested areas in a spatial database distributed by Minnemeyer et al. (2009). The analyses over the period 2000 to 2005 indicate that between 92 and 96% of areas with increasing deforestation are in zones of very low and low susceptibility, and between 0.2 and 1% in zones of high and very high susceptibility. Furthermore, the deforested areas on these high and very high susceptibility zones are only 0.03% of the total area of high and very high susceptibility. Considering these statistics, and the national scale of the present study, the hazard model does not seem to be adequate for capturing the localised influence of deforestation on landslide hazard. It is suggested that studies at district level or site specific may be more adequate for exploring such connection.

Physical exposure was calculated by weighting the landslide hazard maps with respect to the population density at pixel level. The maps of physical exposure are presented in section 1.6 of this report.

Risk for precipitation-induced landslides was calibrated at district and province level using the corresponding exposure values, data from DesInventar (for estimating consequences), and several combinations of the following socio-economic parameters:

- Percent forest cover
- Percent arable land
- Percentage population without access to clean water
- Percentage population without access to health facilities
- Human Development Index (HDI)

- Gender Development Index (GDI)
- Human Poverty Index (HPI)

At province level, the calibration explained about 85% of the variation of the risk data. This is an extremely robust performance for the model and far better than that obtained in any previous studies. The optimum combination of predictors was (in parenthesis, the sign of correlation with risk):

- Physical exposure (+)
- Percent arable land (-)
- Human Development Index (HDI) (-)

Hence, an increase in physical exposure leads to an increase in risk, while an increase in any of the other parameters produces a reduction in risk. For Human Development Index, this is expected since an improvement in the mean development level in an area normally should reduce risk.

The calibrated equation of risk is as follows:

$$\ln R_r = -12.09 + 1.052 \ln PE_r - 1.114 \ln \left(\frac{AL_{SN}}{AL_N} \right) - 0.238 \ln \left(\frac{HDI_{SN}}{HDI_N} \right) \quad (1)$$

where R_r is the mortality risk (fatalities per year) due to precipitation-induced landslides, PE_r is physical exposure, and the terms in parentheses are transformed and normalised values of Arable Land and Human Development Index, respectively. The equation is only applicable to risk estimation at province level.

The calibrated risk model for the four aforementioned parameters was used as the basis for estimating the relative risk levels for precipitation-induced landslides for all Indonesia. The resulting maps are shown in section 1.6.

The calibration of risk at district level yielded low correlation (between 31 and 57% of the variation explained), even when attempting subsets of districts within the same province or in neighbouring provinces. The main reason for this is that the number of events in the database of landslides with fatalities is not sufficient for making a meaningful statistical analysis of the spatial distribution of landslide risk at district level.

1.5. Landslide hazard

Figures 4 and 5 present the hazard distribution for precipitation-triggered landslides. Large regions of high hazard levels are notable in the following provinces:

- In Sumatra:

- Sumatera Utara.
- Sumatera Barat.
- In Sulawesi:
 - Sulawesi Barat.
 - Sulawesi Selatan.
- In Java:
 - Banten.
 - Jawa Barat.
 - Jawa Tengah.

