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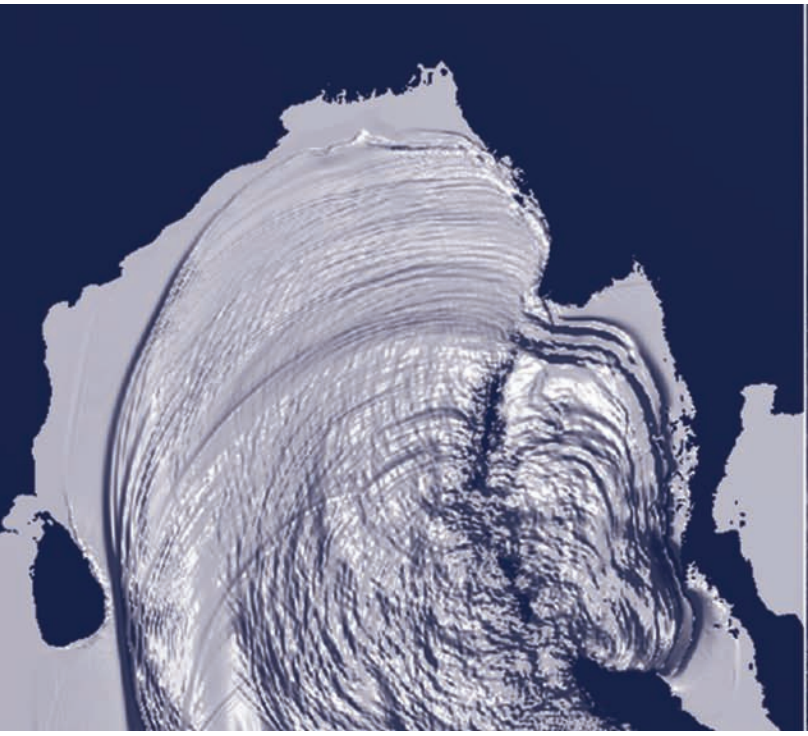
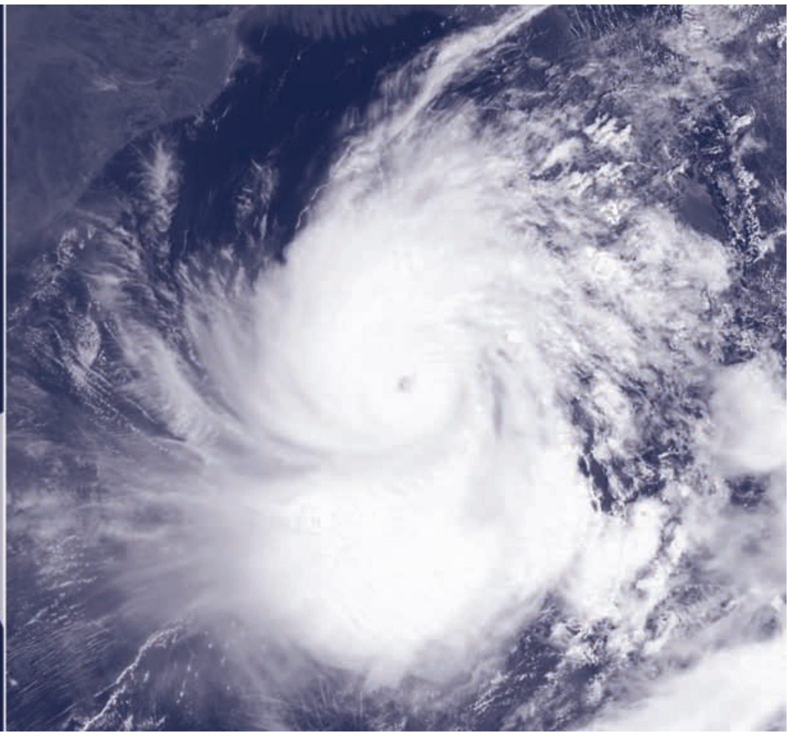
Natural and Conflict Related Hazards in Asia-Pacific





Risk assessment and mitigation measures for natural and conflict related hazards in Asia-Pacific

NGI report 20071600-1

23 April 2009

Project

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Client

Client:	United Nations Office for Coordination of Humanitarian Affairs, OCHA Regional Office for Asia and the Pacific, Bangkok
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Summary

Natural hazards, driven by geological and hydrological processes, affect many countries in Asia because of their geographical setting. According to a recent publication by the Asian Disaster Preparedness Center (ADPC) in Bangkok, loss of life from natural hazards in Asia amounted to two-thirds of the total global mortality due to natural hazards in the period 1980-2000. Just in the past five years, the region has experiences two catastrophic tsunamis (December 2004 and July 2006), two catastrophic earthquakes (Pakistan in October 2005

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and Sichuan, China in May 2008) and several catastrophic typhoons (e.g. typhoon Nargis in May 2008).

In addition to the risk posed by natural hazards, many of the countries in the Asia-Pacific region are exposed to the risk of civil conflict. New data from International Peace Research Institute, Oslo (PRIO) show that Asian countries accounted for 1/3 of all battle-related casualties during the past 25 years. Almost half of the on-going armed intrastate conflicts in the world today are fought in the Asia Pacific region. While the rest of the world has been experiencing a decline in the number of civil conflicts since the early 1990s, little discernable trend is evident in the Asia Pacific.

This report presents the results of a study that aimed to quantify the risk posed by earthquake, flood (and storm surge), landslide, cyclone and tropical storm, tsunami, drought, and social unrest in form of intrastate armed conflict in the Asia-Pacific countries. The study was commissioned by the United Nations Office for Coordination of Humanitarian Affairs, OCHA Regional Office for Asia and the Pacific, Bangkok; and financed by the Norwegian Ministry of Foreign Affairs.

The semi-quantitative approach adopted for the risk assessment was the same for all countries in the study area to ensure consistent modelling for the whole region. The main outcomes of the study were:

- hazard maps that show the geographical hotspot areas for single hazards and for multi-hazards on regional (sub-national) level,
- estimates of the exposed population to selected hazards,
- tabulated indices that attempt to rank the countries in terms of risk level, and
- recommendations for preventive actions in terms of how vulnerability can be reduced and/or how coping capacity could be improved.

In the development of hazard maps, each natural hazard was classified into four categories in term of its severity: negligible, low, medium and high.

A key challenge in the study was the quantification of the coping capacity of different countries in dealing with these risks. Quantification of the coping capacity was essential in designing the appropriate risk mitigation strategies.

In many situations there is interaction and strong correlation between the risks posed by natural hazards and armed conflict. This interaction, however, was not evaluated in the present study.

During the course of the study it became apparent that with the present level of our knowledge and availability of high quality data (or lack thereof), it is not possible to estimate the risk in terms of expected mortality for all hazards.

Therefore, the exposed population was used as proxy for risk. The estimation of the exposed population was based on a weighted average of the people living in areas with different hazard severity categories, combined with spatial characteristics of the hazard in question.

Note about the contributors

The following persons contributed to the work described in this report:

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Contents

Enclosed CD: Full report 20071600-1 including Appendices A-H, ArcGIS maps and spreadsheets for coping capacity and risk index calculations.

1 Background

The global risk posed by natural hazards has had an increasing trend over the past century. Figure 1 shows the number of major natural disaster events since 1950. The economic consequences of natural disasters show an even more dramatic increasing trend (Munich Re, 2007). Some of the reasons for this increase are obvious, others less so. The post-disaster effects can be especially severe in a vast, densely-populated area where sewers fail and disease spreads. Slums spring up in disaster-prone areas such as steep slopes, which are prone to landslides or particularly severe damage in an earthquake (The Economist, 2007). Many of the world's fastest growing cities are located on coastal land or rivers where climate variability and extreme weather events, from cyclones to heat waves to droughts, pose increasing risks of disaster.

Economic dislocation and great human discomfort are also caused by events like the 2007 floods in the Indian city of Kolkata (Figure 2). Such events are too small and frequent to grab global headlines.

Several well-documented studies have shown clearly that developing countries are more severely affected by natural disasters than developed countries, especially in terms of lives lost (UNDP 2004, ISDR 2004 and International Federation of Red Cross 2004). Table 1 shows the data compiled by IFRC (2001) for the decade 1991-2000. Of the total number of persons killed by natural disasters in this period, the highly developed countries accounted for only 5% of the casualties. In absolute numbers, the material damage and economic loss due to natural hazards in highly developed countries by far exceed those in developing nations. However, this reflects the grossly disproportionate values of fixed assets, rather than real economic vulnerability.

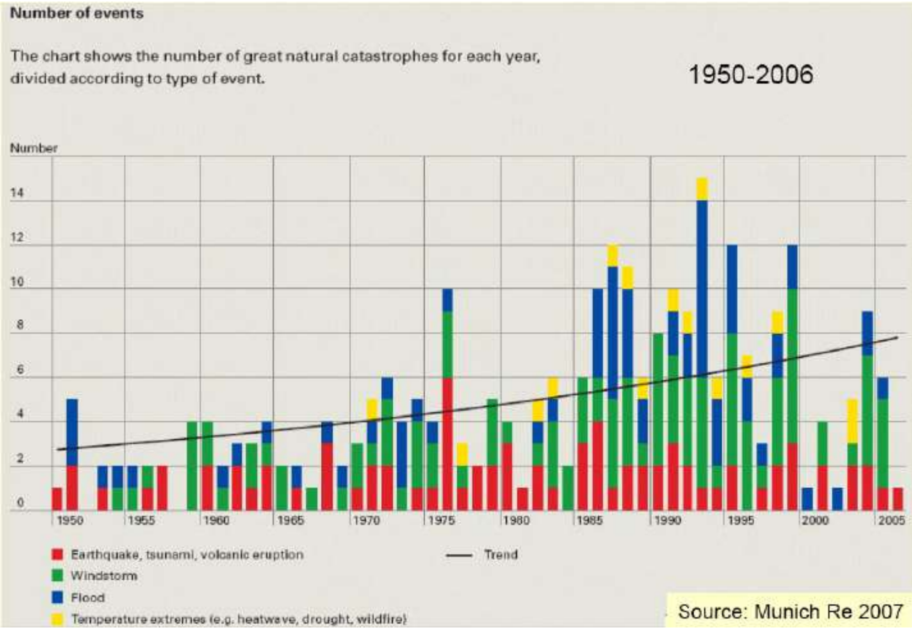


Figure 1. Trends in natural catastrophes since 1950 (Source: Munich Re).

Figure 2. Floods in Kolkata, India in 2007 (Source: The Economist, 2007).

Table 1. Natural disasters in the period 1991- 2000 (Source: IFRC 2001).

Country classification	**No. of disasters**	**No. of lives lost**
Low and medium developed countries	1838	649 400
Highly developed countries	719	16 200

Natural hazards, driven by geological and hydrological processes, affect many countries in Asia because of their geographical setting. According to a recent publication by the Asian Disaster Preparedness Center (ADPC) in Bangkok, loss of life from natural hazards in Asia amounted to two-thirds of the total global mortality due to natural hazards in the period 1980-2000. Just in the past five years, the region has experiences two catastrophic tsunamis (December 2004 and July 2006), two catastrophic earthquakes (Pakistan in October 2005 and Sichuan, China in May 2008) and several catastrophic typhoons (e.g. typhoon Nargis in May 2008).

Three recent projects have already attempted to identify the risk posed by natural hazards on a global scale. The Disaster Risk Index (DRI) created by UNEP/GRID-Geneva for UNDP/BCPR (UNDP 2004) was the first attempt in identifying the risk and vulnerability parameters leading to disaster at national level. It used the data and some of the methods developed by the UNEP Project for Risk Evaluation, Vulnerability, Information and Early Warning (PREVIEW). The Global Natural Disaster Risk Hotspots Study initiated by ProVention, which was completed in 2005, addressed the risks associated with multiple natural hazards for the Asia region at the both national and sub-national levels. High-risk countries in terms of mortality risk from natural hazards were found to be Indonesia, Philippines, Vietnam, China, Bangladesh, India, Pakistan, Nepal and Sri Lanka.

In addition to the risk posed by natural hazards, many of the countries in the Asia-Pacific region are exposed to the risk of civil conflict. New data from

International Peace Research Institute, Oslo (PRIO) show that Asian countries accounted for 1/3 of all battle-related casualties during the past 25 years. Almost half of the on-going armed intrastate conflicts in the world today are fought in the Asia Pacific region (Figure 3). While the rest of the world has been experiencing a decline in the number of civil conflicts since the early 1990s, little discernable trend is evident in the Asia Pacific. As a result, the proportion of the world's armed conflicts fought in Asia has been on the rise. From 1975 to 2006, the number of civil conflicts in this region has ranged from 11 to 19. The number of countries experiencing armed conflict peaked in 1990 (10) and was at its lowest point in 2002 (5). As with other regions of the world, very few interstate wars have been fought in Asia.

In contrast to counting the number of conflicts being fought, the severity of wars fought in the Asia Pacific region has varied considerably. Indeed, the Korean War, Chinese Revolution and Vietnam War are three of the bloodiest wars in the world since WWII. Since the end of the Cold War, the annual number of battle deaths in Asia Pacific has remained quite stable (between 6,000 and 9,000 per year) and low compared to the rest of the world.

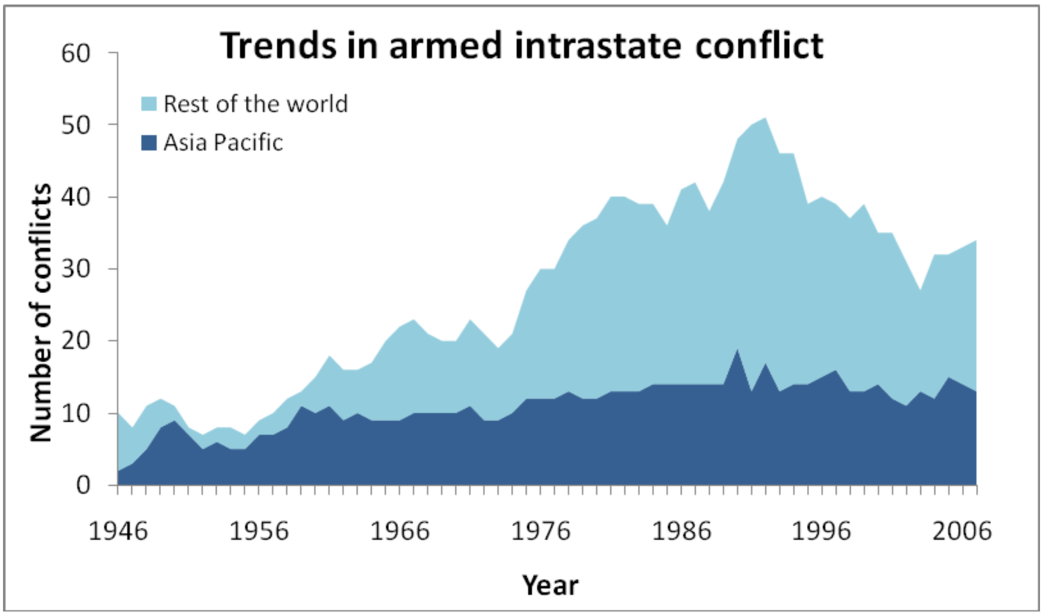


Figure 3. Trends in intrastate armed conflicts since WWII (Source: PRIO).

This report presents the main results of a study which aimed to quantify the risk posed by earthquake, flood (and storm surge), landslide, cyclone and tropical storm, tsunami, drought, and social unrest in form of intrastate armed conflict in the Asia-Pacific countries. A key challenge in the study was the quantification of the coping capacity of different countries in dealing with these risks.

The semi-quantitative approach used for risk assessment was the same for all countries in the study area[1] to ensure consistent modelling for the whole region. The main outcomes of the study were:

(I) hazard maps that show geographical hotspot areas for single hazards and for multi-hazards on regional (sub-national) level,
(II) estimates of the exposed population to selected hazards,
(III) tabulated indices that attempt to rank the countries in terms of risk level, and
(IV) recommendations for preventive actions in terms of how vulnerability can be reduced and/or how coping capacity could be improved.

In many situations there is interaction and strong correlation between the risks posed by natural hazards and armed conflict. This interaction, however, was not evaluated in detail in the present study.

In the development of hazard maps, each natural hazard was classified into four categories in term of its severity: negligible, low, medium and high. Since no country is exempt from the risk of armed conflict, the lowest conflict hazard category (i.e. the category denoted “negligible” for natural hazards) should be interpreted as low, and the following ones as medium, high and very high. It must be noted, however, that the different hazards should not be compared to each other on the basis of this qualitative classification. For example, a high hazard for earthquake signifies a much different risk potential than a high hazard for landslide in the same area.

During the course of the study, it became apparent that with the present level of our knowledge and availability of high quality data (or lack thereof), it is not possible to estimate the risk in terms of expected mortality for all hazards. Therefore, the exposed population was used as proxy for risk. The estimation of the exposed population was based on a weighted average of the people living in areas with different hazard severity categories, combined with spatial characteristics of the hazard in question.

2 Population data

The Global Rural Urban Mapping Project (GRUMP) dataset prepared by the Center for International Earth Science Information Network (CIESIN) at Columbia University was used for estimating the population exposed to

[1] In alphabetical order: Australia, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Fiji, India, Indonesia, Japan, Kiribati, Korea DPR, Korea RO, Lao PDR, Malaysia, Maldives, Marshall Islands, Micronesia, Mongolia, Myanmar, Nauru, Nepal, New Zealand, Pakistan, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon islands, Sri Lanka, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, and Vietnam.

different hazards. The GRUMP population surfaces and urban-rural extents have been developed based on three inputs: administrative boundary data sets and associated population estimates used in the preparation of Gridded Population of the World, version 3 (GPWv3); Night-time Lights of the World from the National Geophysical Data Center, the world stable lights data for 1994-1995; and a collection of population place locations and population estimates put together at CIESIN based on a number of public sources.

The GRUMP population surfaces consist of raster grids of population counts (persons) and densities at 30 arc-second resolution. The GRUMP population distribution in 2007 for the study region is shown on Figure 4.

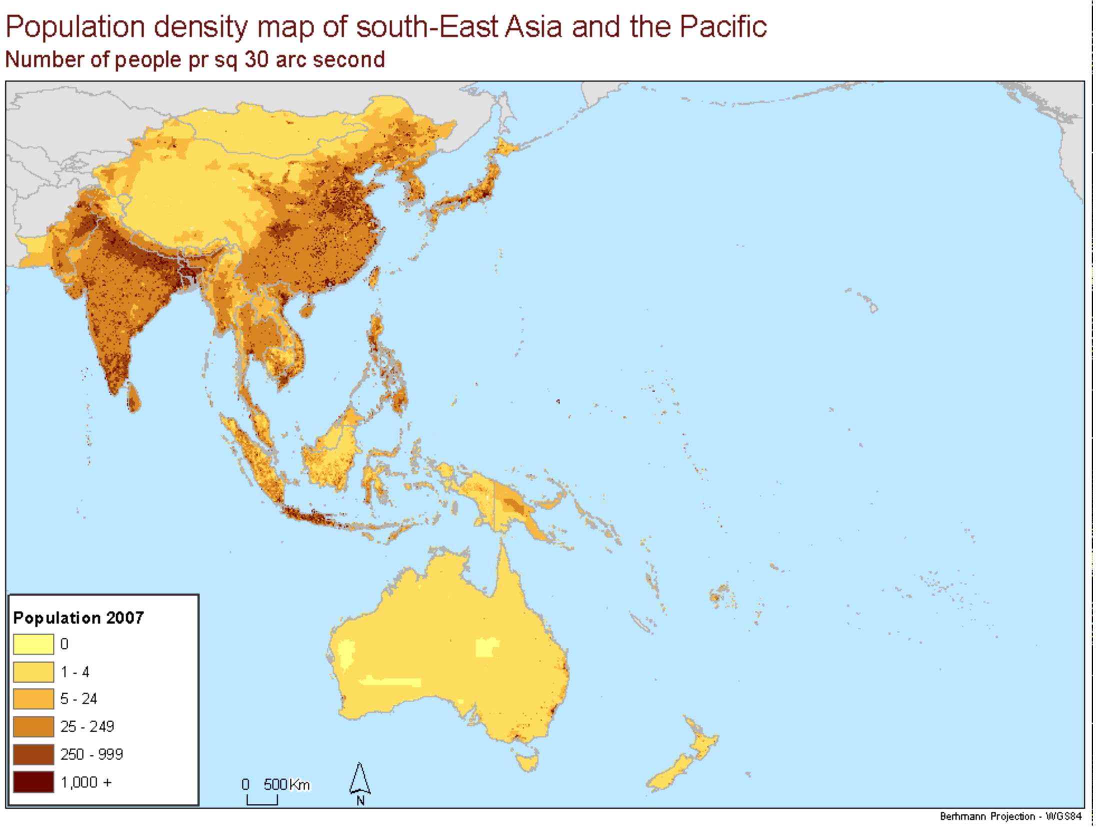


Figure 4. GRUMP – Population density (per pixel of 30 arc_sec × 30 arc_sec) in the study area in 2007.