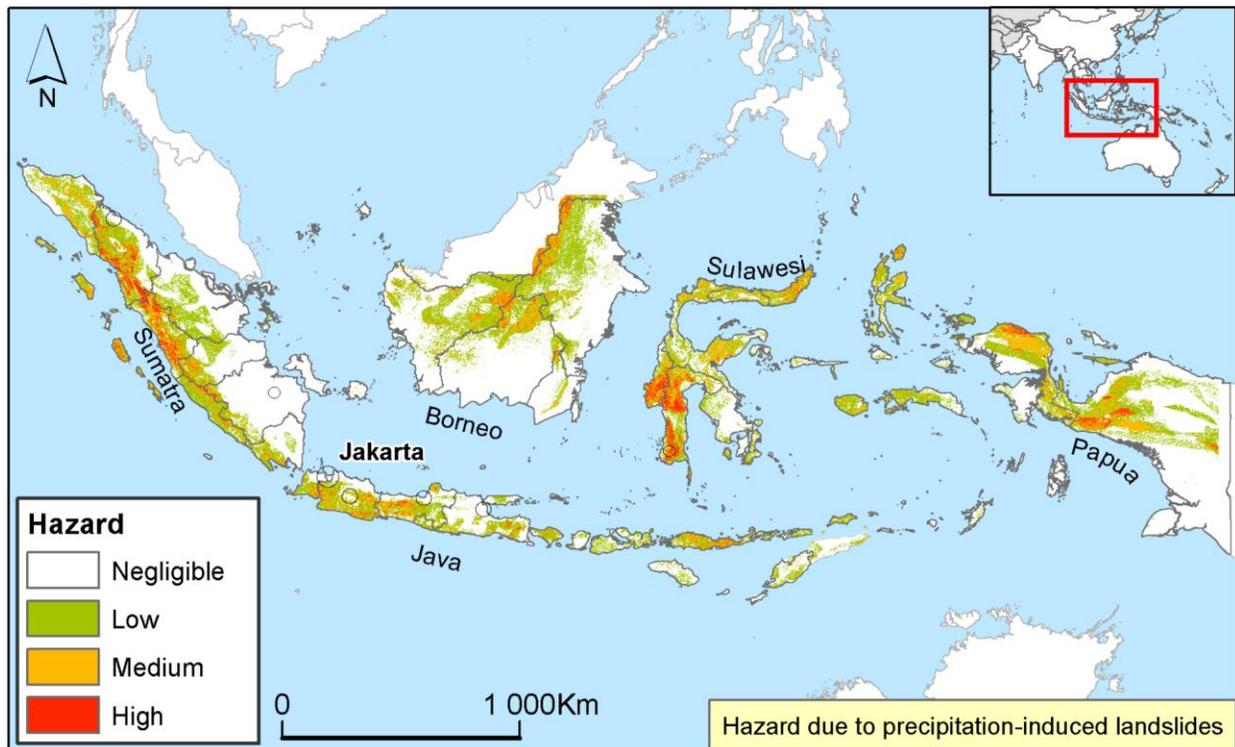


Figure 4. Map of precipitation-triggered landslides hazard distribution for Indonesia.

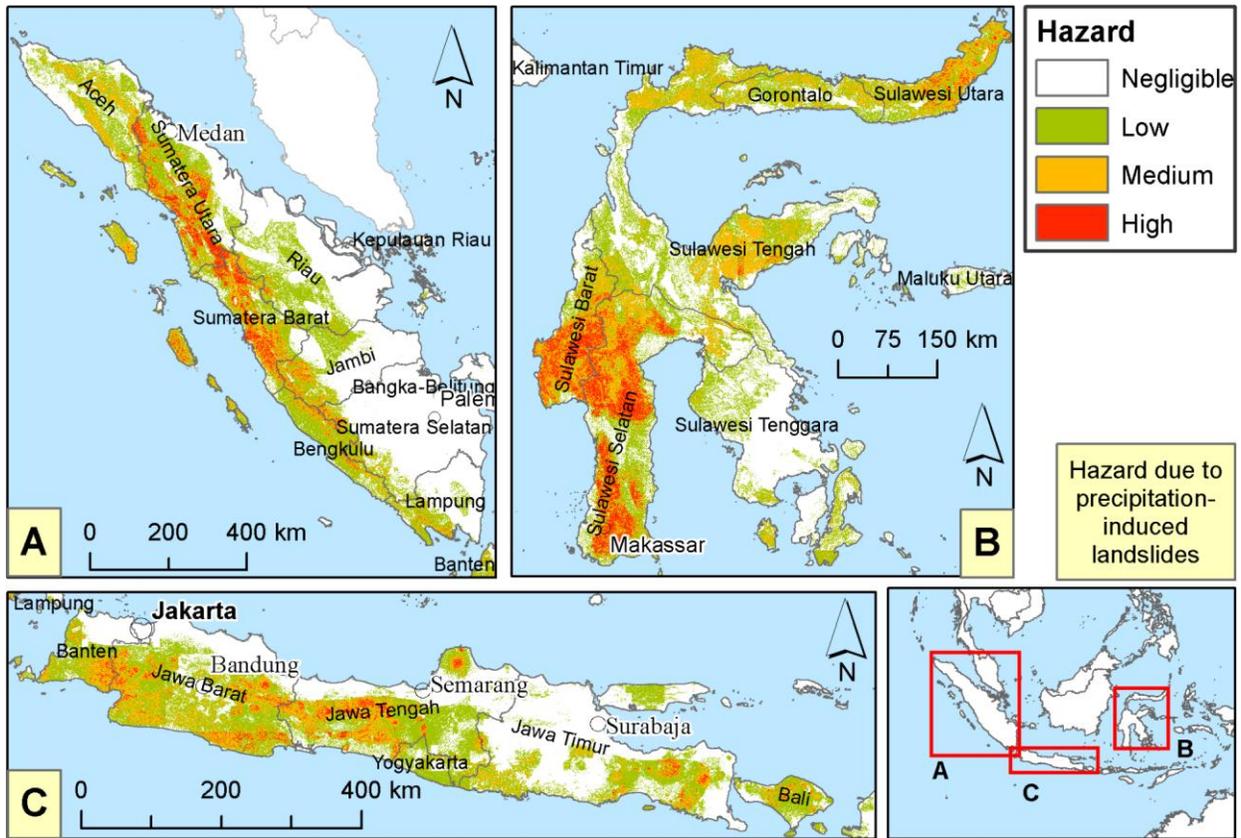


Figure 5. Maps of precipitation-triggered landslides hazard distribution for: (A) Sumatra, (B) Sulawesi, and (C) Java and Bali.

The distribution of the events in the inventory of West Java in Figure 3 shows good agreement with the medium and high hazard levels.