3 Earthquake

The earthquake hazards maps developed in this study were on the basis of the maps developed in the Global Seismic Hazard Assessment Program (GSHAP). The GSHAP was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council for Science (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/IDNDR). The

GSHAP was implemented in the 1992-1998 period and was concluded about 10 years ago.

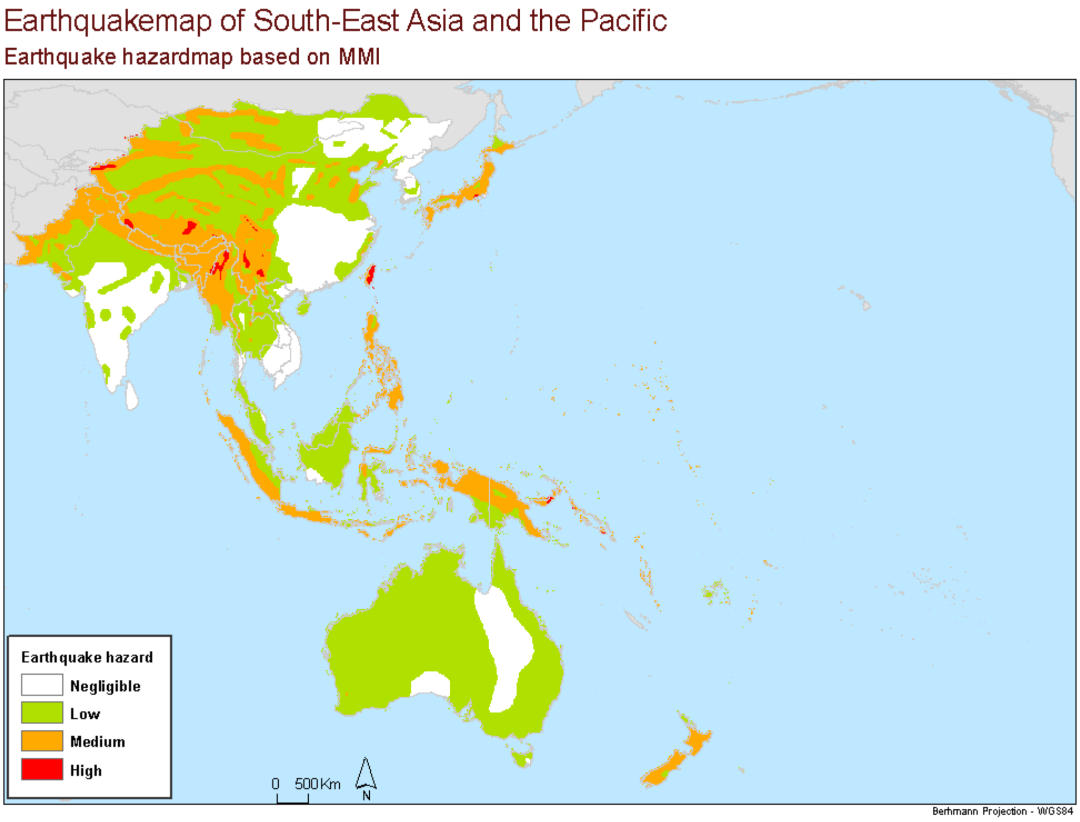


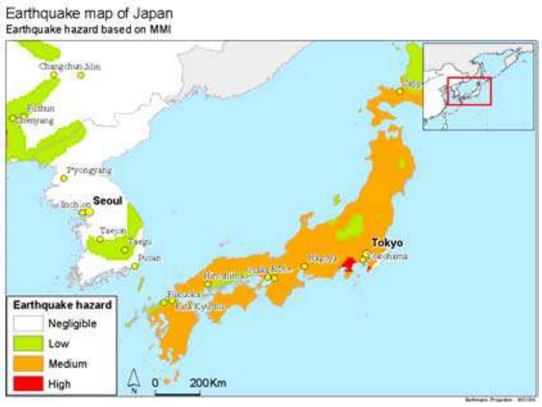
Figure 5. Map of earthquake hazard in Asia-Pacific, classified into 4 categories on the basis of MMI intensity.

The results of the GSHAP were converted to Modified Mercalli Intensity (MMI) maps for the Asia-Pacific using the methodology developed by Wald et al. (1999). The MMI intensity scale classifies the severity of earthquake shaking on a scale of I to XII. The lowest intensities are not felt by people, while the highest intensities correspond to nearly total destruction of all constructed facilities. The MMI maps derived from GSHAP were in turn classified into 4 earthquake hazard categories for this study: negligible, low, moderate, and high.

Figures 5 through 8 show the earthquake hazard categories and the exposed population in the study area.

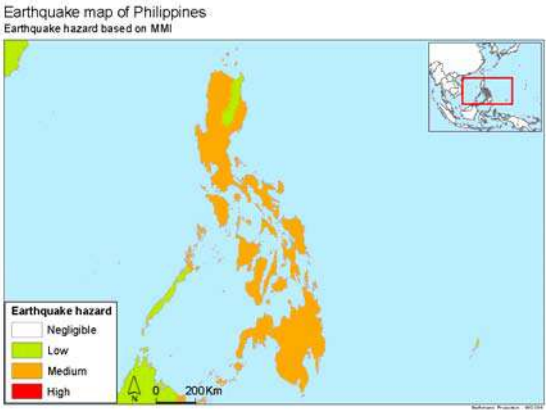
3.1 Assessment of impact of earthquakes in Asia Pacific

In the past five centuries, the global death toll from earthquakes has averaged 100,000 per year, a rate that is dominated by large infrequent disasters, mostly in the developing nations. During the past few years, two of the most catastrophic earthquakes in history have occurred in the region covered by this study (Pakistan in October 2005 and Sichuan, China in May 2008). Earthquakes can be especially devastating when they occur in areas with high population density. The risk posed by earthquakes to people living in Asian megacities is by far greater than all other natural hazards combined.

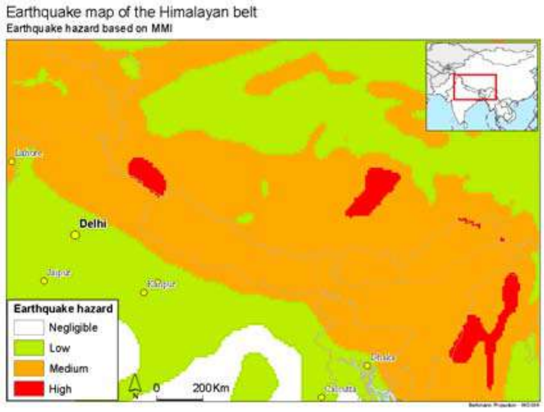


Japan

Java



The Philippines



Himalayan belt

Figure 6. Map of earthquake hazard in selected regions of Asia-Pacific.

Similar to other natural hazards, the global fatality count from earthquakes continues to rise. The increase in total fatalities is most likely due to high rates of population growth in high risk areas. At the same time, there is a decline in the fatality rate expressed as a percentage of instantaneous population. It is tempting to attribute this observation to the application of earthquake-resistant construction code in new city developments. A more realistic interpretation could be, however, that the apparent decline in the overall fatality rate is a statistical anomaly related to the long periods between major earthquakes.

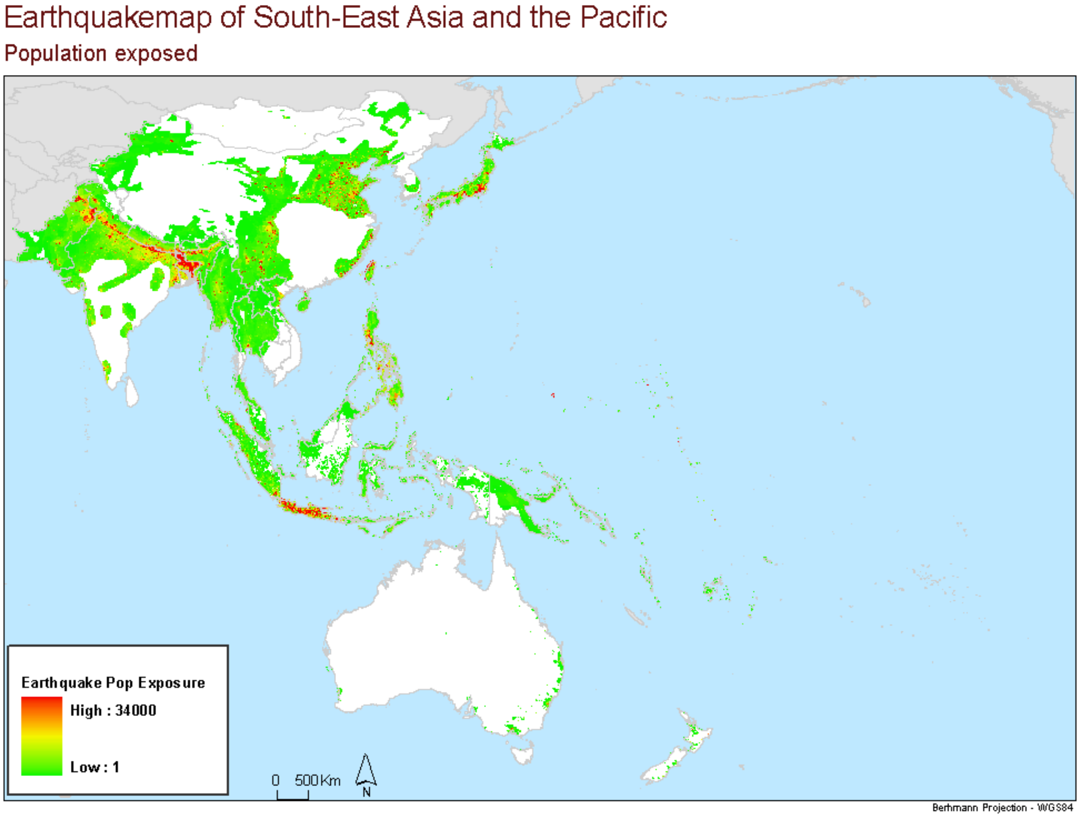
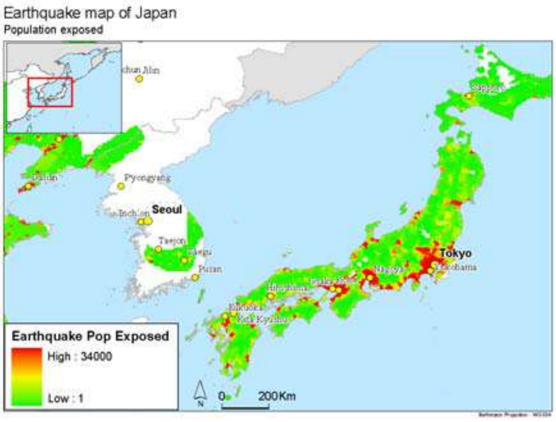
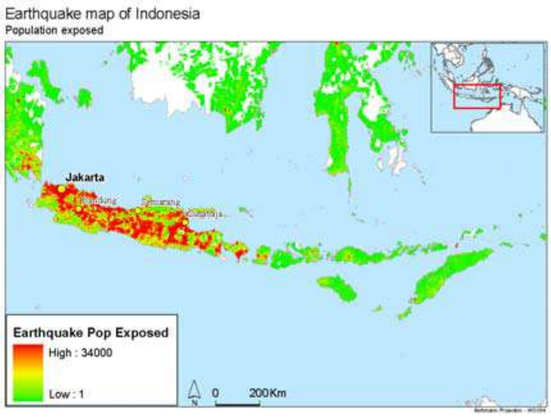


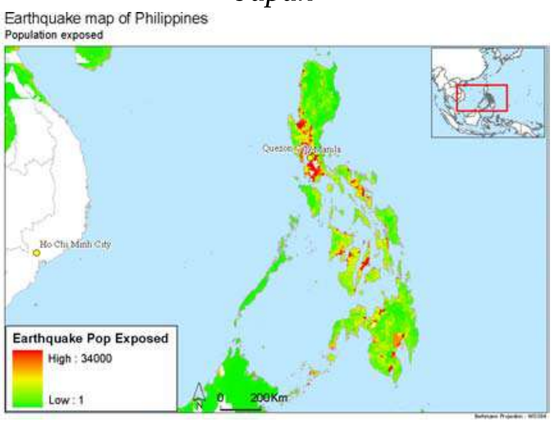
Figure 7. *Population exposure to earthquake in Asia-Pacific (No. of persons per pixel of 30 arc_sec× 30 arc_sec, ca 1 km × 1 km near equator).*



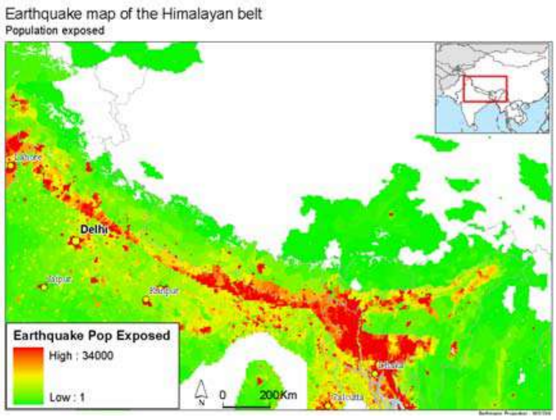
Japan



Java



The Philippines



Himalayan belt

Figure 8. Map of exposed population to earthquake hazard in selected regions of Asia-Pacific.

4 Flood

Flood is the one of the most frequent natural hazards that occurs in almost every country. Flood is generally defined as an excess of the amount of discharged water compared to the drainage capacity. At present there is no systematic global detection of flood events as there is for cyclones and earthquakes. Details of the flood hazard studies done in this project are provided in Appendix A.

Floods are triggered by various phenomena and there are different types of floods. For example one often differentiates among flash floods, river floods, and urban floods, all of which are caused by combination of heavy precipitation and poor drainage. The severity of these flood types depends on rainfall intensity, spatial distribution of rainfall, topography and surface conditions.

The current study focused on river floods. Other flooding events are not caused by precipitation, e.g. coastal flooding is associated with atmospheric low-pressure systems driving ocean water inland. Glacial lake outburst flooding (GLOF) occurs when a terminal or lateral moraine fails, releasing the glacial melt water it was damming in a sudden, violent burst. These flood types would require different modelling than what was done in the present study. Coastal flooding was, however, included in the modelling of storm surge during tropical cyclones (see Chapter 5).

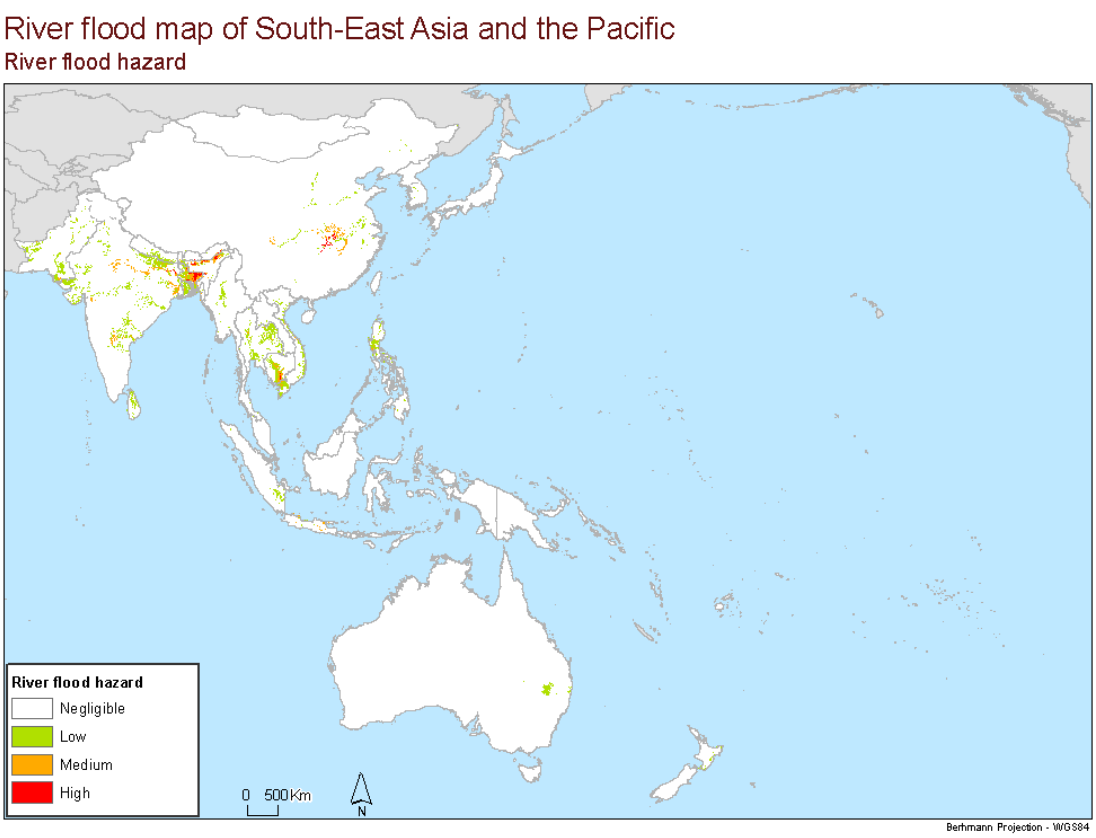


Figure 9. Hazard classification for river floods in Asia-Pacific.

4.1 Assessment of impact of floods in Asia Pacific

Every year, over 48 million people are affected by floods in rural areas in the Asia-Pacific countries, 40% of whom are in Bangladesh and 32% in India. Urban flooding, which is caused by inappropriate drainage and impervious surfaces, is also a serious hazard, particularly in large cities. In Munich Re's list of risk profile for the 50 largest cities of the world, Dhaka in Bangladesh and Kolkata in India are ranked as having very high exposure to flood risk.

All coastal areas are vulnerable to flood events, which could be devastating when heavy rainfall occurs at the same time as high tide or storm surge. Many climate change models predict more frequent extreme precipitation events, which in combination with global sea level rise makes the situation even more critical in the future. Consequently, the risk associated with flooding is expected to increase significantly in coastal regions with high population density in the future. Because of the predictability of the flooding events, however, the main consequences will hopefully be damage to constructed facilities and discomfort of the exposed population, rather than loss of life.

The results for river flood hazard and the exposed population in the study area are presented in Figures 9 through 12.

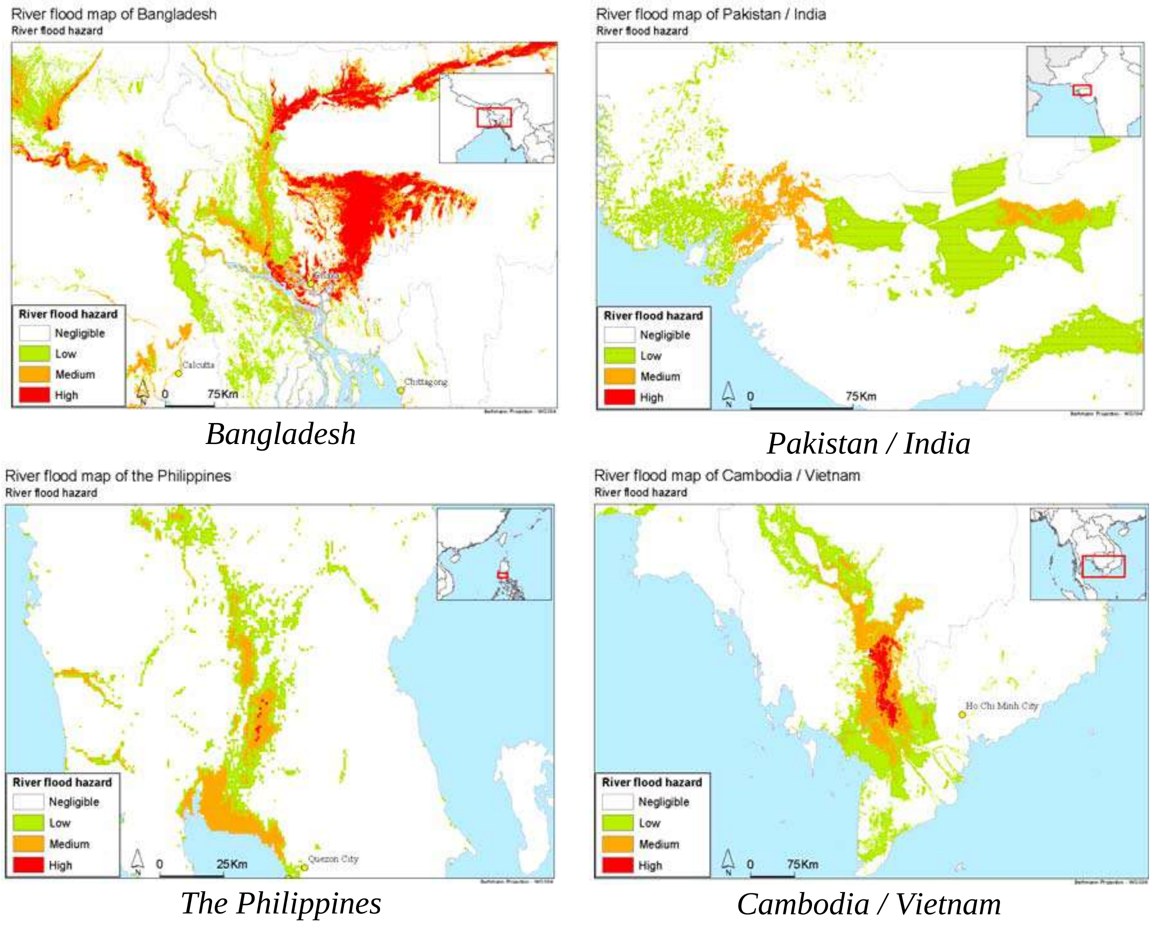


Figure 10. River flood hazard classification in selected regions of Asia-Pacific.