Figures 6 and 7 present the hazard distribution for earthquake-triggered landslides. Large regions of high hazard levels are notable in the following provinces:

- In Sumatra:
 - Sumatera Utara.
 - Sumatera Barat.
 - Bengkulu.
- In Sulawesi:
 - Sulawesi Tengah.
 - Sulawesi Barat.
- In Java:
 - Jawa Barat.

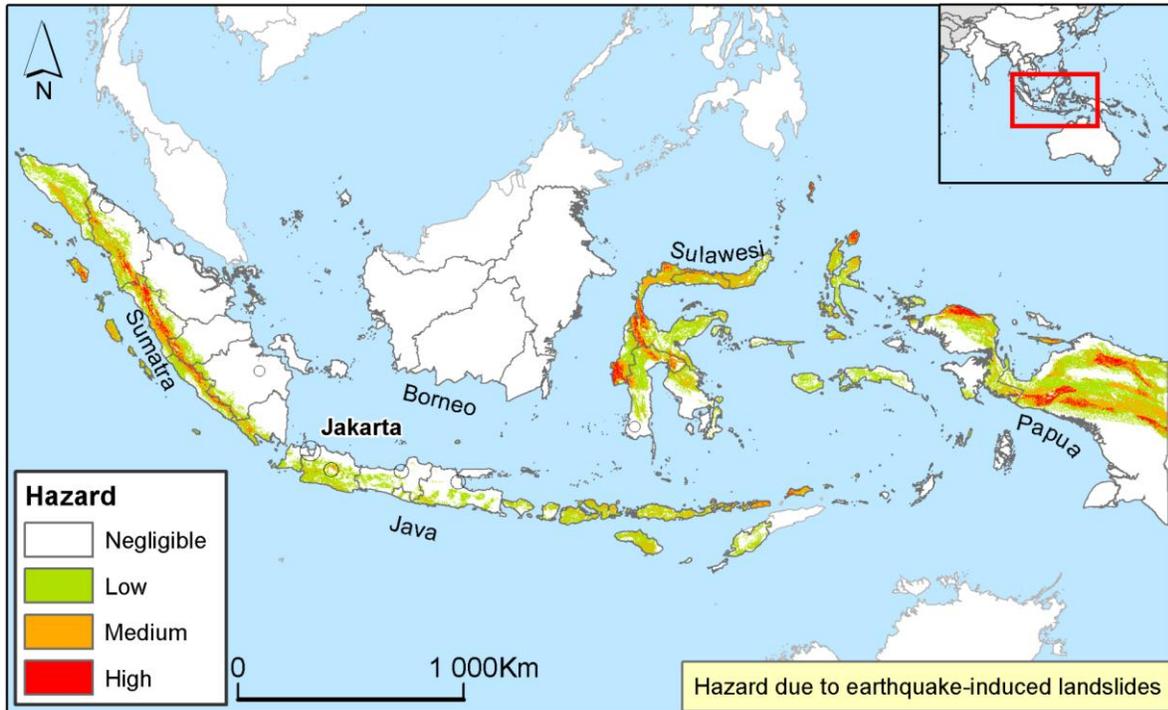


Figure 6. Map of earthquake-triggered landslides hazard distribution for Indonesia.