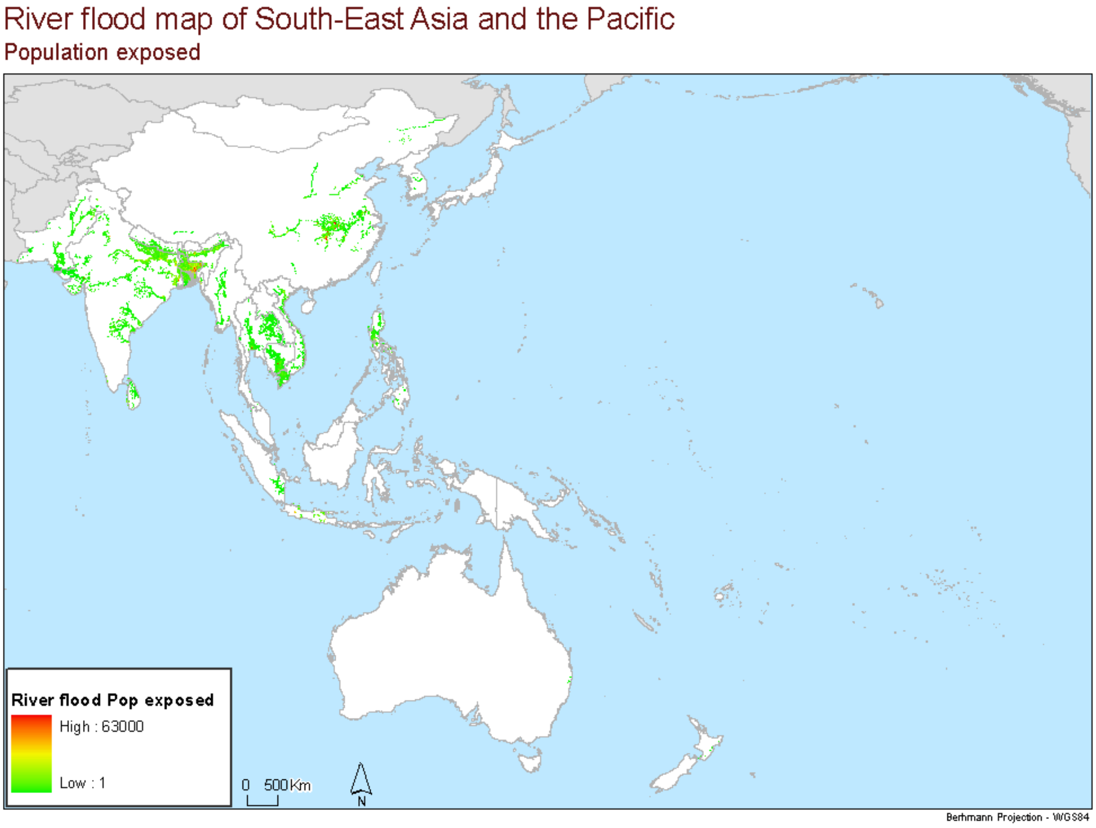


Figure 11. Population exposure to river floods in Asia-Pacific (No. of persons per pixel of 30 arc_sec × 30 arc_sec).

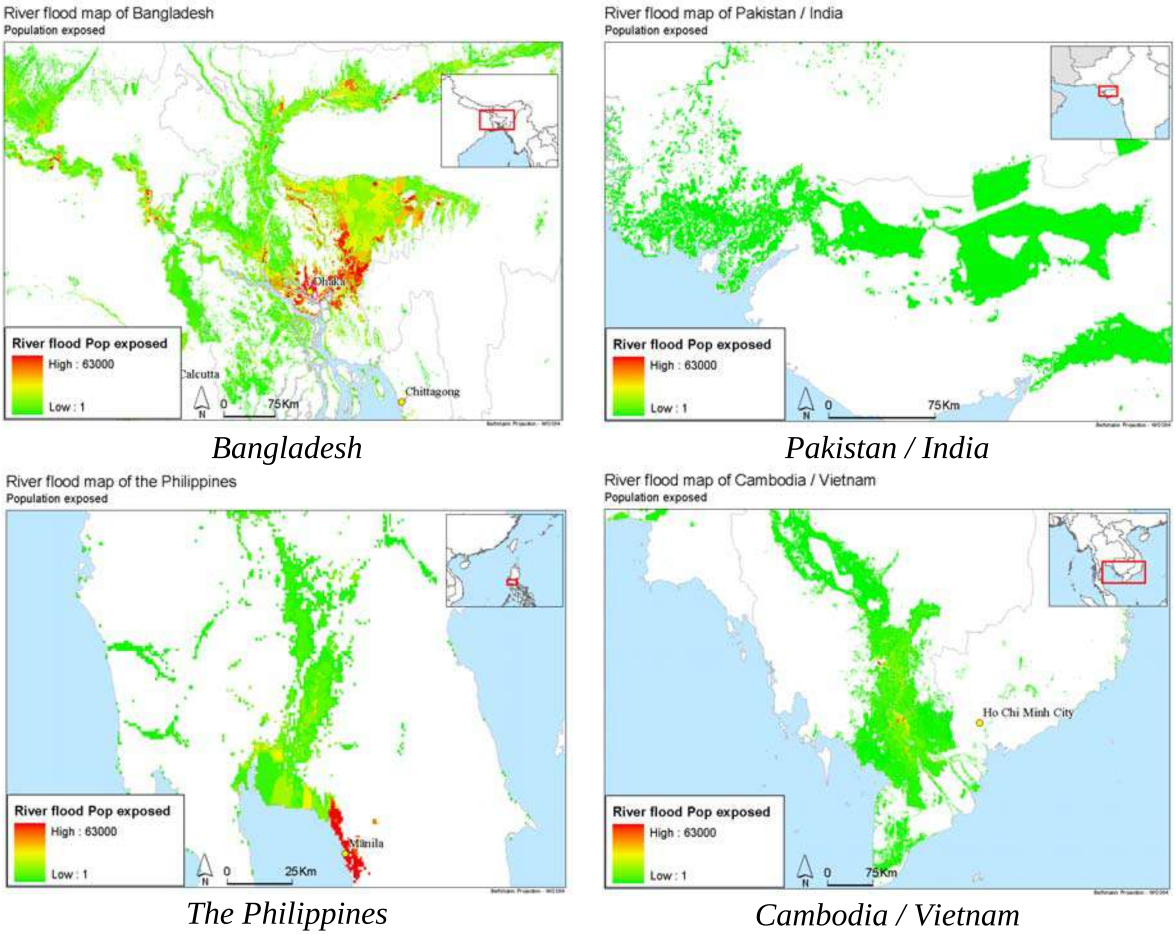


Figure 12. Population exposure to river floods in selected regions of Asia-Pacific.

5 Tropical Cyclones

Tropical cyclones are powerful hydro-meteorological hazards. On average, over 83 million people are affected globally by between 50 to 60 events each year. Tropical cyclones are unevenly spread around the globe as their development depends on specific climatic and oceanic conditions. A tropical cyclone has multiple impacts on the affected areas, including:

- Extremely powerful winds.
- Torrential rains leading to floods and/or landslides.
- High waves and damaging storm surge, leading to extensive coastal flooding.

The complexity of the multiple forms of impact triggered by tropical cyclones would call for integrated modelling of wind, rain, storm surge and landslides. However given the limited time available for the present study, priority was given to modelling the winds and storm surge (see Section 5.1). Details of the tropical cyclone studies done in this project are provided in Appendix B.

The model for tropical cyclone wind hazard used in this study was based on the observations of historical cyclone events during the time period 1975 to 2007.

5.1 Storm surge

A storm surge is a high flood of water caused by wind and low pressure, most commonly associated with tropical cyclones. The strong winds blowing towards the shore help push water towards shore on the right side of the tropical cyclone’s direction of motion. In addition, the central pressure of a tropical cyclone is so low that the relative lack of atmospheric weight above the eye and eye wall causes a bulge in the ocean surface level (see Figure 13).

Storm surge is the main cause of most coastal flooding events. A storm surge is different from a tidal surge, which is a violent surge of water caused exclusively by the tidal shift in sea level. Typical storm surge heights vary with the hurricane's intensity, but they can range from less than one to more than 5 metres. In the United States in 2005, the storm surge associated with Hurricane Katrina reached 9m in some locations.

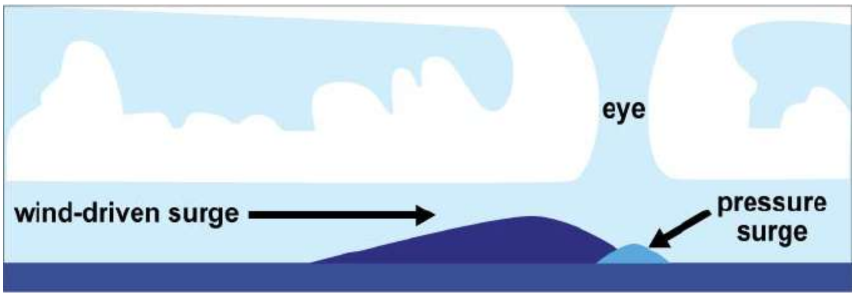


Figure 13. Schematic of storm surges (Source: Robert Simmon, NASA GSFC, 2007).

5.2 Assessment of impact of cyclones in Asia Pacific

In the past, tropical cyclones have sometimes had catastrophic consequences, such as the 1991 Bangladesh disaster killing more than 130,000 people, and the more recent Cyclone Nargis that caused a similar number of fatalities in Myanmar in May 2008.

An important point regarding the future risk of tropical cyclones is the current debate about whether climate change might cause more intense tropical cyclones than in the past. However, tropical cyclones are predictable events, which risk could be effectively mitigated through proper warning systems and evacuation procedures. Using the available knowledge and technology, it would be possible to limit the consequences of tropical cyclones to damage to constructed facilities and discomfort of the exposed population, rather than loss of life.

The results for wind impact of tropical cyclones in the Asia-Pacific are shown on Figures 14 through 17. The results for storm surge impact in the Asia-Pacific are shown on Figures 18 and 19.

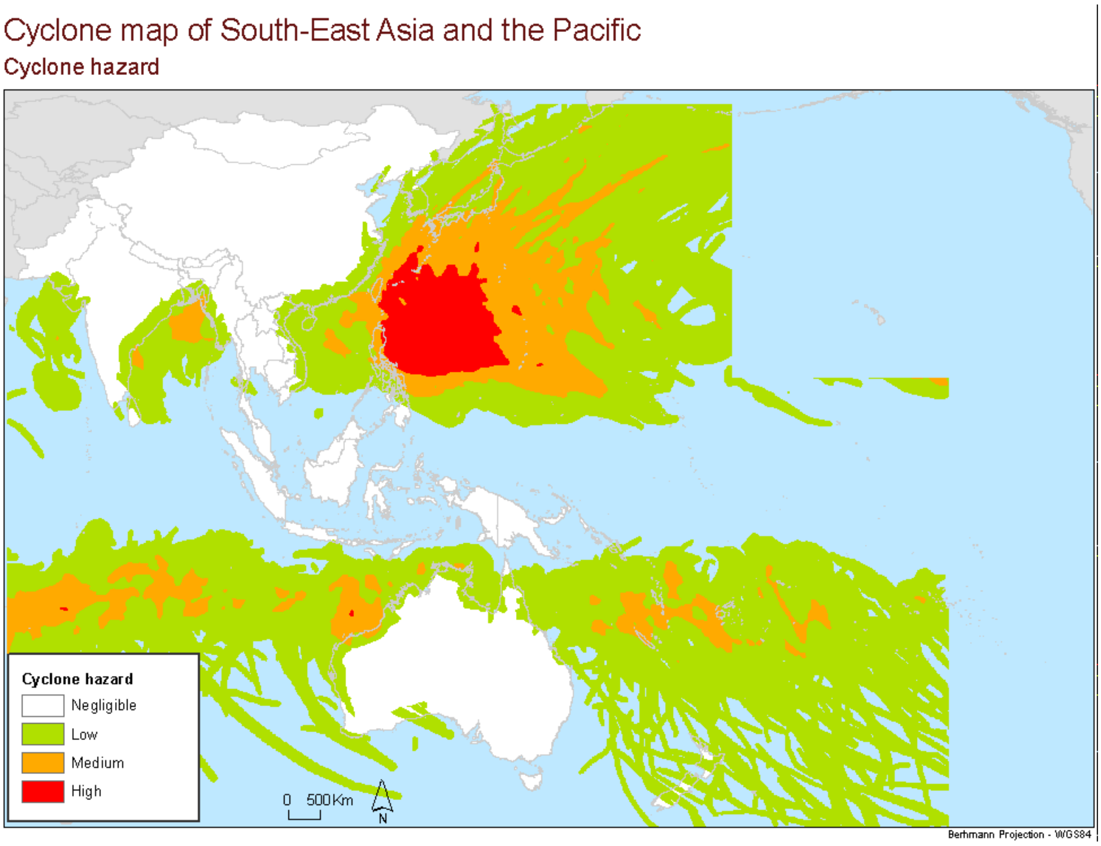
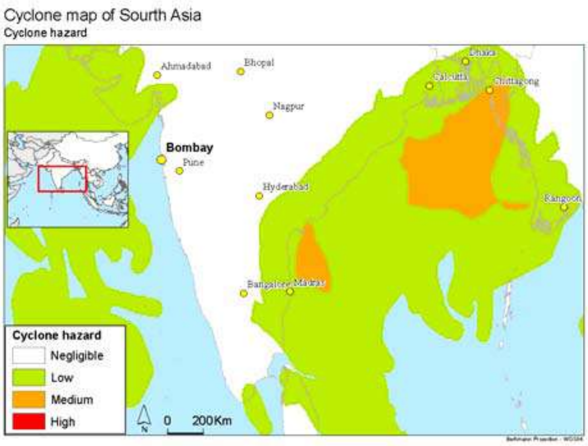
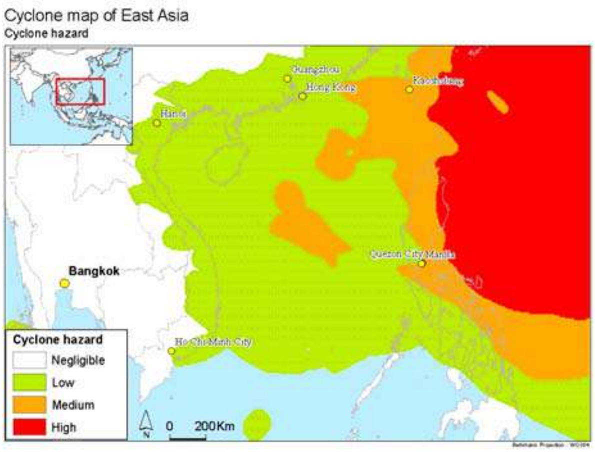


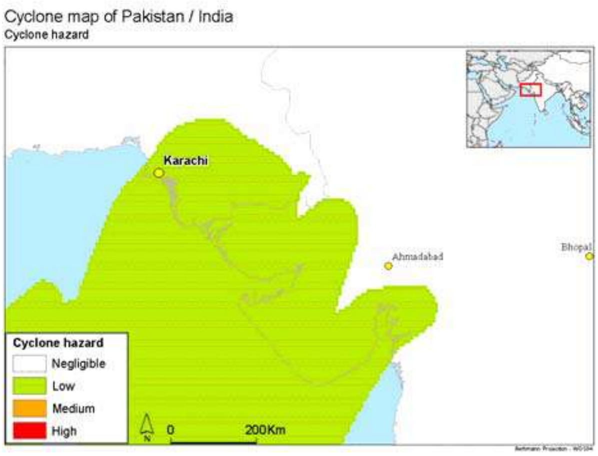
Figure 14. Hazard classification map for tropical cyclones in Asia-Pacific.



South Asia



East Asia



Pakistan and western India

Figure 15. Tropical cyclone hazard classification in selected regions of Asia-Pacific.

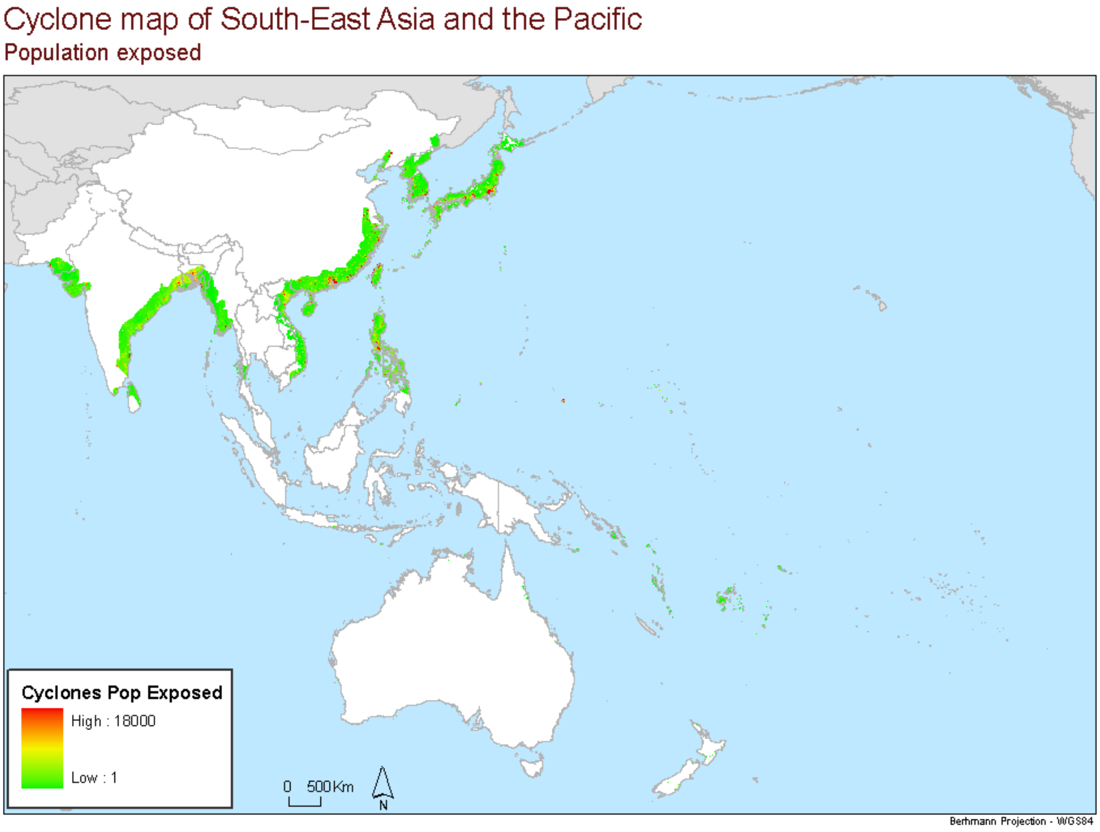
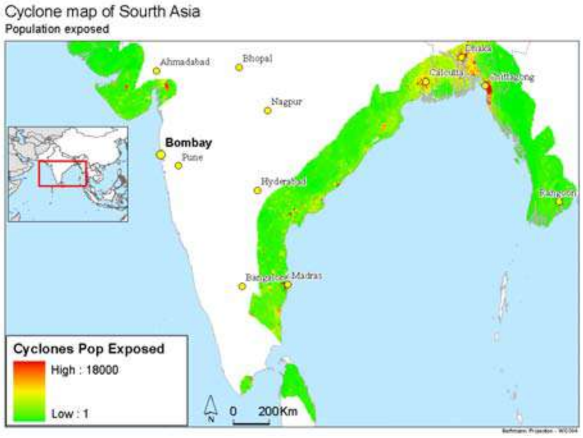
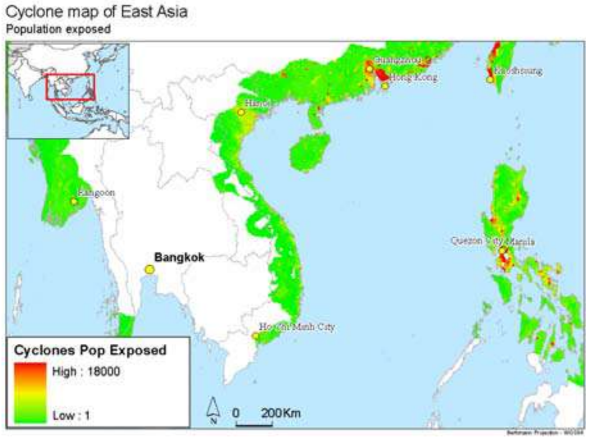


Figure 16. Population exposure to tropical cyclones in Asia-Pacific (No. of persons per pixel of 30 arc_sec × 30 arc_sec, ca 1 km ×1 km near equator).