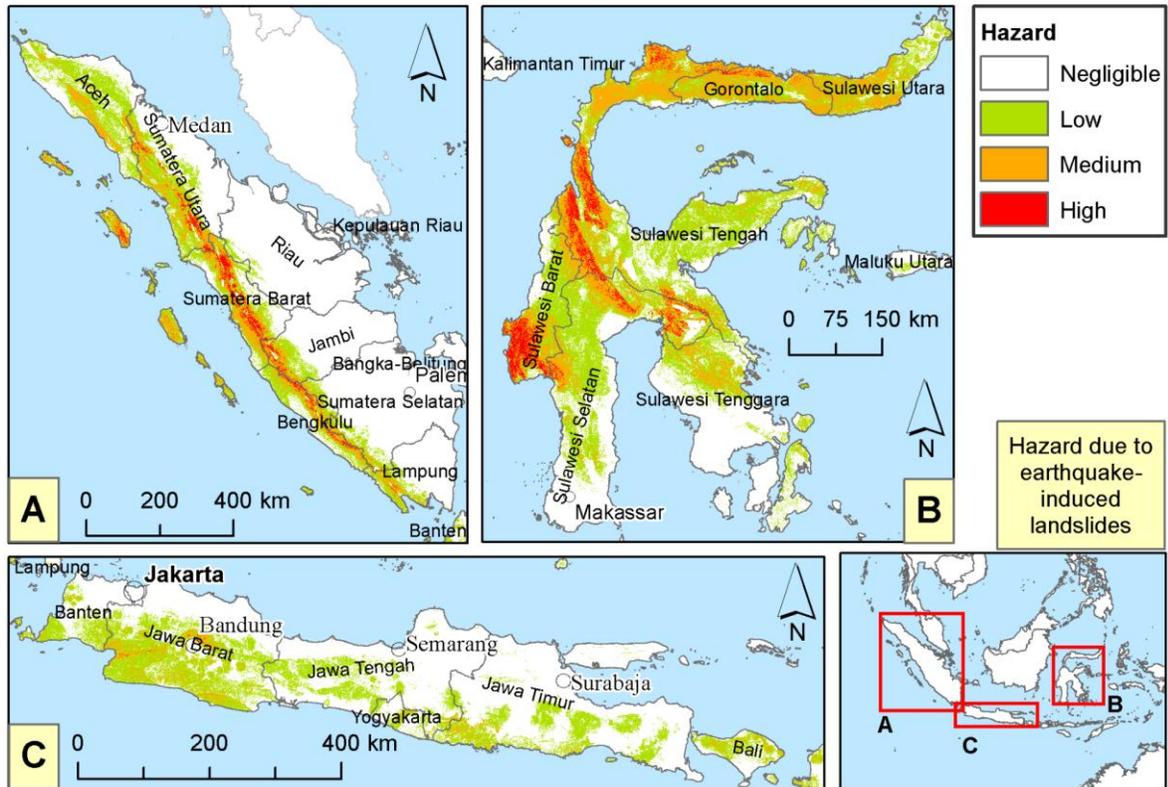


Figure 7. Maps of earthquake-triggered landslides hazard distribution for: (A) Sumatra, (B) Sulawesi, and (C) Java and Bali.

The differences in hazard levels and distribution between the precipitation-induced and earthquake-induced scenarios are solely due to differences in the distribution of the triggering factors.

1.6. Landslide risk

Figures 8 and 9 present the distribution of exposure for precipitation-triggered landslides. Large regions of high exposure levels are notable in the following provinces:

- In Sumatra:
 - Sumatera Utara.
 - Sumatera Barat.
- In Sulawesi:
 - Sulawesi Barat.
 - Sulawesi Selatan.
 - Sulawesi Utara.
- In Java:
 - Banten.
 - Jawa Barat.
 - Jawa Tengah.
 - Yogyakarta.
- Bali.

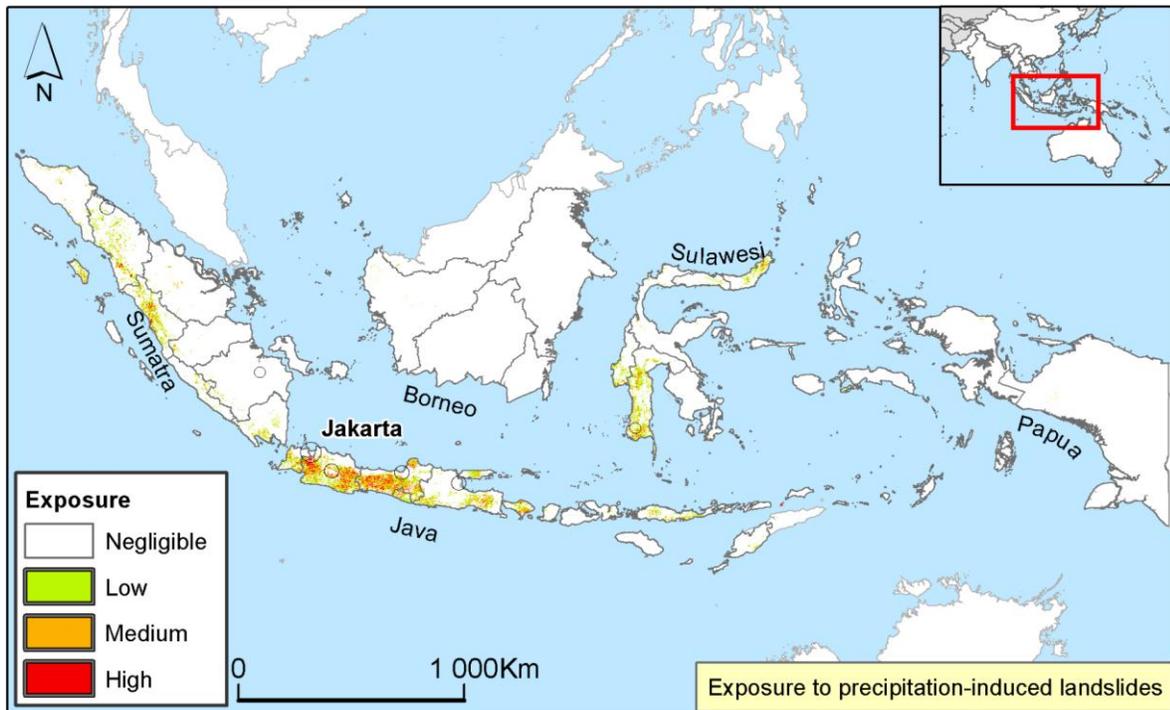


Figure 8. Map of exposure to precipitation-triggered landslides for Indonesia.