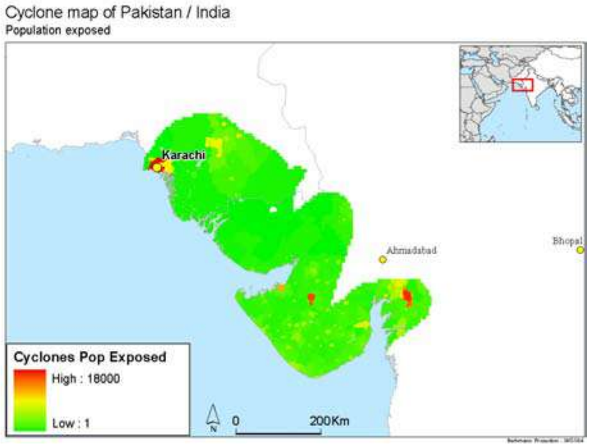


South Asia

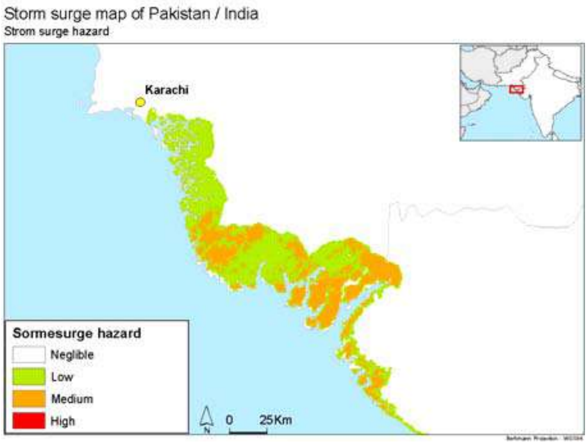


East Asia

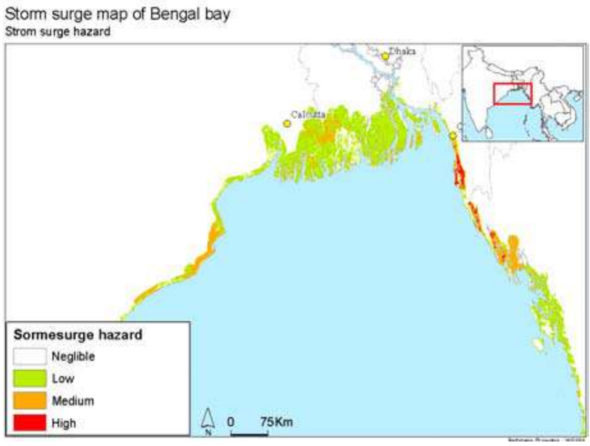
Figure 17. Exposed population to tropical cyclones in selected regions of Asia-Pacific.



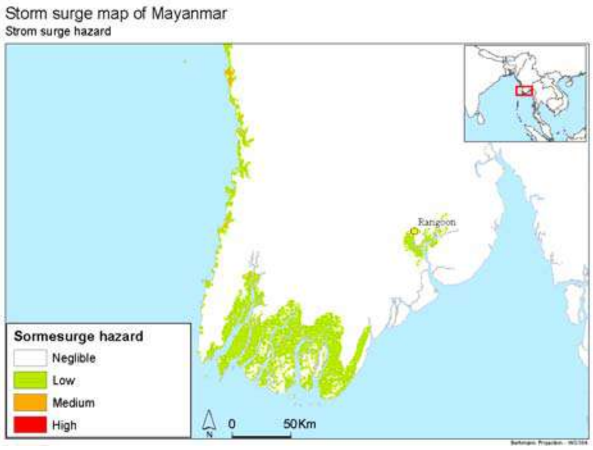
Pakistan and western India



Pakistan and western India

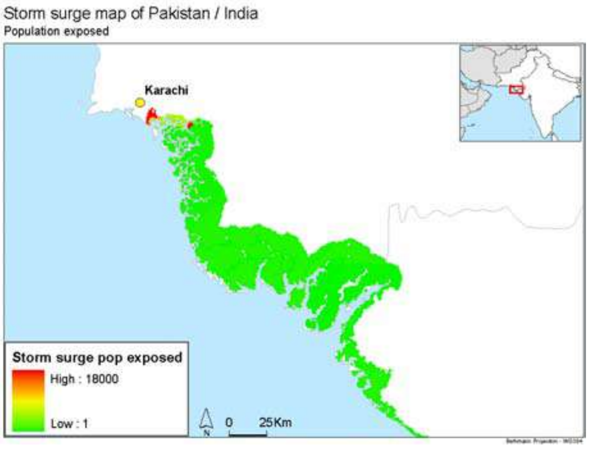


Bay of Bengal

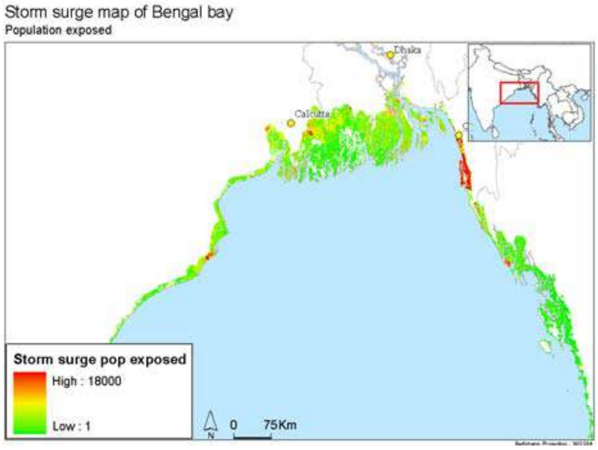


Myanmar

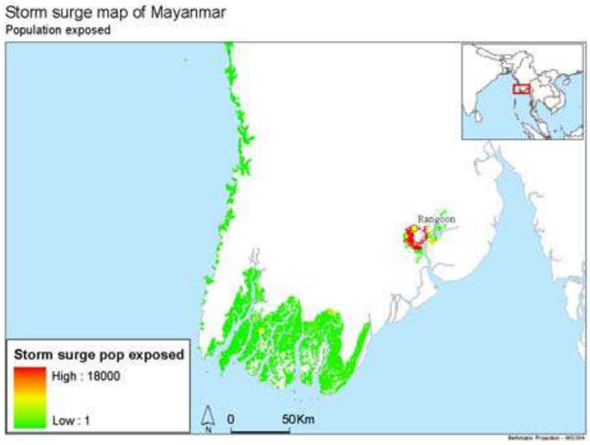
Figure 18. Storm surge hazard in selected regions of Asia-Pacific.



Pakistan and western India



Bay of Bengal



Myanmar

Figure 19. Population exposed to storm surge in selected regions of Asia-Pacific.

6 Landslide

In the analyses performed in this study, a landslide hazard index was defined using six parameters: slope, geological condition, soil moisture condition, vegetation cover, precipitation, and seismic condition. Details of the landslide hazard model used in this project are provided in Appendix C.

The results of the landslide hazard analyses and exposed population for the study area are shown on Figures 20 through 24. Only the population exposure to precipitation-induced landslides was considered in the calculations. The fatalities caused by earthquake-induced landslides are attributed to "earthquakes" in the EM-DAT database, and including them again under "landslides" would lead to an overestimation of risk.

6.1 Assessment of impact of landslides in Asia Pacific

Landslides represent a major threat to human life, property and constructed facilities, infrastructure and natural environment in most mountainous and hilly regions of the world. 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. The socio-economic impact of landslides is, however, greatly underestimated because landslides are usually not separated from other natural hazard triggers, such as extreme precipitation, earthquakes or floods in natural catastrophe databases. This underestimation contributes to reducing the awareness and concern of both authorities and general public about landslide risk.

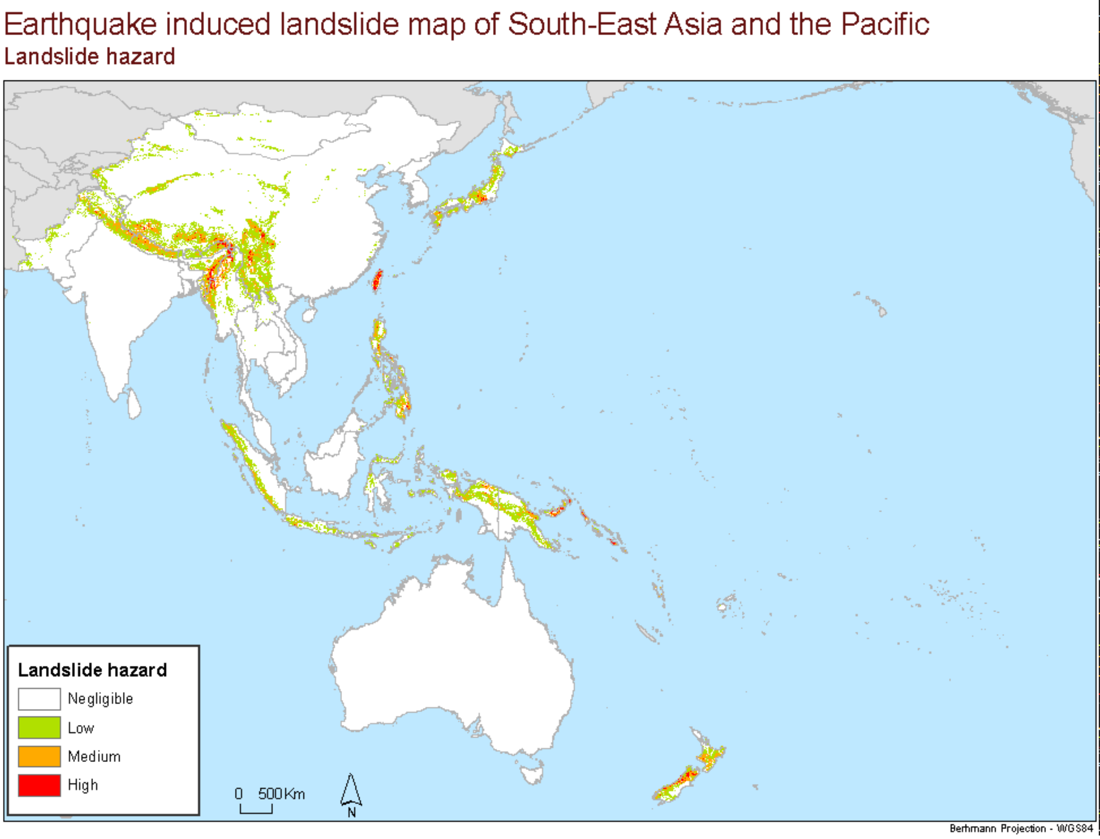


Figure 20. Hazard classification map for earthquake-induced landslides in Asia-Pacific.

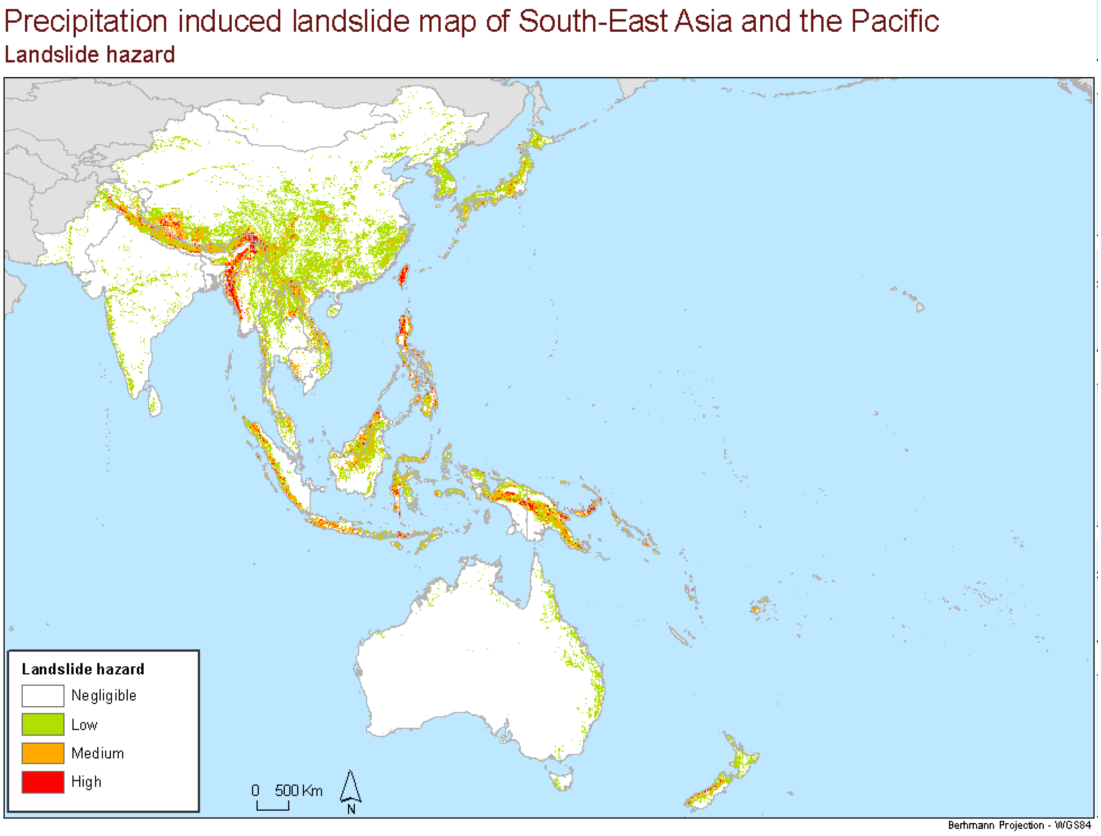
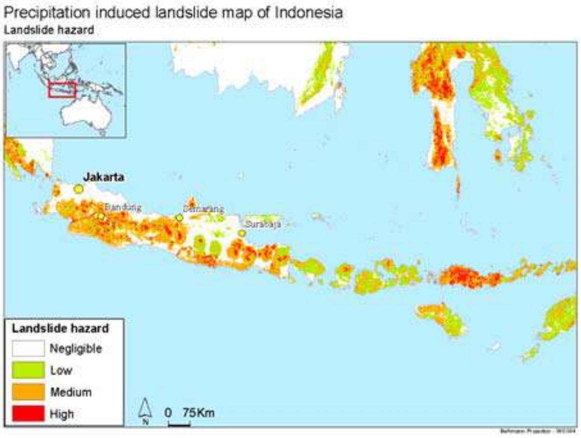
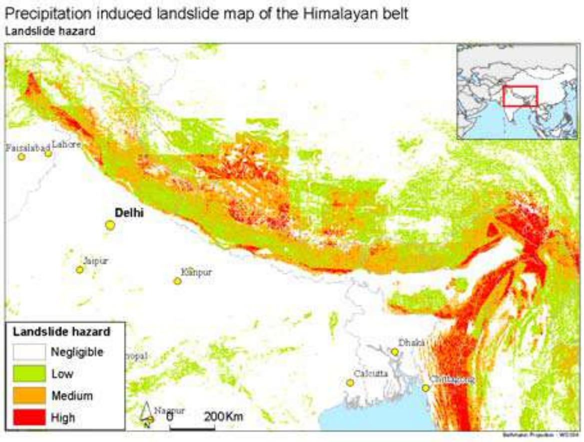


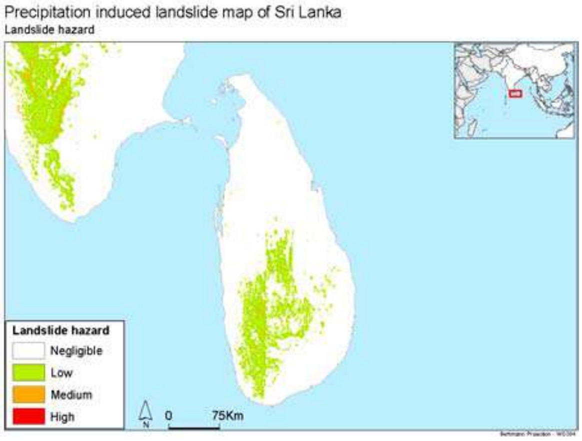
Figure 21. *Hazard classification map for precipitation-induced landslides in Asia-Pacific.*



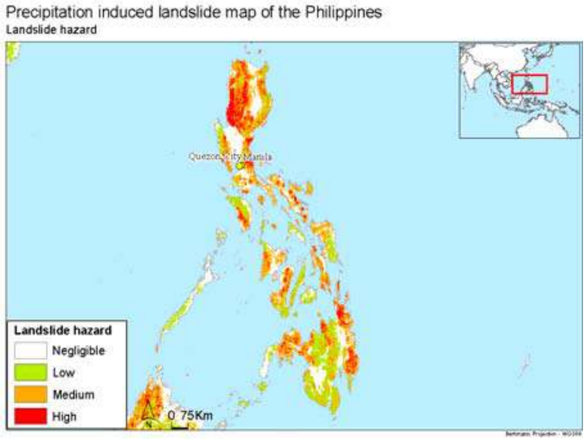
Indonesia



The Himalayan belt



Sri Lanka



The Philippines

Figure 22. Precipitation-induced landslide hazard maps for selected regions of Asia-Pacific.

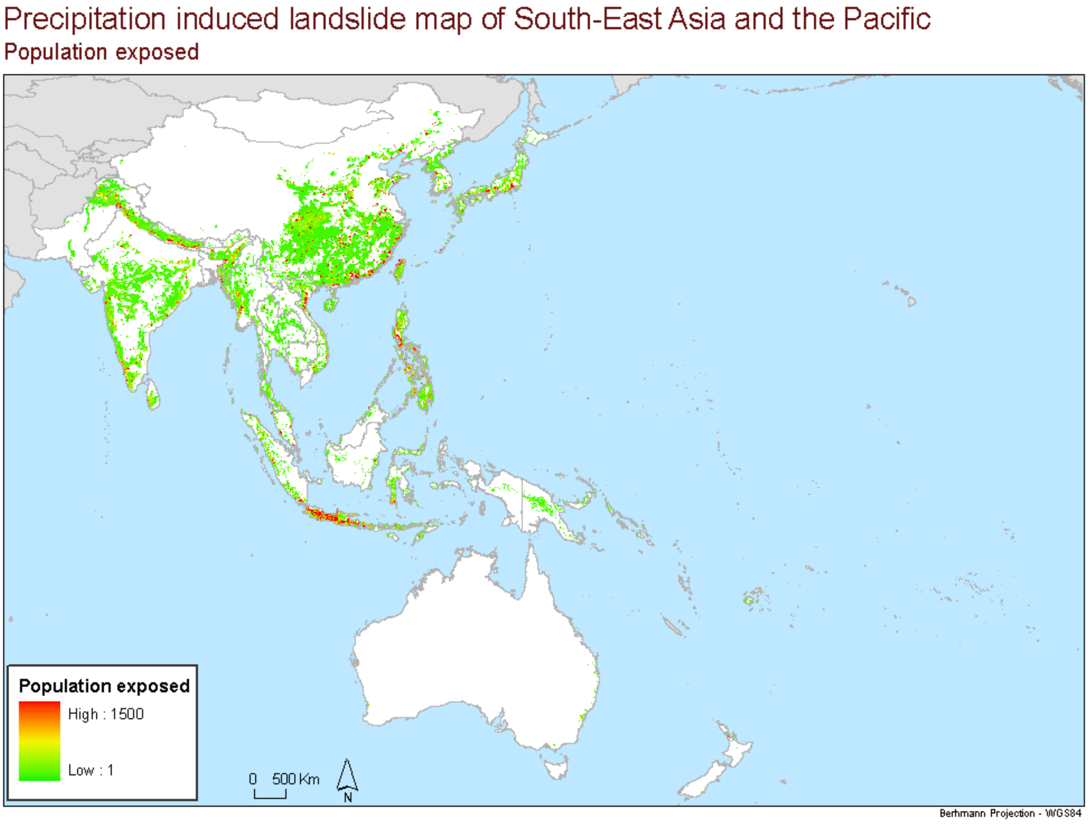
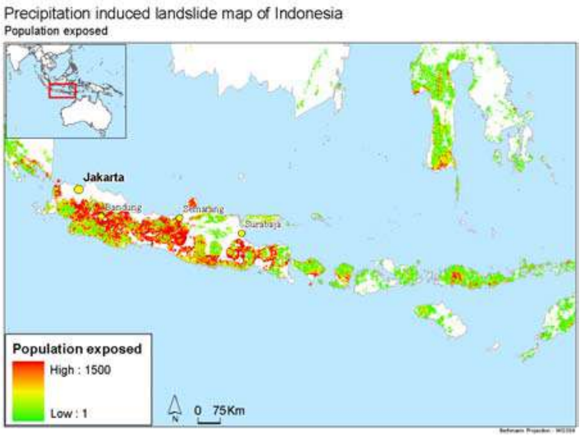
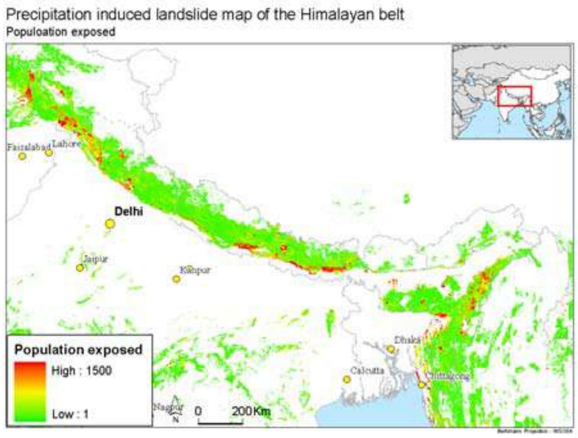


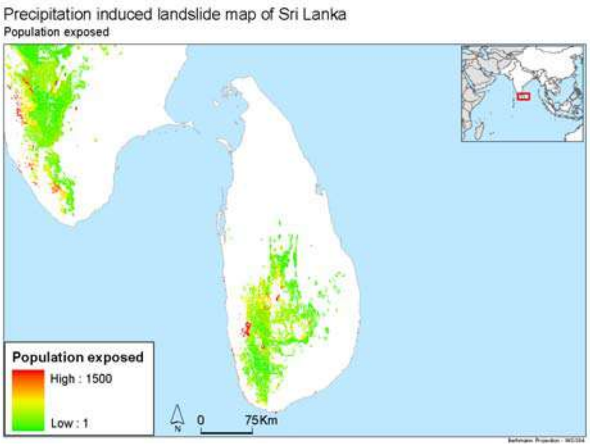
Figure 23. *Population exposed to precipitation-induced landslides (No. of persons per pixel of 30 arc_sec × 30 arc_sec).*



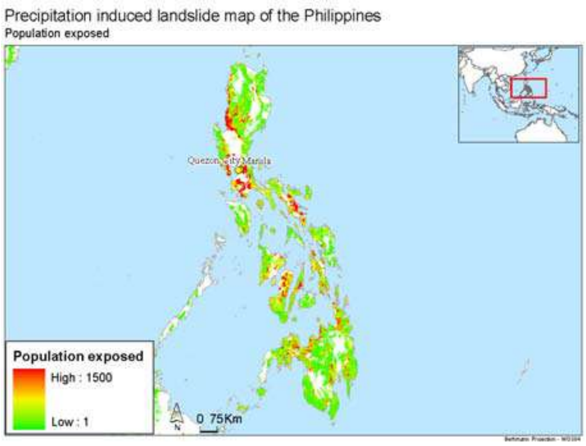
Indonesia



The Himalayan belt



Sri Lanka



The Philippines

Figure 24. Population exposed to precipitation-induced landslides in selected regions of Asia-Pacific.

Landslide risk changes in many regions of Asia-Pacific because of climate change and anthropogenic activities (e.g. growing urbanisation and uncontrolled land use), leading to increased vulnerability of population and infrastructure. It is important to develop risk assessment and management tools and strategies for dealing with the landslide risk at local, regional, and national scales. In a rapidly changing world, these tools should be designed such that they could readily incorporate the effects of global change on the underlying parameters.

7 Drought

Drought is a phenomenon that affects more people globally than any other natural hazard. Unlike aridity, which refers to a semi-permanent condition of low precipitation (desert regions), drought results from the accumulated effect of deficient precipitation over a prolonged period of time. Here "deficient" refers to values being less than the expected, or long-term average value at a particular location. Ultimately, drought refers to a condition of an insufficient supply of water necessary to meet demand, both being highly location-specific. For example, a few months of deficient rainfall can adversely affect rain-fed agricultural systems while several months to a year (or more) of drought may be necessary to impact a water supply system with substantial storage capacity. Given the varying impacts of drought several drought indicators are in use around the world. Details of the drought model(s) used in this project are provided in Appendix D.

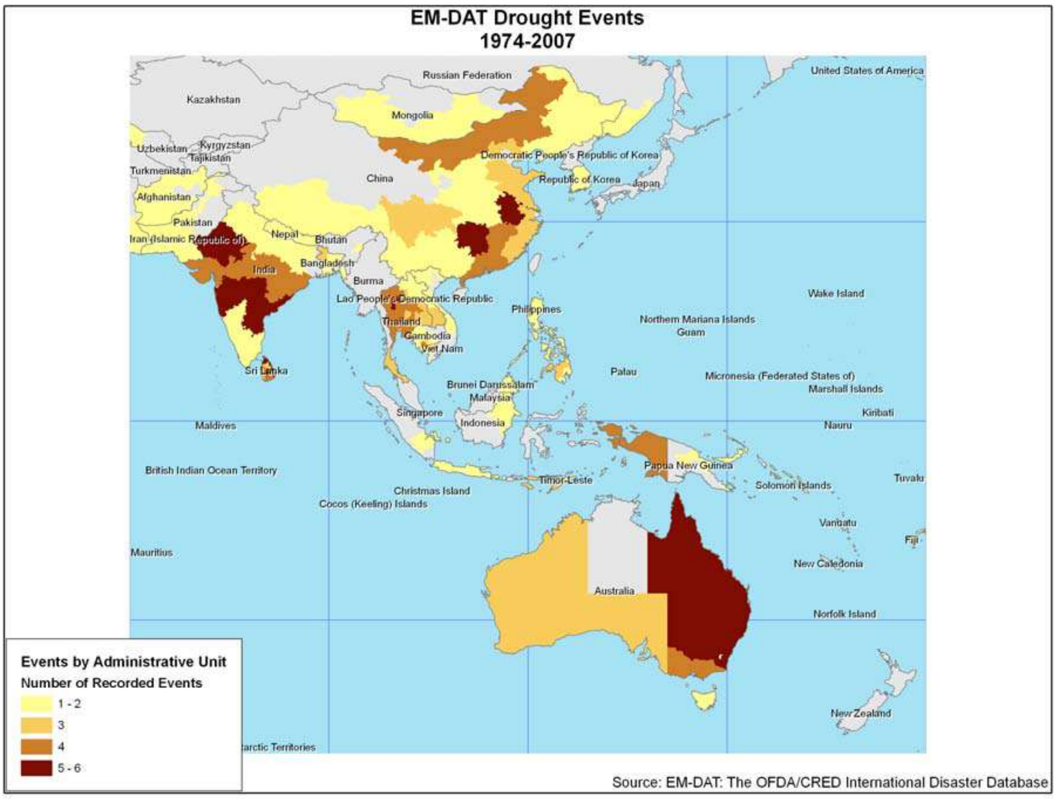
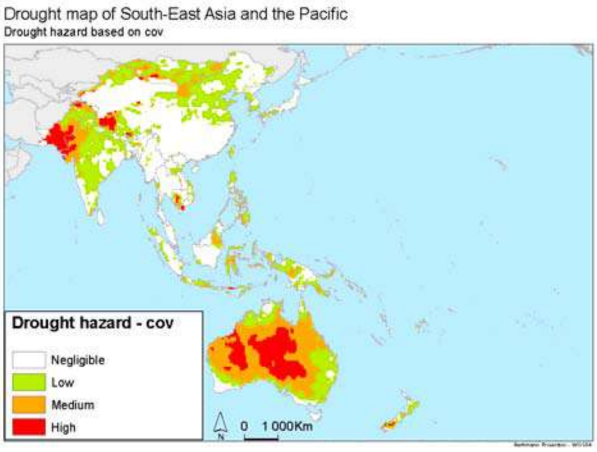


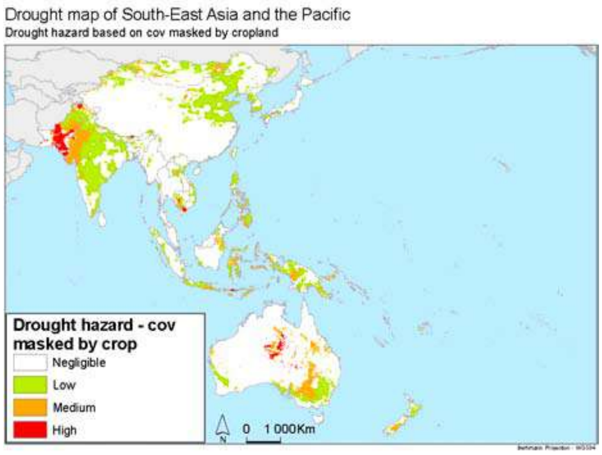
Figure 25. Number of geo-referenced drought disasters recorded in EM-DAT 1974-2004.

Drought is often described as falling into three main categories: *meteorological*, *agricultural*, and *hydrologic*. Meteorological drought refers to a prolonged period of deficient precipitation that may last from a season to several years. Agricultural drought occurs when soil moisture is depleted to the point where it begins to adversely affect crops, pasture, or rangeland. A reduction in soil moisture is in part related to precipitation but also depends on other meteorological conditions such as temperature and wind as well as non-meteorological factors such as soil type and terrain. Hydrologic drought refers to a condition of persistent, below-average surface water levels in rivers, streams, lakes and reservoirs or subsurface water such as an unusually low water table. These conditions are again partially related to precipitation variability but also to non-meteorological factors. Given the importance of non-meteorological factors, there is often a delay between the onset of meteorological drought and agricultural or hydrologic drought. The "best" indicator for drought is the one that most closely corresponds to the specific drought-sensitive application being considered.

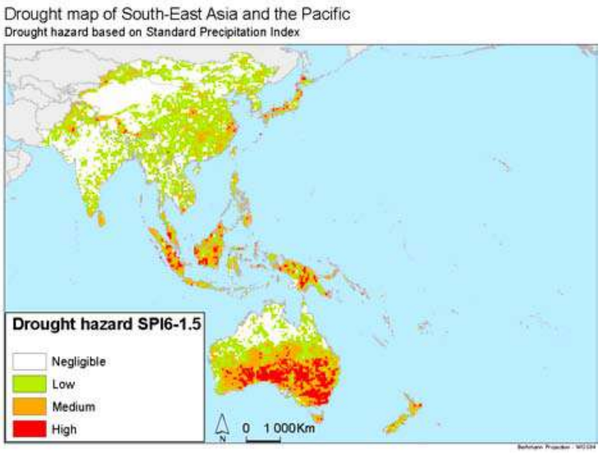
Because of the different definitions of drought, there is no universally agreed-upon method for mapping the drought hazard. Figure 25 shows the number of geo-referenced drought disasters recorded in EM-DAT database during the time period 1974-2004.



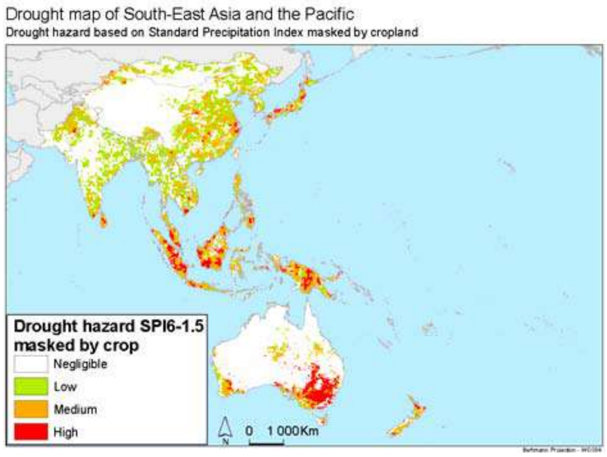
a) *Method I, all areas*



b) *Method I – Agricultural areas and croplands only*



c) *Method II – all areas*



d) *Method II – Agricultural areas and croplands only*

Figure 26. Drought – Hazard classification maps for Asia-Pacific using two different methods.

Figure 26 shows the geographical distribution of drought hazard in the Asia-Pacific region assessed using two different methods. The maps on the left show all areas identified as susceptible to drought hazard, while the areas that are not used for food production are removed from the maps on the right. The map on Figure 26d (designated “Method II – Agricultural areas and croplands only”) was used for estimating the exposed population shown on Figure 27.

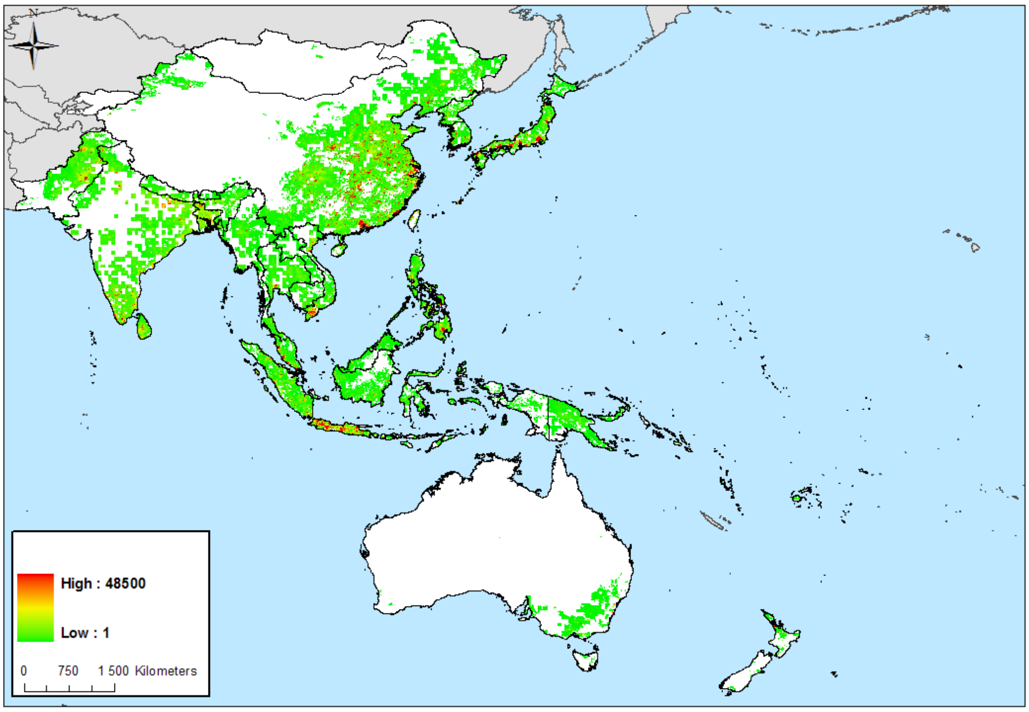


Figure 27. Exposed population to drought (No. of persons per 30 arc_sec × 30 arc_sec pixel, using the map on Fig. 26d for drought hazard).

7.1 Assessment of impact of drought in Asia Pacific

Among natural hazards, drought risk is especially difficult to quantify. First, unlike earthquakes, floods or tsunamis that occur along generally well-defined fault lines, river valleys or coastlines, drought can occur anywhere (with the exception of deserts where it doesn’t have meaning). Defining what constitutes a drought across the wide range of regional climates around the globe is challenging in its own right, identifying what drought characteristic (its intensity, duration, spatial extent) is most relevant to a specific drought-sensitive sector (agriculture, water management, etc.) poses another layer of complexity. Drought does not destroy infrastructure or directly lead to human mortality. Famines may be triggered by drought but increased human mortality during famine is ultimately linked to a broader set of issues surrounding food security. Thus, once a methodology for defining drought is achieved, evaluating mortality risk from drought remains a region-specific challenge.

Despite these challenges, in contrast to other natural hazards drought is a slow onset phenomenon making it particularly amenable to the development of early warning systems. In addition to its slow onset, a major climate factor leading to drought, particularly in tropical locations, is the El Niño-Southern Oscillation (ENSO) phenomenon. Generally speaking, El Niño events are associated with drought across much of Indonesia, India, the Philippines and eastern Australia while also affecting many other regions of the globe. Advances in climate science have made possible skilful seasonal predictions of both ENSO and its associated seasonal rainfall variations with three or more month lead-time. Thus, the combination of real time drought monitoring and availability of seasonal rainfall forecasts constitutes a solid foundation for a drought early warning system.

8 Tsunami

Tsunamis are waves set in motion by large and sudden forced displacements of the sea water, having characteristics intermediate between tides and swell waves. Although tsunamis are infrequent (ca. 5-10 events reported globally pr. year), they do represent a serious threat to the coastal population in many areas, as demonstrated by the devastating effects of the 2004 Indian Ocean tsunami. Tsunamis are often generated by submarine earthquakes. However, submarine landslides are becoming increasingly recognized as important triggers as well. Other sources of tsunamis include collapsing/exploding volcanoes, and asteroid impacts. Tsunamis generated by large earthquakes in subduction zones (area where one continental plate moves beneath another) along the major plate boundaries contribute most to the global tsunami hazard. Details of the tsunami studies done in this project are provided in Appendix E.

When the tsunami is generated, it propagates in the open sea with speeds of several hundred kilometres per hour, and may hence reach coastlines distant from the earthquake within a relatively short time. The wave slows down when it reaches the shoreline, and its height increases. Because of its relatively large wave-length, the tsunami may travel far inland compared to wind waves and swells, and because of its relatively short period, it inundates much faster than tidal waves and storm surges. When the tsunami inundates land, flow velocities become large, enabling the tsunami to carry very large objects, erode the landscape, and destroy buildings. The tsunami becomes lethal due to its impact on structures and flotsam, and its potential for drowning the exposed population. Generally, a tsunami may damage any coastal structure. However, buildings of poor quality are particularly vulnerable. Tsunami is most destructive close to the shoreline where the flow velocity and wave load are largest.

The results of the present study represent a first-pass assessment of the tsunami hazard and population exposure based on today's knowledge. The study considered the tsunamis caused by megathrust earthquakes only, as these events will often contribute more to the risk than the smaller events. Tsunamis caused by landslides, rockslides, and volcanoes were not included in this study.