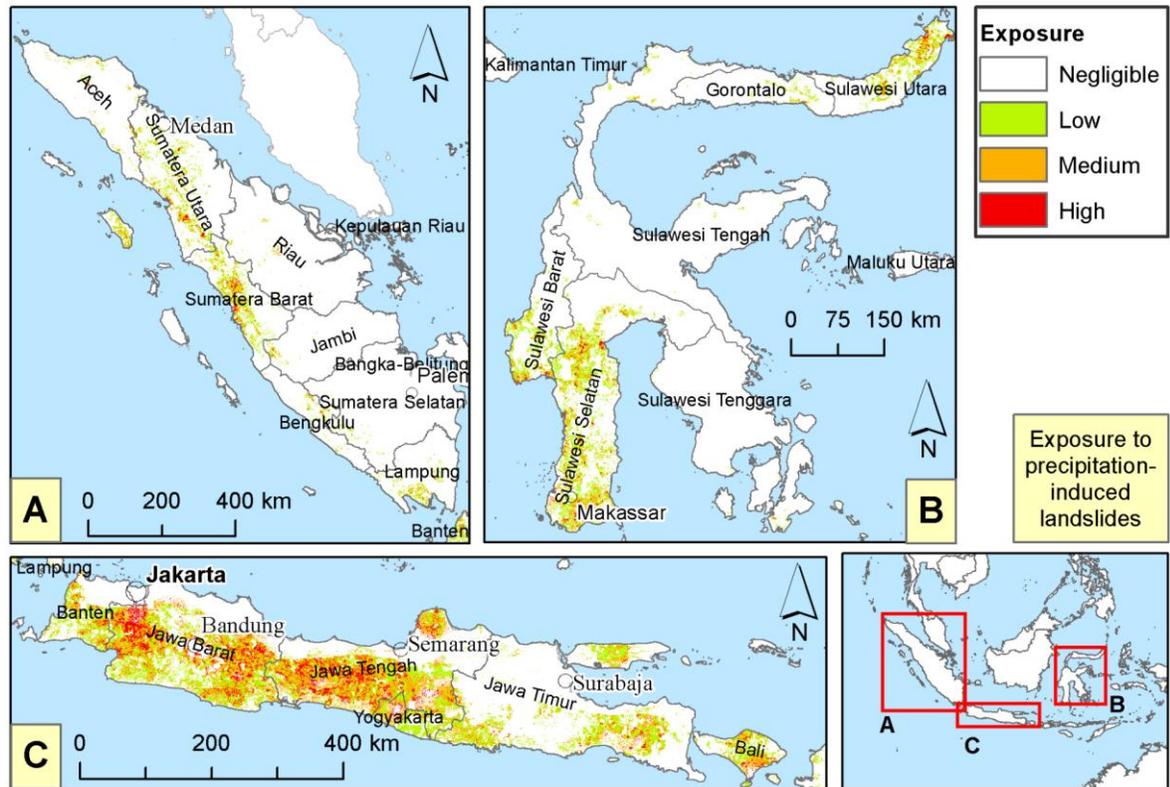


Figure 9. Maps of exposure to precipitation-triggered landslides for: (A) Sumatra, (B) Sulawesi, and (C) Java and Bali.

Figures 10 and 11 present the distribution of exposure for earthquake-triggered landslides. Large regions of high exposure levels are notable in the following provinces:

- In Sumatra:
 - Sumatera Utara.
 - Sumatera Barat.
- In Sulawesi:
 - Sulawesi Tengah.
 - Sulawesi Barat.
- In Java:
 - Jawa Barat.
 - Jawa Tengah.
 - Yogyakarta.
 - Jawa Timur.
- Bali.