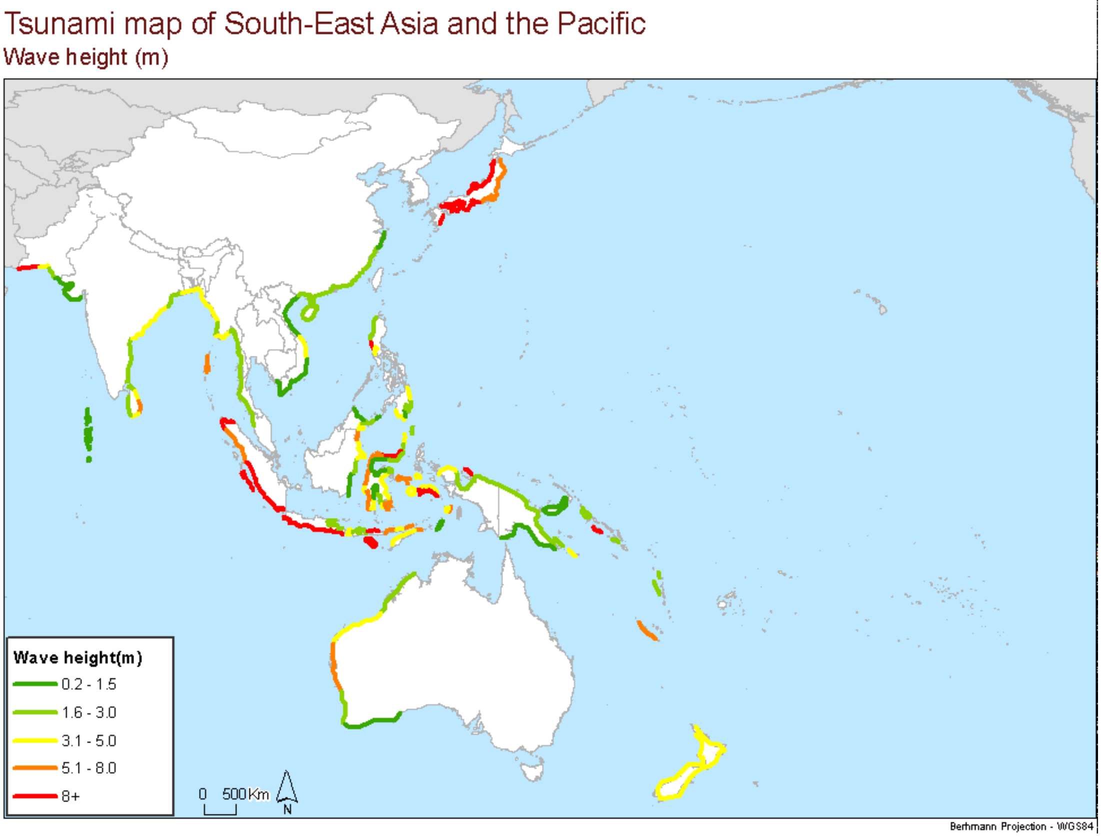


Figure 28. Tsunami hazard map for Asia-Pacific. The legend indicates ranges of the shoreline wave-height. Note: The coastal areas with no tsunami hazard indicated on map mostly represent areas where no data are available.

Similar to the earthquakes, the tsunami events in this study have a probability of occurrence of 10% in 50 years, which implies an expected return period of about 500 years. The results of the study are summarised on Figure 28.

8.1 Assessment of impact of tsunamis in Asia Pacific

Important areas of tsunami generation in Asia Pacific includes the following major subduction zones: the Sundra Arc, ranging from western Indonesia to the Philippines; the Philippine trench; the Manila trench; Makran, south of Pakistan; and the New Guinea trench. Moreover, the coastlines facing the Pacific are all exposed to the far-field tsunamis generated along the so-called “Ring of Fire” located along the perimeter of the Pacific Ocean.

Tsunami hazard is a combination of anticipated wave-height and exposed population within a region. The tsunami hazard map for Asia Pacific is shown in Figure 28. The number of people exposed in each region is listed in Table 2 and depicted in Figure 29. Maximum wave-height of more than 10m was estimated along the coast of Pakistan. These waves are associated with short travel times; hence there is little time for warning. Along the neighbouring shorelines of India the waves are an order of magnitude smaller, posing a smaller hazard. The Bengal Bay and Andaman Sea coastlines show potentially destructive waves of 5-8m at Andaman, Nicobar, Sri-Lanka, and a small section of the Myanmar coast. Almost 3 million people are exposed throughout India, Bangladesh and Myanmar. Indonesia and its 1.5 million exposed inhabitants are subject to the largest anticipated wave heights of 5-20m over large parts of the country. As in Pakistan, early warning is difficult here due to short travel time of the waves. Similarly, a large population could be exposed to high waves in the Philippines. Although large populations are also exposed along the coasts of China and Vietnam, the hazard is marginalized by smaller waves and long travel times. With the exception of New Zealand, population exposure was generally found to be an order of magnitude smaller for Pacific countries.

Table 2: Exposed population to tsunami in Asia-Pacific.

Country	Exposed population in Year 2000	Percent of total population
Australia	13,300	0.07
Bangladesh	1,400,000	1.00
China	720,000	0.06
Fiji	28,000	3.5
Indonesia	1,600,000	0.76
India	1,030,000	0.10
Japan	3,600,000	2.8
Sri Lanka	155,000	0.85
Maldives	22,000	8.0
Myanmar	650,000	1.4
New Caledonia	23,000	11
New Zealand	73,000	1.9
Pakistan	180,000	0.12
Philippines	1,150,000	1.5
Papua New Guinea	1,300	0.02
French Polynesia	850	0.36
Solomon Islands	3,100	0.75
Thailand	11,500	0.02
Tonga	1100	1.1
Vietnam	430,000	0.54
Vanuatu	1,100	0.6
Western Samoa	1,400	0.8

The analysis conducted for Japan was not as extensive as that performed for countries in South Asia, albeit Japan has the largest exposed population. With the exception of New Zealand, an order of magnitude smaller population exposure was generally found for the Pacific countries compared to the larger countries in Asia. However, the smaller island countries generally have a similar or higher percentage of the exposed to the total population.

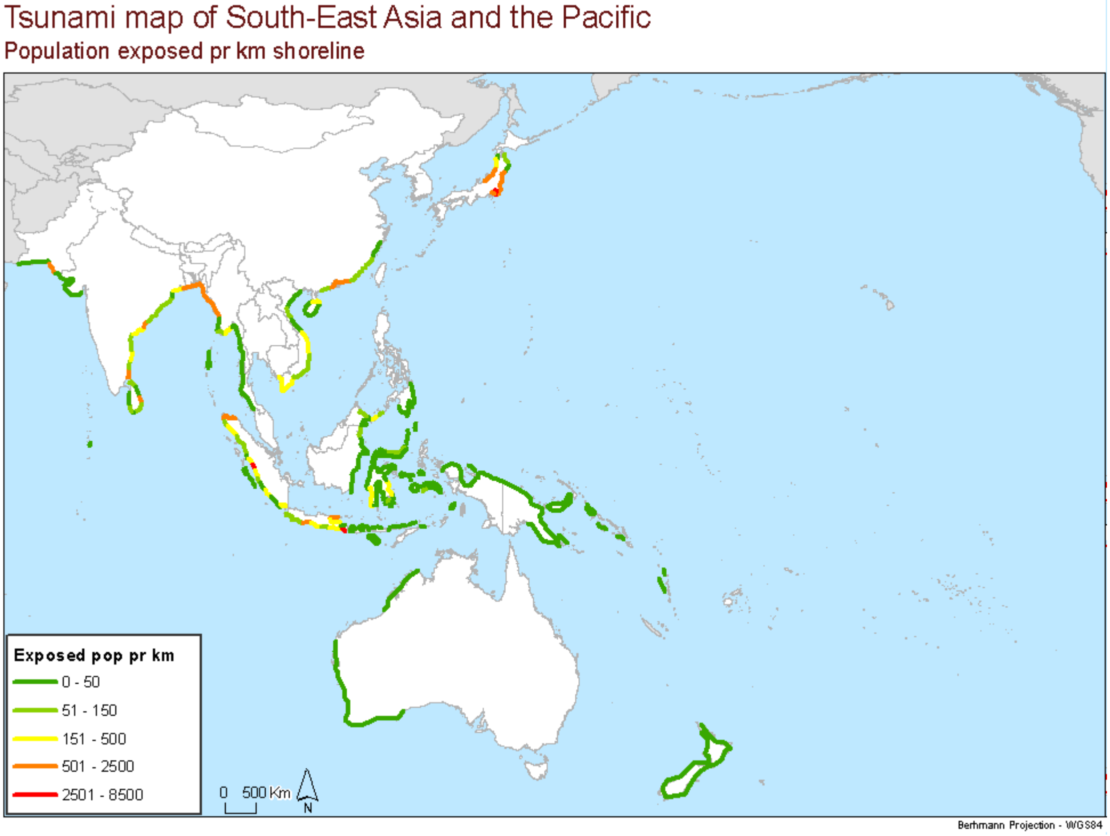


Figure 29. Population exposed to tsunami risk at coastal regions of Asia-Pacific (No. of persons per km length of coastline).

9 Civil Conflict

Only severe armed intrastate conflicts, involving governmental forces and causing at least 25 battle deaths in a calendar year, were considered in the assessment of conflict hazard and population at risk in this study. Based on a benchmark statistical model of conflict propensity at the national level, 23 Asian countries were ranked in terms of estimated likelihood of conflict prevalence. While political, socio-economic and demographic characteristics have some influence on the likelihood of an armed conflict occurring, the overall most important prediction factor is conflict history. Several countries, in particular small-island states in the Pacific, were excluded due to missing data.

The study looked into sub-national variation in conflict propensity for twelve high-priority countries in the region, from which basic population-at-risk maps were generated. Details of the study are provided in Appendix F. Conflict likelihood at the first-order administrative level was estimated for these twelve countries. For some other countries, crucial socio-economic and demographic data were unavailable or inconsistent, while a high-resolution hazard assessment was deemed irrelevant for developed democracies with no recent history of armed intrastate conflict (e.g. Australia, Japan, New Zealand).

Four complementary factors were assumed to affect the local conflict propensity: socio-economic status, ethnic inclusion/exclusion, distance from the capital, and conflict history. A number of country-specific sources (such as national bureaus of statistics and human development reports) as well as international data providers (e.g. CIESIN, Columbia University) were consulted. From these components a relative conflict hazard index was constructed. The relative hazard scores were then joined with the country-level hazard scores to facilitate comparison between countries. The resulting unified sub-national hazard indicator consists of four categories, denoting low, medium, high or very high overall conflict likelihood.

The size of the exposed population in the medium-to-high hazard regions was estimated. While population density is a poor indicator of likely casualty levels if a conflict occurs, it gives some indication of the number of people potentially affected by the conflict.

The results of the study are summarized in Figures 30 through 33.

9.1 Assessment of impact of civil conflict in Asia Pacific

Almost half of all on-going armed intrastate conflicts in the world today are fought in the Asia-Pacific region (Figure 3). While the rest of the world has been experiencing a decline in the number of civil conflicts since the early 1990s, little discernable trend is evident in the Asia Pacific. From 1975 to 2006, the number of civil conflicts in this region has ranged from 11 to 19. The number of countries experiencing armed conflict peaked in 1990 (10) and was at its lowest point in 2002 (5). As with other regions of the world, very few interstate wars have been fought in Asia.

As Figure 30 illustrates, the region is essentially split in two in terms of conflict hazard (the probability in Figure 30 refers to the probability of conflict occurring within a calendar year). The top eight countries are estimated to have a probability of armed conflict that is more than ten times higher than the next country on the list. This significant divide is driven largely by the countries' previous conflict involvement. Six of the top eight countries hosted one or more armed conflict in the last year of observation (2007), while the remaining two countries had just emerged from conflict (Nepal in 2006 and Indonesia in 2005). In contrast, the most recent armed conflict in the sample of low-risk countries ended ten years ago, in 1998 (Cambodia). A large population and low per capita income are other factors that explain the variation in conflict hazard, although the inertia of these features implies that they are better at estimating base-line hazards – i.e. distinguishing between cases – than predicting the timing of conflict outbreak for a given country. One factor that does increase the short-time hazard is irregular regime change (coups, assassination of executive). While this effect is less pronounced than that of conflict history, it nonetheless constitutes a non-trivial hazard that frequently precedes armed intrastate conflict. As a means of forecasting the onset of new armed conflict, irregular regime change serves as a reasonable early warning indicator.

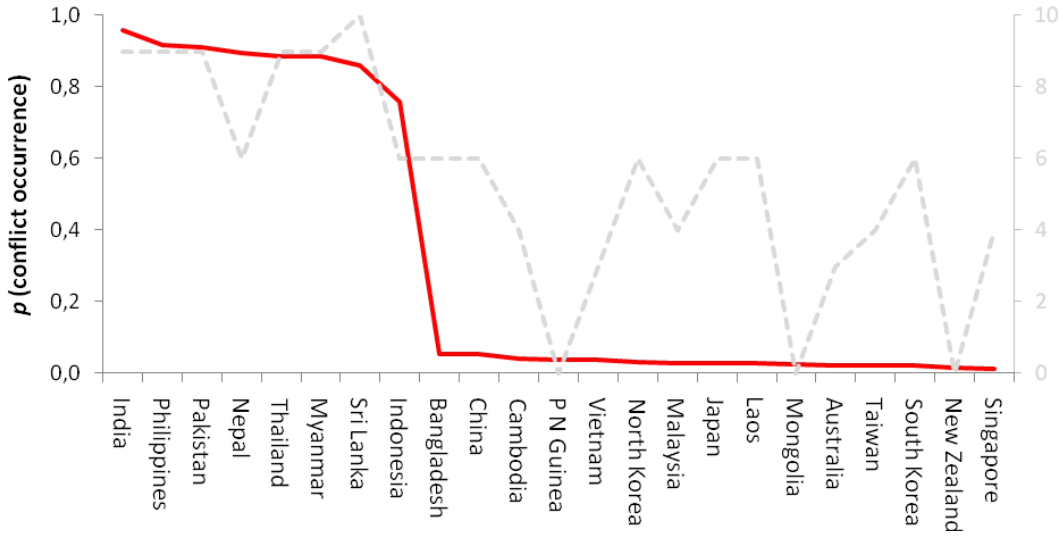


Figure 30. Estimated probability of armed intrastate conflict in 2008. Note: the dotted line, plotted against the right vertical axis, displays the scores from OCHA's assessment of conflict hazard, which also accounts for the intensity of earlier violence (OCHA Global Focus, August 2007).

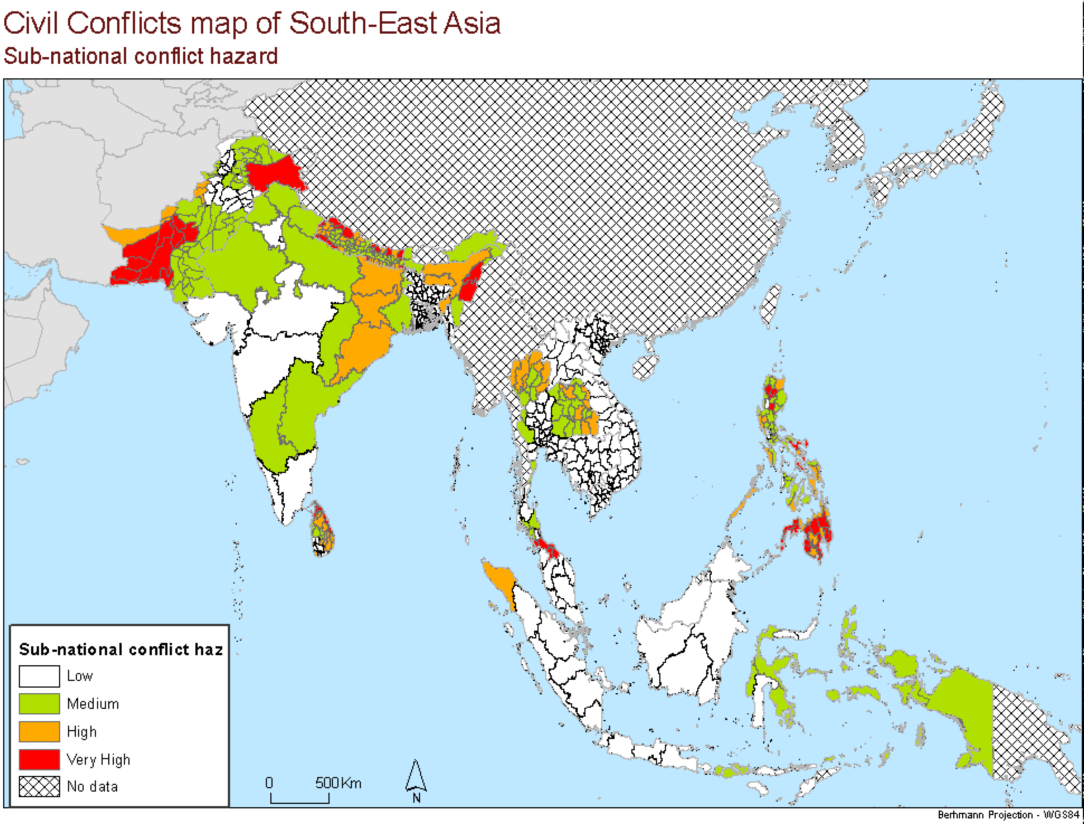
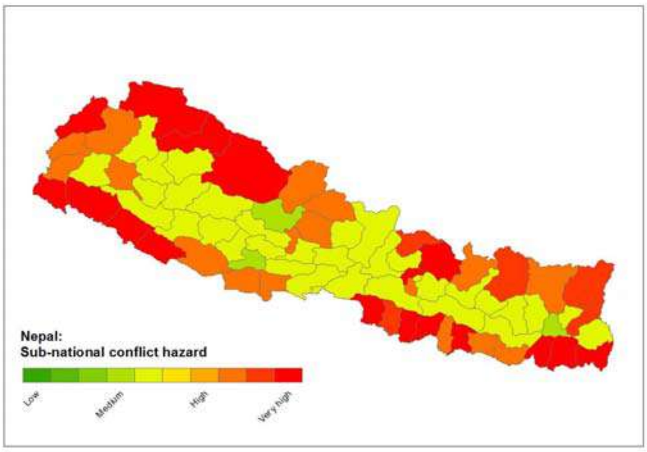
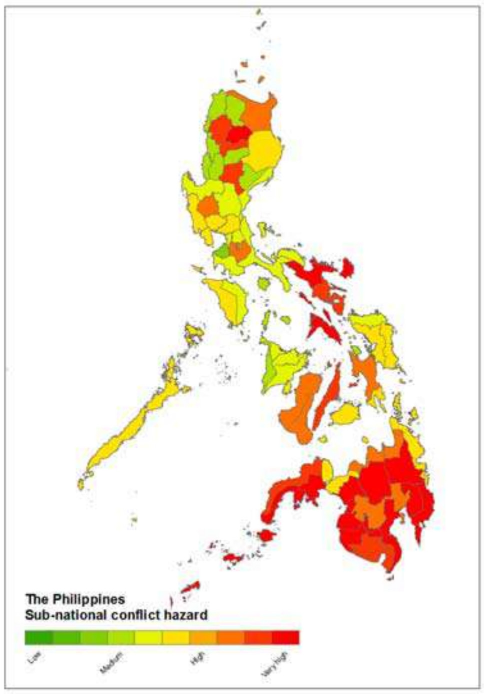


Figure 31. Sub-national distribution of conflict hazard in Asia-Pacific, 2008.



Nepal

Figure 32. Sub-national distribution of conflict hazard in Nepal (above) and the Philippines (right) in 2008.



The Philippines

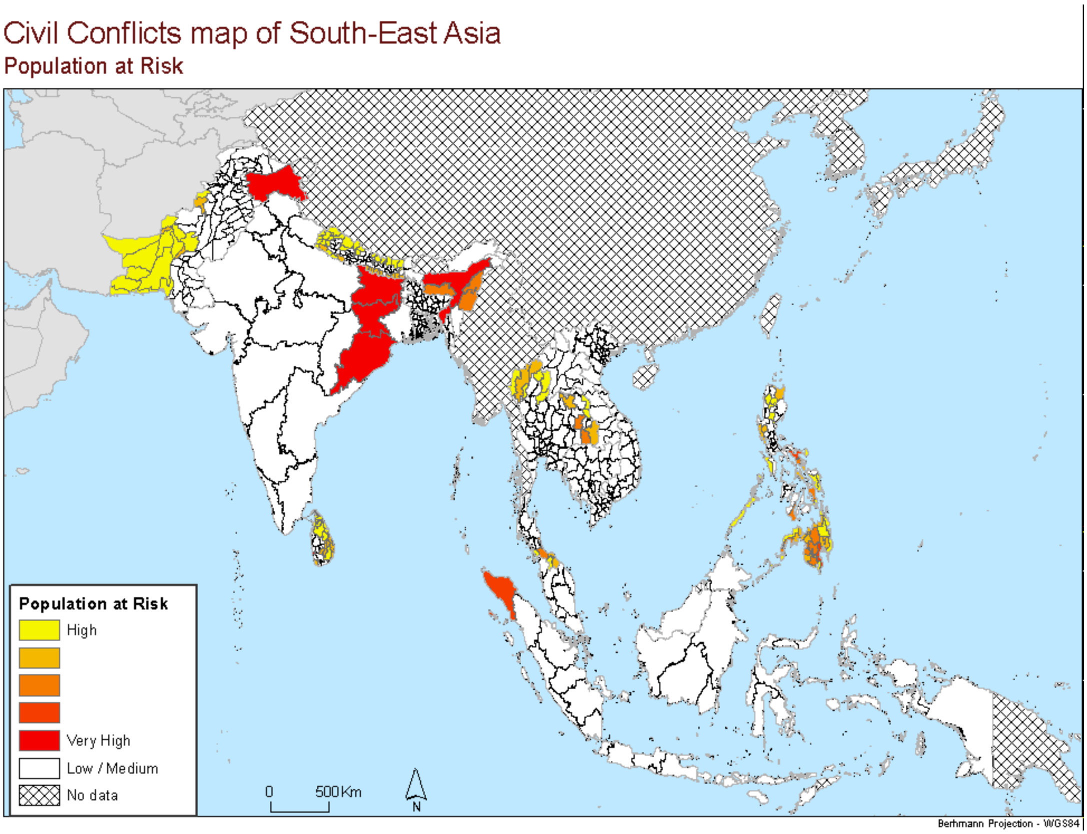


Figure 33. Population-weighted hazard map in high-to-very-high conflict hazard regions, 2008.