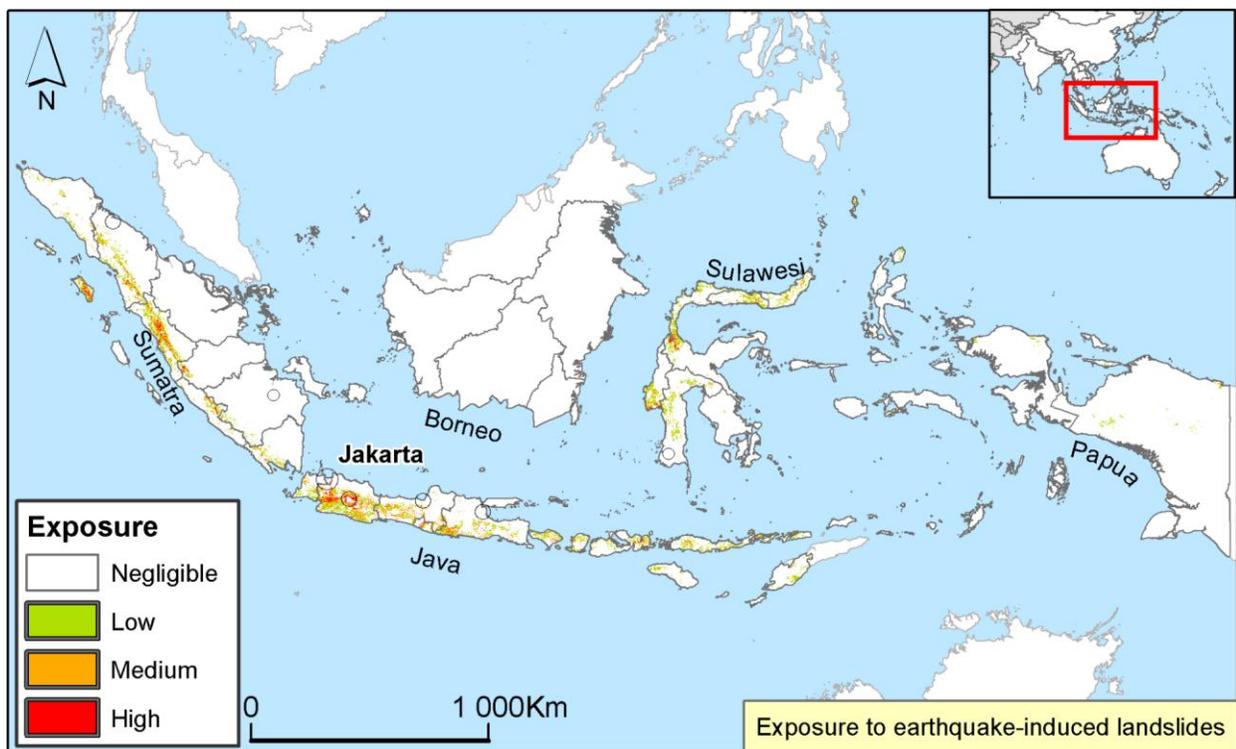


Figure 10. Map of exposure to earthquake-triggered landslides for Indonesia.

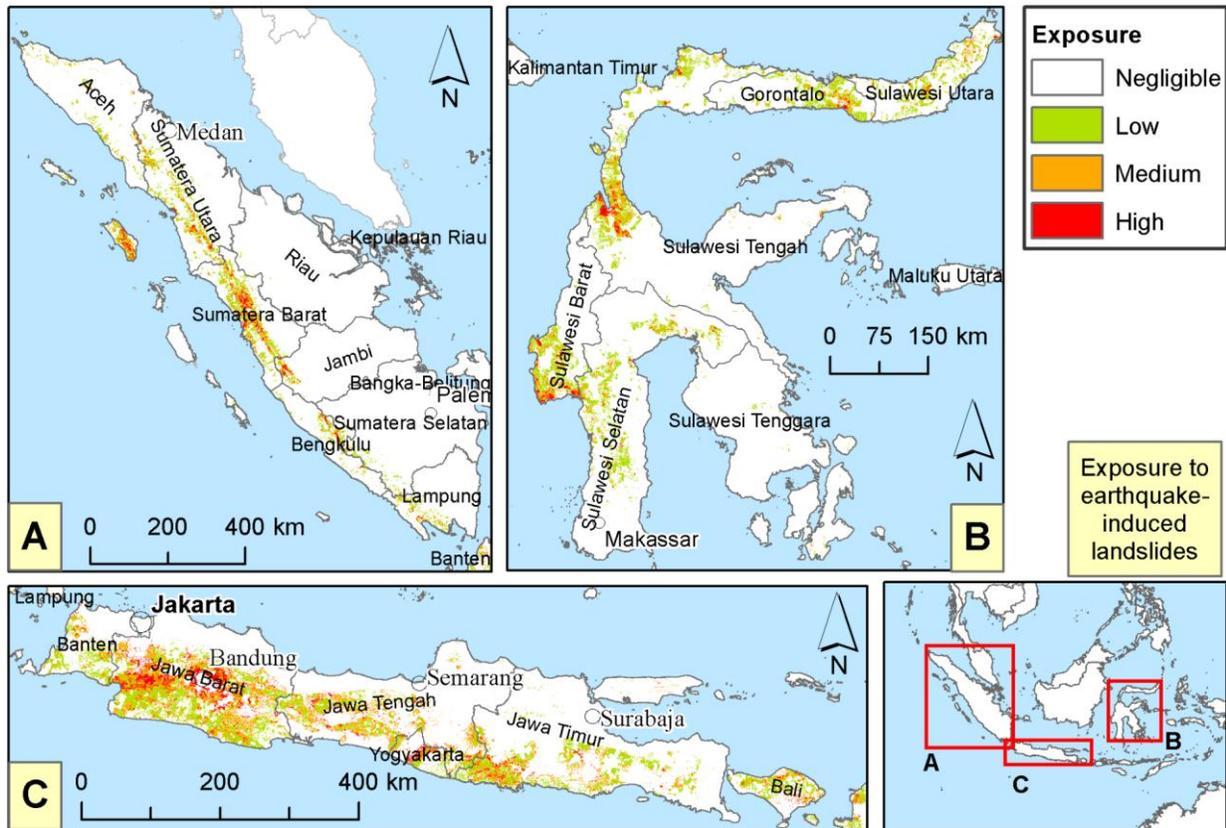


Figure 11. Maps of exposure to earthquake-triggered landslides for: (A) Sumatra, (B) Sulawesi, and (C) Java and Bali.