Figure 31 shows the sub-national distribution of conflict hazard in the study region (Figure 31 is based on Figure F3 of Appendix F, where the 10 hazard categories in Fig. F3 are converted to 4 hazard categories). Details for Nepal and the Philippines are shown on Figure 32. Most of the twelve countries that are exposed to the risk of armed conflict have considerable sub-national variation in conflict likelihood. India, in particular, displays high internal variation in conflict hazard, with violence being very likely in the northwest and northeast but much less so in central parts of the country. This reflects the long-lasting separatist conflicts in Kashmir, Assam, Manipur, and Nagaland, as well as the Naxalite rebellion around Chhattisgarh, Jharkhand, and Andra Pradesh. Of course, low-conflict hazard areas are also vulnerable, as was evident in November 2008 in Mumbai. However, the explicit targeting of civilians rather than governmental bodies means that this event falls outside the definition of armed conflict applied in this study. Recent conflict history, peripheral location, and local dominance of minority groups also explain the high likelihood of violence in the predominantly Muslim southern provinces of Thailand. In Nepal, the conflict hazard is highest among the border districts, most of which are economically marginalized and contain politically excluded populations. This reflects parts of the area where the Maoist rebellion took place, although the conflict was most widespread in the mid-western interior.

Figure 33 shows the geographical distribution of the exposed population in the medium-to-high hazard regions. For simplicity, the map in Figure 33 distinguishes merely between regions with above-average population density and those that are less densely populated, but the underlying data can be displayed in various fashions depending on purpose. Orange regions represent medium to high conflict hazard and below-average population density, whereas red denotes high conflict hazard and high population density. This procedure highlights the high-priority areas where more people are at risk.

The difference between conflict hazard (Figure 31) and conflict risk (Figure 33) is clearly illustrated by the case of Nepal. Most rural border districts have high conflict hazard due to adverse socioeconomic and cultural characteristics and a recent history of conflict. However, many of these districts, in particular those in the northern Himalayan region, are sparsely populated so the number of high-risk areas is substantially lower.

10 Interaction between Natural Disasters and Armed Conflict

A number of contemporary events suggest that severe natural disasters influence the risk and dynamics of conflict, and likewise, that armed conflicts affect societal vulnerability to disasters. Some of the most deadly disasters in recent years have occurred in regions with long-lasting conflict, including the 2004 Indian Ocean tsunami (Indonesia and Sri Lanka), the 2005 Kashmir earthquake (Pakistan and India), and the 2008 tropical cyclone *Nargis* (Myanmar). While conflict indirectly may have contributed to the high death tolls in all these cases, the impact of the disasters on the conflicts differed considerably.

The complex connection between natural disasters and armed conflict is still poorly understood. Most systematic research on the topic focuses on how disasters affect the country-level probability of conflict outbreak. While results indicate that civil war is somewhat more likely in the wake of disaster, the limited number of cases bodes against statistical robustness. Moreover, the mechanisms whereby a natural disaster translates into an elevated risk of conflict are yet to be identified, although loss of livelihoods, population displacement, collapse of local infrastructure, and insufficient relief response are plausible intermediate factors.

A less studied but equally important connection concerns the influence of disasters on ongoing conflict, how they affect the character, duration, and outcome of the violence. The radically different outcomes of the conflicts in Ache, Indonesia and Tamil territories in Sri Lanka in the aftermath of the 2004 Indian Ocean tsunami clearly demonstrate the non-deterministic nature of this connection. While the peace process in Ache was well underway prior to the tsunami, there is little doubt that the disaster boosted the prospects for a lasting peace. Conversely, massive human and material destruction on Sri Lanka did little to halt the fighting and the violence has since escalated.

Natural and man-made disasters may also be connected in a third way, whereby armed conflict increases the vulnerability of societies to natural disasters. For example, the drought in Ethiopia in the early 1980s lead to a disastrous famine that is usually blamed on the Derg regime's unwillingness to assist the population in rebel-held areas. International aid operations in post-tsunami Sri Lanka were also complicated by the *de facto* system of parallel governments in Tamil-controlled parts of the country.

A number of important factors found to increase the conflict propensity of states, such as poverty, weak political institutions, and high population, also influence disaster resilience and states' ability to effectively conduct relief operations. Indeed, parts of the developing world are struggling to break out of a vicious cycle of natural and man-made disasters – each phenomenon increasing the propensity for the other.

11 Coping capacity

The notion of coping capacity designates the ability of a group of individuals to address the risks related to an adverse event, be it before, during or after its occurrence. Obviously, this ability has a strong influence on the eventual impact of natural and man-made disasters.

One of the aims of this study was to develop a method for measuring coping capacity, so that it could be combined with the usual components of risk, i.e. hazard characteristics, exposure and vulnerability, and provide a better understanding of the actual level of risk that people are facing. The working definition of coping capacity in this study attempted to cover all institutional means to protect and support individuals and communities facing the risk of a disaster. This "institutional coping capacity" is not covered by common measures of vulnerability.

The institutions that deal with disaster risk reduction and disaster situations can operate at local, regional, national or international levels. A rigorous assessment of coping capacity should consider all these levels. In this study, only the national level institutions were considered (see Appendix G for details). As a consequence, it was not possible to account for sub-national differences.

To estimate the components of coping capacity, one can then either use existing indicators and data, or set up field surveys. Choosing one option rather than the other is a matter of weighing the loss of accuracy related to the use of proxies against the cost and limitations of collecting information *ad hoc*. A combination of both approaches was used in the present study. The questionnaire that was designed for this study considered ten components of coping capacity (see Appendix G):

- Hazard evaluation
- Consequence and vulnerability assessment
- Awareness-raising activities
- Sectoral regulations
- Structural defences
- Continuity planning
- Early warning
- Emergency response
- Insurance and disaster funds
- Reconstruction and rehabilitation planning.

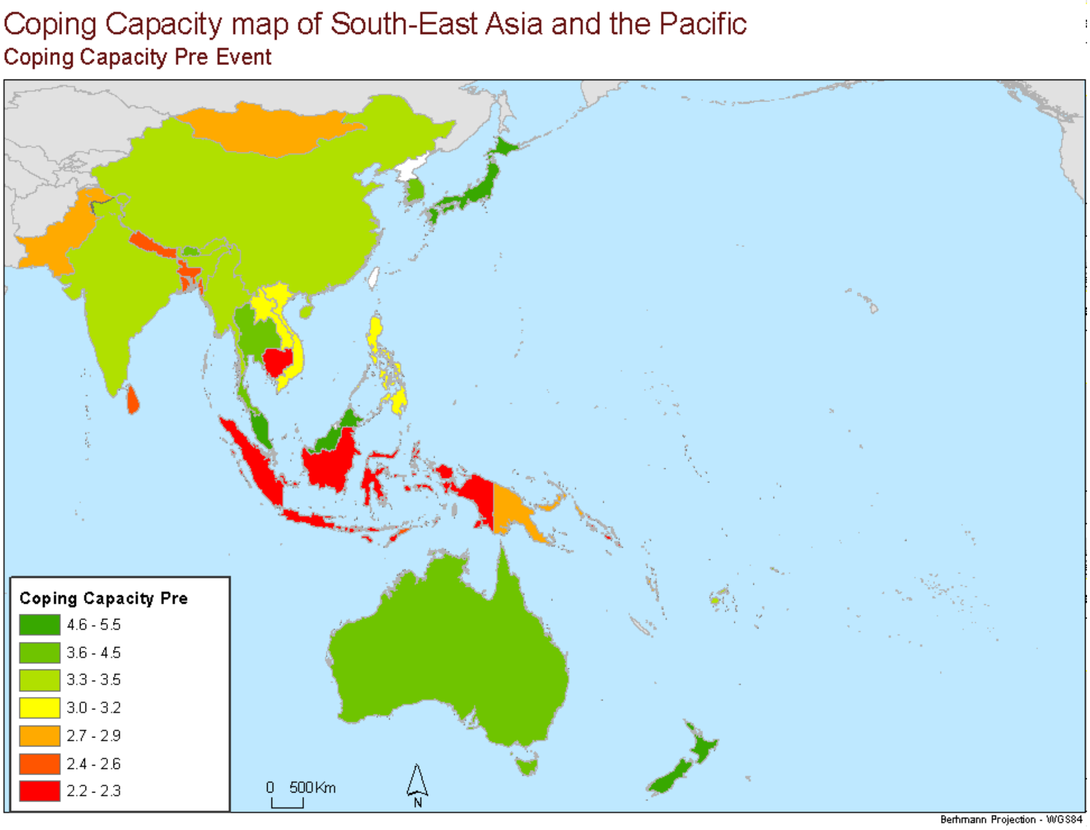


Figure 34. Computed pre-event coping capacity index for countries in Asia-Pacific (higher values indicate greater coping capacity).

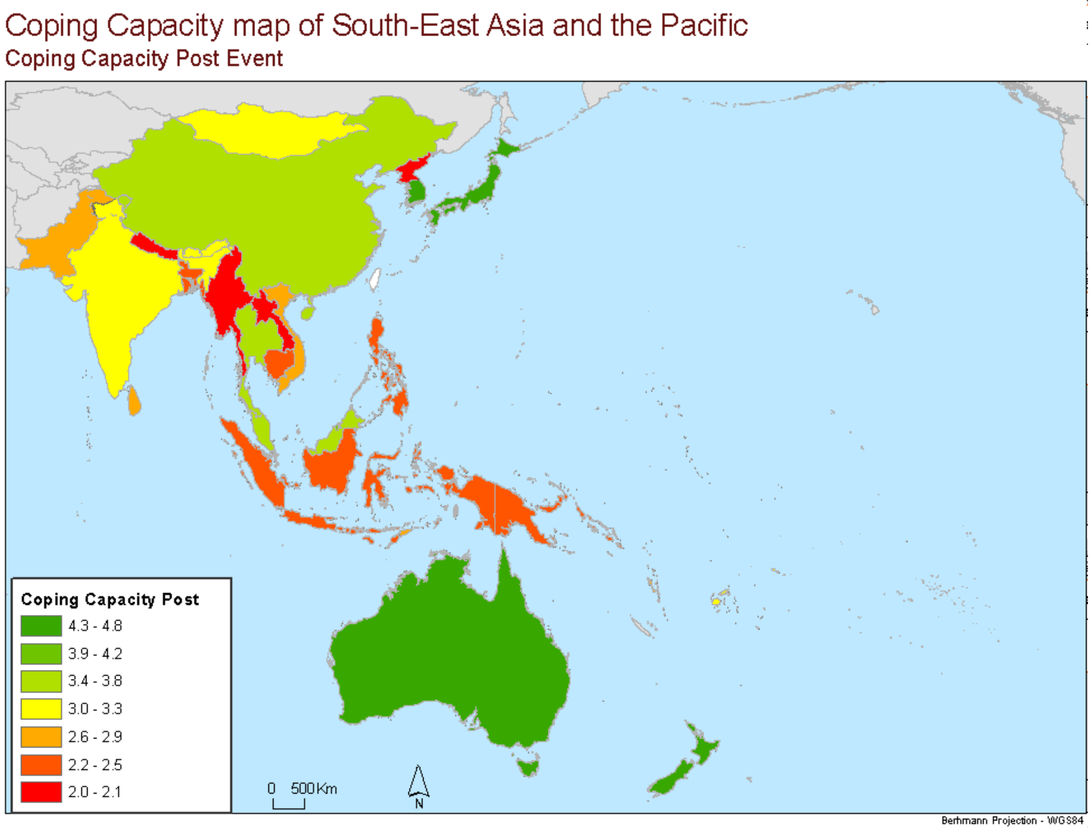


Figure 35. Computed post-event coping capacity index for countries in Asia-Pacific (higher values indicate greater coping capacity).

In principle, the coping capacity depends on the specific circumstances of a risk. For instance, a country might be well equipped to address frequent medium-sized events, but totally unprepared to face a low-probability large-scale event. Or it can have particular instruments (international agreements, warning mechanisms, etc.) to face one type of disaster and none for other types. However, it is reasonable to assume that some of the factors affecting coping capacity are constant across hazards. The quality of the legal and regulatory framework, for instance, is probably a reliable gauge of a country's ability to prevent and mitigate all natural disaster risks through the law.

To develop hazard-specific coping capacity indices, the results of the questionnaire would have been required for most countries in the study region. By the time the study was concluded, however, filled- questionnaires were available for only a handful of countries. Therefore, the combined index of coping capacity evaluated for this study focused on the factors that are constant across hazards at national level. The computed coping capacity index varied from 2.06 to 4.83 (higher values indicating higher coping capacity) for the Asia-Pacific countries. Figures 34 through 36 show the variation of the coping capacity index in the study area on a national level. The computed values of the coping capacity index are listed in Table 3.

Table 3. Computed coping capacity indicators for Asia-Pacific countries.

Country	Aggregate indicator	Pre-event indicator	Post-event indicator
Australia	**4.7**	4.5	4.8
Bangladesh	**2.5**	2.6	2.4
Bhutan	**3.3**	3.9	3.0
Brunei Darussalam	**4.2**	0.0	4.2
Cambodia	**2.3**	2.3	2.4
China	**3.6**	3.5	3.7
Fiji	**3.3**	3.5	3.3
India	**3.2**	3.3	3.2
Indonesia	**2.3**	2.2	2.5
Japan	**4.8**	5.0	4.7
Kiribati	**2.9**	3.4	2.7
Korea, Dem People's Rep.	**2.1**	0.0	2.1
Korea, Republic of	**4.4**	4.5	4.4
Lao People's Democratic Republic	**2.4**	3.0	2.1
Malaysia	**4.1**	5.0	3.6
Maldives	**3.5**	3.3	3.7
Marshall Islands	**2.8**	0.0	2.8
Micronesia (Federated States of)	**3.2**	0.0	3.2
Mongolia	**2.9**	2.8	3.1
Myanmar	**2.5**	3.5	2.0
Nepal	**2.3**	2.5	2.1
New Zealand	**4.8**	5.5	4.4
Pakistan	**2.7**	2.7	2.7
Palau	**4.0**	0.0	4.0
Papua New Guinea	**2.4**	2.8	2.3
Philippines	**2.8**	3.2	2.5
Samoa	**3.4**	4.0	3.0
Singapore	**4.5**	0.0	4.5
Solomon Islands	**2.3**	2.3	2.3
Sri Lanka	**2.6**	2.5	2.6
Thailand	**4.0**	4.5	3.8
Timor-Leste	**2.6**	2.5	2.6
Tonga	**2.9**	2.5	3.1
Vanuatu	**2.8**	2.9	2.8
Viet Nam	**3.0**	3.0	2.9

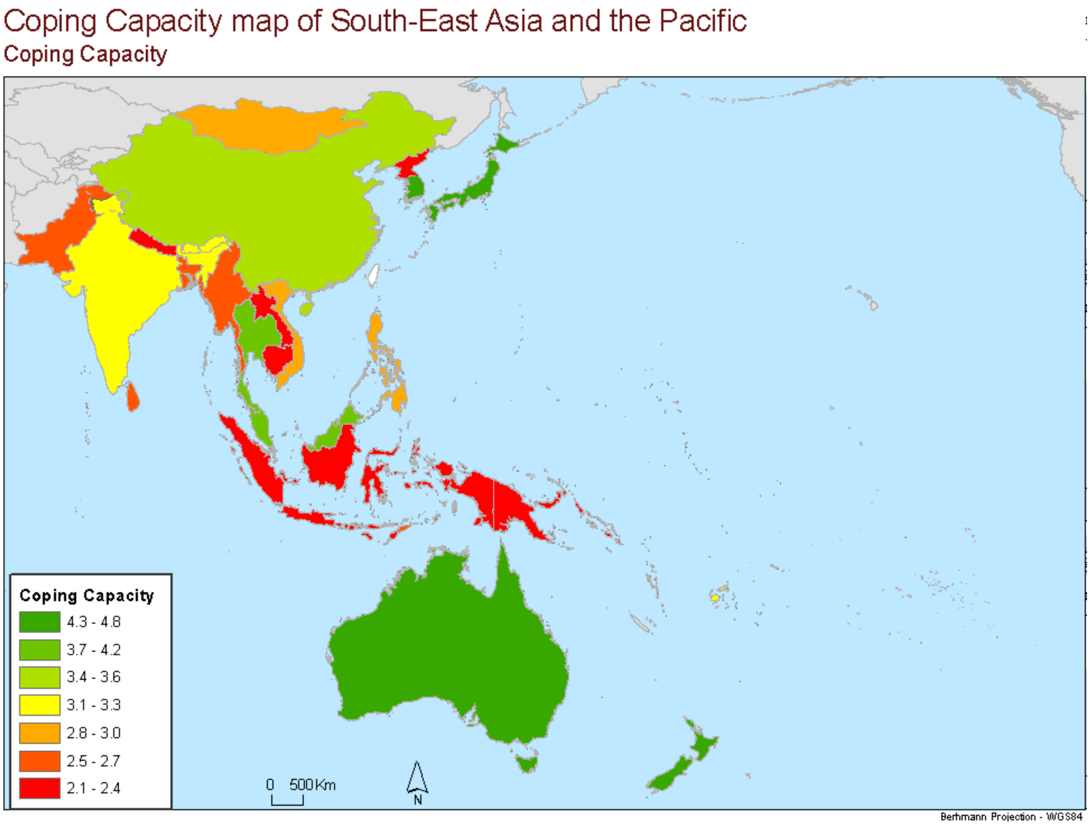


Figure 36. Computed aggregate coping capacity index for countries in Asia-Pacific (higher values indicate greater coping capacity).

12 Risk index for countries in study area

Appendix H provides the description of the Risk Index developed in this study. Seven hazards were considered in the calculation of the risk index: river flood, earthquake, tropical cyclone (including storm surge), drought, precipitation-induced landslide, tsunami and civil conflict. The index, directly or indirectly, accounts for percent of population exposed to different natural hazards and civil conflict, vulnerability, and coping capacity.

For each country in the study area, the equivalent population exposed to each hazard was defined as 100% of the population living in Hazard Category 3, plus 30% of the population living in Hazard Category 2, plus 10% of the population living in Hazard Category 1. For landslides, which have a limited spatial extent even within a pixel of 30 arc_sec ×30 arc_sec, and for civil conflict, which is impossible to resolve spatially to the same resolution as natural hazards, a correction factor of 0.10 was applied to the equivalent exposed population.

Table 4. Risk Index with same weighting factor for all hazards

Country	Risk Index
Bangladesh	9.7
Philippines	9.3
Indonesia	7.2
Myanmar	6.4
Nepal	6.2
Papua New Guinea	5.3
Japan	5.2
Pakistan	5.1
Bhutan	3.8
Sri Lanka	3.6
Malaysia	3.5
New Zealand	3.5
Viet Nam	3.1
Dem People's Rep of Korea	2.6
Cambodia	2.5
Thailand	2.2
India	2.1
China	2.0
Timor-Leste	1.9
Lao People's Democratic Republic	1.9
Brunei Darussalam	1.8
Republic of Korea	1.7
Australia	1.2
Maldives	1.2
Singapore	0.9
Mongolia	0.8
Island nations of the Pacific	**Risk Index**
Micronesia (Federated States of)	10.7
Vanuatu	7.8
Solomon islands	6.0
Samoa	4.7
Palau	4.5
Tonga	4.4
Fiji	4.2
Nauru	3.2
Kiribati	2.3
Tuvalu	2.3

Table 5. Risk Index with varying weighting factor for different hazards

Country	Risk Index
Bangladesh	11.0
Philippines	10.9
Myanmar	8.0
Nepal	6.5
Indonesia	6.3
Japan	5.9
Papua New Guinea	5.1
Pakistan	5.1
Bhutan	4.0
New Zealand	3.2
Sri Lanka	3.0
Dem People's Rep of Korea	2.9
Viet Nam	2.9
Malaysia	2.4
India	2.1
Timor-Leste	2.1
Republic of Korea	2.0
Lao People's Democratic Republic	2.0
Thailand	1.9
China	1.8
Brunei Darussalam	1.5
Cambodia	1.5
Marshall Islands	1.4
Maldives	1.3
Australia	1.1
Singapore	0.9
Mongolia	0.8
Island nations of the Pacific	**Risk Index**
Micronesia (Federated States of)	13.0
Vanuatu	10.1
Solomon islands	7.2
Palau	7.0
Fiji	5.9
Samoa	5.8
Tonga	5.5
Nauru	3.5
Kiribati	2.5
Tuvalu	2.5

The calculation of the Risk Index involves assigning weighting factors (importance factors) by the user to the different hazards. Tables 4 and 5 show the values of the Risk Index computed for the countries in the study area using two different sets of weighting factors. For the values shown in Table 4, the same weighting factor was applied to all natural hazards and civil conflict. Table 5 shows the results for the following weighting factors: flood = 1, earthquake = 2, drought= 1, tropical cyclone = 3, landslide = 1, tsunami = 2 and conflict = 2.