Figures 12 and 13 present the distribution of risk for precipitation-triggered landslides. Large regions of high risk levels are notable in the following provinces:

- In Sumatra:
 - Sumatera Barat.
- In Sulawesi:
 - Sulawesi Barat.
 - Sulawesi Selatan.
- In Java:
 - Banten.
 - Jawa Barat.
 - Jawa Tengah.
 - Yogyakarta.
- Bali.

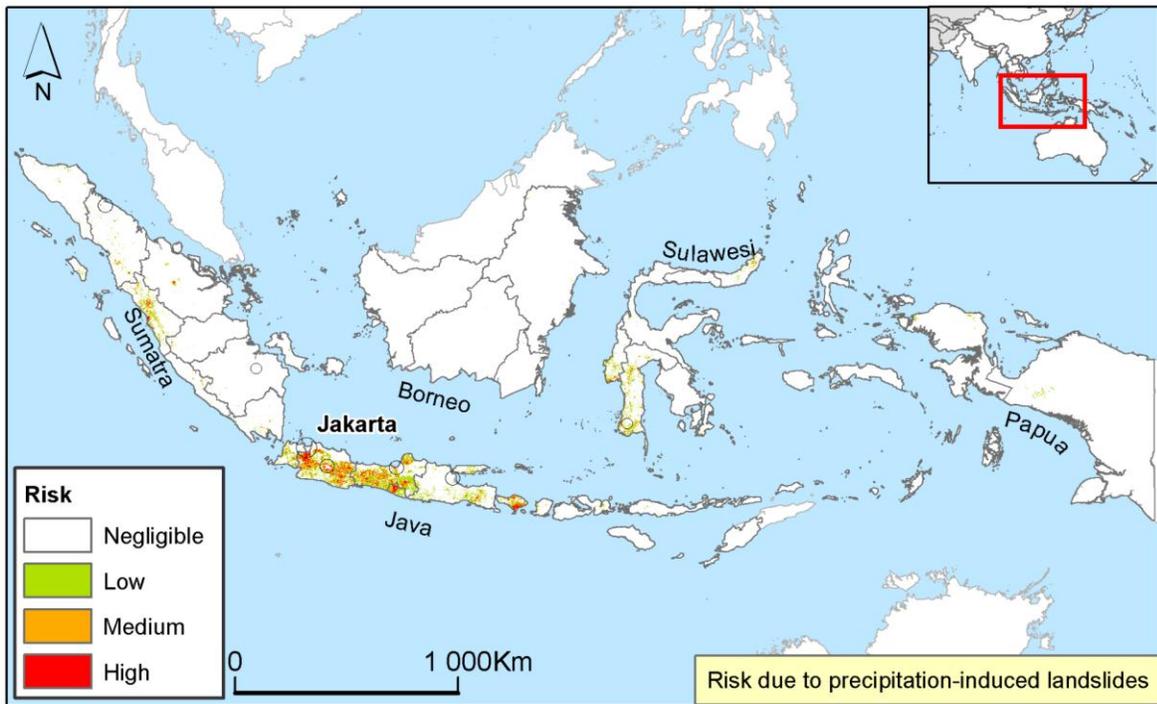


Figure 12. Map of precipitation-triggered landslides risk distribution for Indonesia.

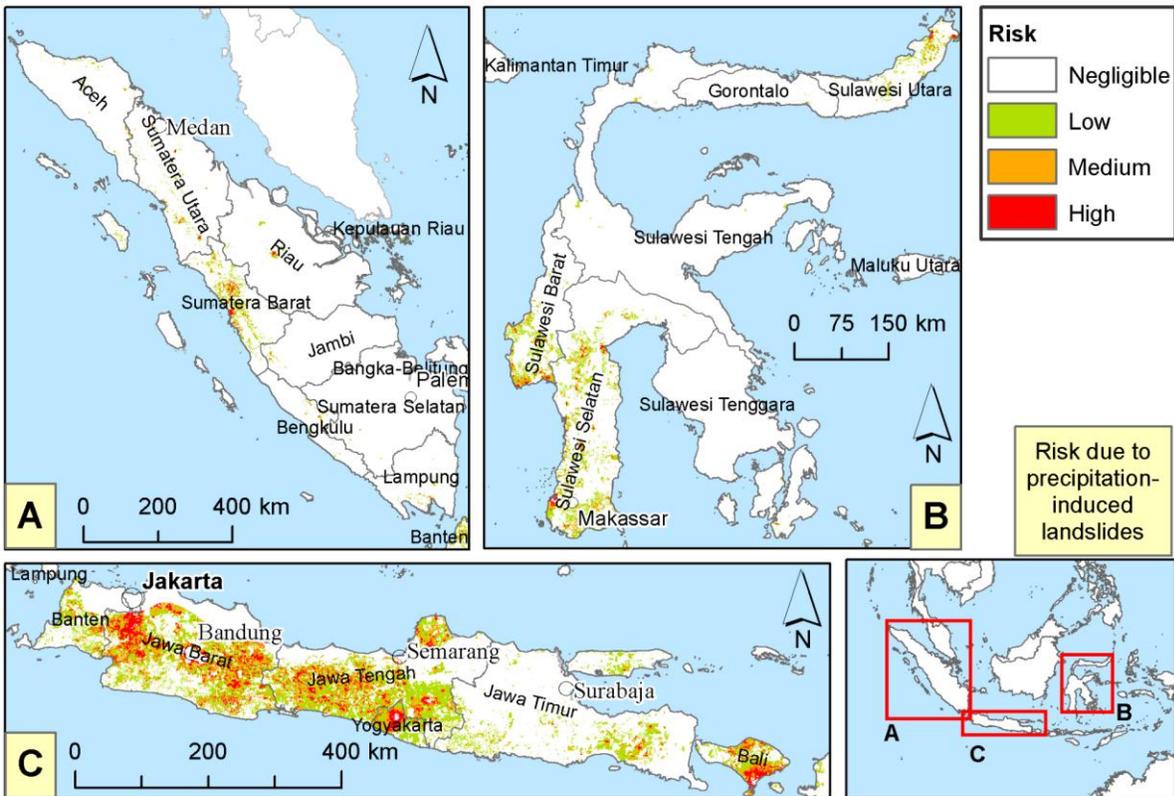


Figure 13. Maps of precipitation-triggered landslides risk distribution for: (A) Sumatra, (B) Sulawesi, and (C) Java and Bali.

1.7. Difficulties and limitations

The influence of human activities is a very important susceptibility or triggering factor for landslides, but it is not accounted for in the hazard model used in the present study. In future refinements of the model, one could introduce an index that is dependent on population density and infrastructure density. For example, crossing maps of road and railway networks with steep slope areas would allow identifying locations that can be critical for initiation of landslides in cuts and fills (embankments). As an illustration, the inventory in Figure 3 shows some clusters of landslide events in areas of low hazard and along roads (see e.g. 7°15' S, 107°55' E). These clusters may correspond in some instances to landslides in man-made slopes (i.e., along cuts or embankments).

The lithology factor was improved from the new reclassification of the global UNESCO map (Commission for the Geological Map of the World and UNESCO, 2000). The OneGeology project (www.onegeology.org) provides a better resolution map for Indonesia but the spatial database that is publicly distributed does not have fields for the lithological units. Therefore, the OneGeology map for Indonesia was not utilizable in the analyses. Based on a previous experience of ICG/NGI in a project in Nepal (ADPC, NGI and CECI, 2010), improvements in the spatial resolution of lithology may increase significantly the agreement between the results of the model and existing inventories. It is foreseen that the use of the OneGeology map could contribute significantly in such improvements for Indonesia.

The triggering factor for earthquake-triggered landslides was estimated using the horizontal peak ground acceleration (PGA) for a return period of 475 years from the seismic hazard study by Irsyam et al. (2010). The PGA map of this recent hazard assessment seems to show a significant improvement in spatial resolution and refinement compared to the GSHAP map (Giardini et al. 1999) used in similar earlier studies. The original spatial database of Irsyam et al. (2010), i.e., with PGA variations at pixel level, was not available to NGI. The map used in the analyses was obtained by digitizing a low resolution image of iso-acceleration contours. A potential improvement in accuracy could be expected by using the original spatial database.

A universally accepted measure of landslide severity is not available at present. Some researchers define landslide intensity qualitatively as “a set of spatially distributed parameters describing the destructiveness of a landslide”. In this context, landslide intensity has been addressed and defined quantitatively using a variety of parameters, such as maximum landslide velocity, total displacement, differential displacement (relative to points adjacent to the point under consideration), depth of the moving mass, depth of deposits after the movement ceases, depth of erosion, unit discharge, kinetic energy per unit area, maximum thrust, impact

pressure, maximum normal or shear strain at or below ground surface, and so on (e.g., see Fell et al. 2008).

In the present study, all landslides capable of causing injury or fatality are considered as “events”. Beyond that, no attempt was made at considering the severity of different landslide events.

The model assesses hazard level as an interaction of hazard frequency and hazard intensity without quantifying each of the two components. A medium hazard level might therefore be the result of high frequency and low intensity levels or of low frequency and high intensity events without the model specifying this.

1.8. Acknowledgments

Dr. Dalia Kirschbaum and her colleagues at NASA have kindly made publicly available their landslide inventory for 2003, 2007, 2008 and 2009. Their contribution is gratefully acknowledged. Dr. Jun-Ichi Hamada and his colleagues at the Japan Agency for Marine-Earth Science and Technology have kindly made publicly available a comprehensive dataset of daily rainfall for Indonesia, which the authors of the present study would like to gratefully acknowledge. The following Indonesian institutions have kindly provided data for this study: the Geological Agency, the Agency for Meteorology, Geophysics & Climatology, the Center for Geotechnology at the Indonesian Institute of Sciences, the Ministry of Forestry, and the Ministry of Public Works. Their support is gratefully acknowledged.

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