The computed Risk Index is not very stable for the island nations of the Pacific because of their small size and population. These island nations should not be directly compared with the other nations in the study area.

Tables 6 through 10 summarise the spatial extent, exposed population and recorded fatalities for different natural hazards and civil conflict in Nepal, Sri Lanka, Pakistan, Indonesia and the Philippines. The following points should be noted about these tables:

- Except for tsunamis, the equivalent exposed population to risk from natural hazards was computed as 100% of people living in high hazard areas, plus 30% of people living in medium hazard areas, plus 10% of people living in low hazard areas.
- For tsunami, the exposed population was defined as all people living in the coastal areas inundated by the tsunami heights shown on Figure 29.
- It should be noted that the resolution of hazard maps for conflict are at the first-order administrative level.
- For landslides, only precipitation-induced landslides were considered. The fatalities (and risk) caused by earthquake-induced landslides are included in earthquake. To account for the limited spatial extent of a landslide, only 10% of the total population living in the slide-prone regions were considered in the calculations.
- The fatality data for natural hazards are taken from the EM-DAT database.
- Fatalities due to civil conflict are based on PRIO Battle Death data 1980-2005, and UCDP Battle Death data 2006-07. Battle death data for Pakistan are not available.
- The values of exposed population to tsunami hazard listed in Table 2 are based on the population data from the Year 2000. The exposed population values listed in Tables 6 through 10 account for population changes from 2000 to 2007.

Table 6. Nepal – Hazard and exposure profile (Total population: 28,278,000 – Total area: 147,900 km²)

Threat	No. of people exposed		Areal extent of high & med. hazard categories, km²	% of total country area	Fatalities (1980 – 2007)
	Equivalent exposed population	% of total population			
Cyclone	0	0	0	0	97[1]
Flood	97,300	< 1	2,000	1.4	5481
Earthquake	8,515,000	30.0	147,900	100	809
Landslide	40,585	< 1	116,700	79	1578
Drought	709,500	2.50	26,500	18	0
Tsunami	0	0	-	-	-
Armed conflict	10,294,000	36	87,200	59	11,228
Coping Capacity: Low					

[1] Fatalities caused by storm events are included in this value.

Table 7. Sri Lanka – Hazard and exposure profile (Total population: 19,076,500 – Total area: 66,000 km²)

Threat	No. of people exposed		Areal extent of high & med. hazard categories, km²	% of total country area	Fatalities (1980 – 2007)
	Equivalent exposed population	% of total population			
Cyclone	290,700	1.5	27,830	42	754
Flood	28,800	< 1	1,730	3	1,695[1]
Earthquake	0	0	0	0	0
Landslide	4,170	< 1	10,420	16	119
Drought	2,882,000	15	25,900	39	0
Tsunami	158,000	< 1	-	-	35,399
Armed conflict	4,345,000	23	42,000	64	64,271
Coping Capacity: Low					

[1] Includes fatalities due to storm surge.

Table 8. Pakistan – Hazard and exposure profile (Total population: 163,350,000 – Total area: 879,200 km²)

Threat	No. of people exposed		Areal extent of high & med. hazard categories, km²	% of total country area	Fatalities (1980 – 2007)
	Equivalent exposed population	% of total population			
Cyclone	2,246,000	1.4	59,500	7	1,446
Flood	292,000[1]	< 1	23,200[1]	3	10,336[1]
Earthquake	36,253,000	22	879,000	100	78,812
Landslide	23,850	< 1	94,200	11	579
Drought	15,071,000	9.2	198,500	22	143
Tsunami	203,700	< 1	-	-	0
Armed conflict	6,357,000	3.9	315,900	36	No data
Coping Capacity: Low					

[1] Includes storm surge.

Table 9. Indonesia – Hazard and exposure profile (Total population: 219,465,000 – Total area: 1,903,600 km²)

Threat	No. of people exposed		Areal extent of high & med. hazard categories, km²	% of total country area	Fatalities (1980 – 2007)
	Equivalent exposed population	% of total population			
Cyclone	47,300	< 1	2,100	0.1	1,692
Flood	469,000	< 1	4,850	0.3	6,919[1]
Earthquake	58,652300	27	1,847,100	97	13,435[2]
Landslide	216,620	< 1	899,000	47	1,816
Drought	47,043000	20	526,500	28	1,329
Tsunami	1,660,000	< 1	-	-	166,000[2]
Armed conflict	433,000	< 1	57,170	3.0	6,597
Coping Capacity: Low					

[1] Includes storm surge.
[2] EM-DAT lists 179,435 fatalities for earthquakes, which includes tsunamis. It is estimated that about 166,000 are due to tsunamis.

Table 10. The Philippines – Hazard and exposure profile (Total population: 88,323,000 – Total area: 297,200 km^2)

Threat	**No. of people exposed**		**Areal extent of high & med. hazard categories, km^2**	**% of total country area**	**Fatalities (1980 – 2007)**
	Equivalent exposed population	% of total population			
Cyclone	15,658,000	18	193,500	65	29,054
Flood	773,000[1]	< 1	5,400[1]	2	31,885[1]
Earthquake	25,748,000	29	297,200	100	8,569
Landslide	126,240	< 1	199,800	67	2,646
Drought	9,490,000	11	143,000	48	8
Tsunami	1,333,000	1.5	-	-	102
Armed conflict	24,116,000	27	188,800	64	47,297
Coping Capacity: Average					

[1] Includes storm surge.

13 Recommendations for risk mitigation measures

Mitigation and prevention of the risk posed by natural hazards have not attracted widespread and effective public support in the past. However, the situation has changed dramatically during the past decade, and it is now generally accepted that a proactive approach to risk management is instrumental in significantly reducing the loss of lives and material damage associated with natural hazards. The wide media attention on major natural disasters during the last decade has clearly changed people's mind in terms of acknowledging risk management as an alternative to emergency management.

A milestone in international collaboration for natural disaster risk reduction was the approval of the "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters" (ISDR 2005). This document, which was approved by 164 UN countries during the World Conference on Disaster Reduction in Kobe, January 2005, clarifies international working modes, responsibilities and priority actions for the coming 10 years. The Hyogo Framework of Actions states three fundamental principles:

- Each nation has the prime responsibility for preventive measures to reduce disaster risk, and is expected to take concrete actions as outlined in the Action Plan.
- Governments in risk exposed countries shall regularly report progress achieved to the UN coordinating unit which is the ISDR Secretariat with headquarters in Geneva.
- International cooperation is called upon to assist countries that need help.

The Hyogo Framework of Action has clearly increased the awareness and importance of preventive measures. It will also contribute to a much better practice for the implementation of risk reduction projects for two reasons: a) by the fact that governments will be in the driving seat, which means that coordination is likely to be improved and b) the fact that ISDR, given the responsibility for the follow-up of the plan, will put pressure for action from countries that are most exposed. Few, if any, of the developing countries have the resources or capacity to implement mitigation measures.

One can observe a positive trend internationally where preventive measures are increasingly recognized, both at the government level and among international donors. There is, however, a great need for intensified efforts, because the risk associated with natural disasters clearly increases far more rapidly than the efforts made to reduce this risk.

Three key pillars for the reduction in risk associated with natural hazards in developing countries are suggested:

Pillar 1: Identify and locate the risk areas, and quantify the hazard and the risk

Hazard and risk assessment are the central pillar in the management of the risk associated with natural hazards. Without knowledge and characteristics of hazard and risk, it would not be meaningful to plan and implement mitigation measures.

Pillar 2: Implement structural and non-structural risk mitigation measures, including early warning systems

Mitigation means implementing activities that prevent or reduce the adverse effects of extreme natural events. In a broad prospective, mitigation includes structural and geo-technical measures, effective early warning systems, and political, legal and administrative measures. Mitigation also includes efforts to influence the lifestyle and behaviour of endangered populations in order to reduce the risk. The Indian Ocean tsunami of 2004, which killed at least 230,000 people, would have been a tragedy whatever the level of preparedness; but even when disaster strikes on an unprecedented scale, there are many factors within human control, such as a knowledgeable population, an effective early warning system and constructions built with disasters in mind. All these measures can help minimize the number of casualties.

Improved early warning systems have been instrumental in achieving disaster risk reduction for floods and tropical cyclones. Cuba has demonstrated that such reduction is not necessarily a question of expensive means. However, the recent tropical cyclone Nargis is a sad reminder that much remains to be done in decreasing the risk to tropical cyclones.

Meteorological forecast in region where cyclones generally occur is quite effective, but early warning and response remains insufficient in unexpected regions (e.g. Catarina 2004 for South Atlantic Ocean). As a consequence the focus on Early Warning System (EWS) development should take into account climatic changes and/or exceptional situations.

Pillar 3: Strengthen national coping capacity

Most of the developing countries lack sufficient coping capacity to address a wide range of hazards, especially rare events like tsunamis. International cooperation and support are therefore highly desirable. A number of countries have over the last decade been supportive with technical resources and financial means to assist developing countries where the risk associated with natural hazards is high. A key challenge with all projects from the donor countries is to secure that they are need-based, sustainable and well anchored in the countries' own development plans. Another challenge is coordination which often has proven to be difficult because the agencies generally have different policies and the implementation periods of various projects do not overlap. A subject which is gaining more and more attention is the need to secure 100% ownership of the project in the country receiving assistance.

The capacity building initiatives should focus on institutions dealing with disaster risks and disaster situations in the following four policy fields:

- Risk assessment and communication, i.e. the identification, evaluation and possibly quantification of the hazards affecting the country and their potential consequences, and exchange of information with and awareness-raising among stakeholders and the general public;
- Risk mitigation, i.e. laws, rules and interventions to reduce exposure and vulnerability to hazards;
- Disaster preparedness, warning and response, i.e. procedures to help exposed persons, communities and organizations to be prepared for the occurrence of a hazard, and initiate alerts and rescue activities after the hazard occurs to reduce its immediate impact;
- Recovery enhancement, i.e. support to disaster-stricken populations and areas in order to mitigate the long-term impact of disasters.

In each of these fields, institutions can operate at local, regional, national or international levels.

Implementing policy measures designed to enhance disaster preparedness are also likely to mitigate the hazard of armed conflict. Such policies increase the delivery of state services in marginalized areas, and by doing so serve as effective means of addressing the social, political and economic grievances that constitute the factors associated with the occurrence of armed conflict. Moreover, there is reason to believe that the resolution of armed conflicts would also lead to a reduction of risk from natural hazards. Despite the fact that the connection between natural disasters and armed conflict is poorly understood, we do know that natural disasters can work to trigger the onset or exacerbate the background factors associated with armed conflict.

The impacts of some natural phenomena strongly depend on a number of political and societal factors, which contribute more to the risk than the natural phenomenon itself. Drought and famine, for example, are often used interchangeably since major famines have always been associated to a drought event. However, it is rare that a drought is going to directly kill anyone. Droughts can impact crops and therefore affect the food supply but the availability of, and access to, food depends on institutional and governmental programs and policies. These policies could, in turn, be influenced by intrastate armed conflict.

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Appendix A - Flood Hazard

Authors:

Hazard GIS flood distribution model
Christian Herold (UNEP/GRID-Europe, Geneva, Switzerland),
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Flood frequency, exposure and risk
Pascal Peduzzi (UNEP/GRID-Europe, Geneva, Switzerland).

Contents

A1 Introduction

Every year, an average of more than 48.3 million people are affected by floods in rural areas of the 25 countries studied. Of these, 40% live in Bangladesh and 32.5% in India (see Table A1 in Section A2).

Flood hazard is the most frequent global hazard, occurring in most countries world-wide. However, there is no systematic registration of major flood events as there is for cyclones or earthquakes. Although floods can be defined as a surplus of water greater than drainage capacity, it manifests itself differently depending on topography and location. Additionally, floods are not caused by a unique event, but can be the result of several different natural occurrences.

Type of floods modelled

One can delineate between flash floods, river floods, and urban floods, all of which are derived from heavy precipitation associated with insufficient drainage. Severity depends on concentrations of rainfall and regional topography. Other flooding events are not caused by precipitation, e.g. coastal flooding is associated with atmospheric low-pressure systems driving ocean water inland. Glacial lake outburst flooding (GLOF) occurs when a terminal or lateral moraine fails, releasing the glacial melt water it was damming in a sudden, violent burst. All these type of floods would require different modelling.

The current model corresponds to river flooding. Urban flooding corresponds to different conditions, mostly occurring due to “waterproofing the surfaces” and inadequate sewages evacuation; this cannot be modelled globally. Coastal flooding is already incorporated into the model of storm surges in tropical cyclones.

Modelling hazard

The model estimates peak-flow magnitudes for unmonitored sites based on records from a set of gauging stations, following the directions of the Bulletin 17B from United States Water Resources Council’s Hydrology Subcommittee: “Guidelines for determining flood flow frequency” and the Water-Resources Investigation Report 98-4055: “Techniques for Estimating Peak-Flow Magnitude and Frequency Relations for South Dakota Streams” by Steven K. Sando.

This is a four-step process: estimation of peak-flow values for a hundred-year recurrence interval for gauging stations, based on log-Pearson type III modelling of the records; organizing groups of gauging stations, taking into account basin and climatic characteristics; establishment of a regression equation for each group, which predicts peak-flow values from basin and climatic characteristics; assign each unmonitored site to a reference group to estimate its peak-flow using the corresponding regression formula.

In order to solve the problem of data homogeneity in some climatic regions, a global approach is adopted for the whole statistical analysis.

Datasets needed for the above-described statistical analysis are prepared by complex automated processes based on Georeferenced Information System.
Flooded areas corresponding to exceptional events of a hundred-year recurrence interval are generated by calculation of river stage. This is achieved using peak-flow estimates and Manning equation for open channel flow (http://en.wikipedia.org/wiki/Open_channel_flow) through complex and automated processes based on Georeferenced Information System.

Observed flood events
In addition to modelled floods, nine years of actual flood events, as detected by satellite from Dartmouth Flood Observatory (DFO), were incorporated. The observed flooding events, based mostly on MODIS satellite sensors at 250 m resolution, provided additional information and were also used for calibration. The data for observed flood events cover only nine years and are not comprehensive. The combination of observed and modelled datasets provides a good picture of the most flood-prone areas.

Frequency
The simulated intensity corresponds to a hundred-year return period event. Given that smaller events are very likely to occur, a model based only on one returning period is not sufficient. Unfortunately, given the limited amount of time and the extensive demand of computation (months of computing time), it was not possible to generate several return periods. To overcome this issue, the frequency was obtained by multiplying the frequency file by the UNEP/GRID-Europe PREVIEW flood frequency. This frequency was based on recorded watersheds flooded between 1980 and 2001 (21 years). From this dataset, only the frequency was taken and applied to the areas predicted to be affected by floods as modelled using this new methodology. When no frequency was recorded for a selected area, it was replaced arbitrarily by 0.02, i.e. 2 events in 100 years, to account for the smaller surfaces that might have been flooded before. This is a questionable assumption. However, it does not have a significant effect on the results as most of the areas are covered by PREVIEW flood frequency.

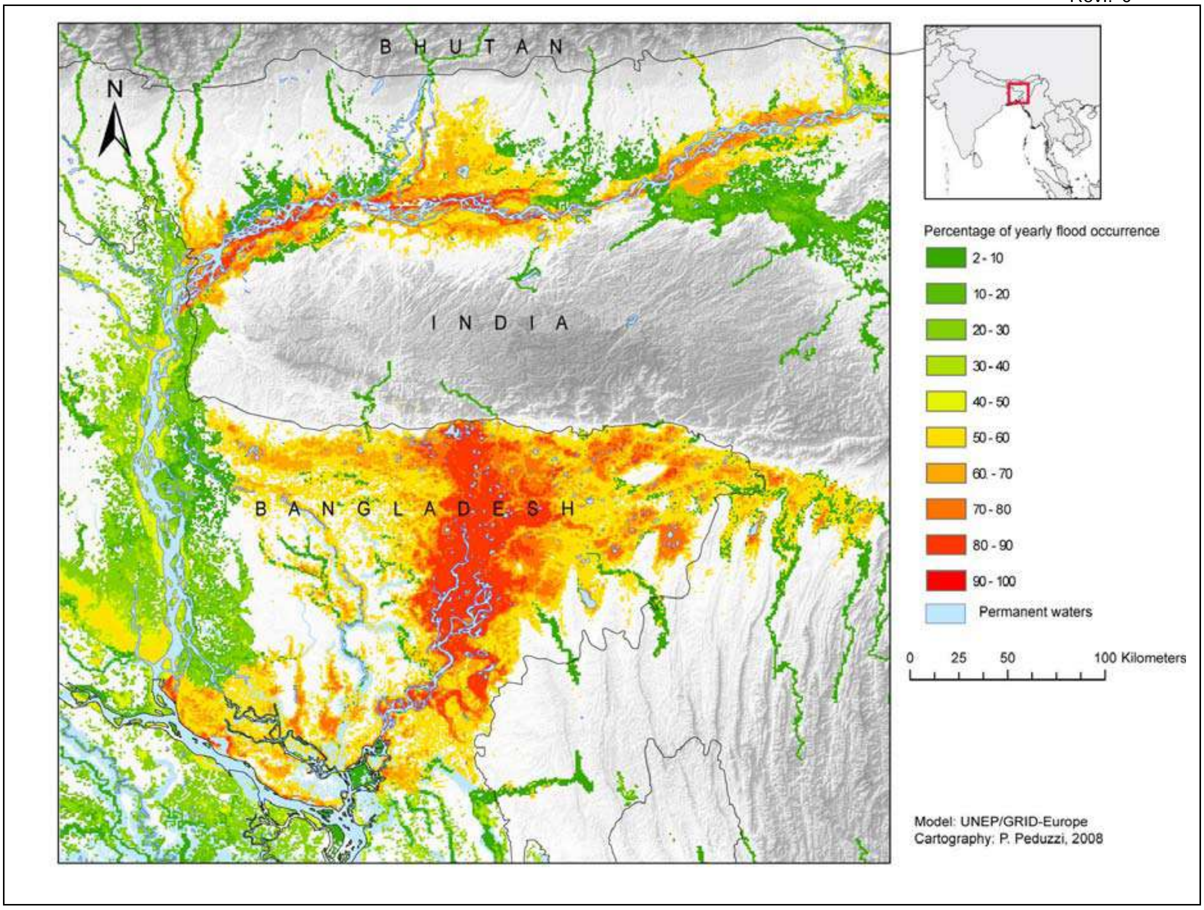

Figure A1 Map of flood hazard frequency in Bangladesh.

A2 Exposure

It is worth noting that this global method could only be applied to watersheds with an area greater than 1000 km^2, meaning that smaller territories, such as most islands, could not be modelled. Coastal flooding is not part of this model, but is covered by storm surge model. The people exposed to storm surge should be added under coastal flooding to Table A1.

Table A1 Average yearly rural flood exposure

Country	**Yearly Average Rural exposure**	**Percentage**
Australia	4,735	0.01%
Bangladesh	19,216,450	39.77%
Brunei	8	0.00%
Bhutan	10,505	0.02%
China	3,765,495	7.79%
Indonesia	1,076,204	2.23%
India	15,693,230	32.48%
Japan	104,120	0.22%
Cambodia	1,744,875	3.61%
Rep. Korea	148,403	0.31%
Laos	59,174	0.12%
Sri Lanka	100,986	0.21%
Myanmar	418,265	0.87%
Mongolia	2,974	0.01%
Malaysia	20,864	0.04%
Nepal	329,480	0.68%
New Zealand	20,746	0.04%
Pakistan	549,411	1.14%
Philippines	777,329	1.61%
PNG	2,733	0.01%
DPR Korea	96,251	0.20%
Thailand	789,952	1.63%
Timor-Leste	1,025	0.00%
Taiwan	12,521	0.03%
Vietnam	3,370,764	6.98%

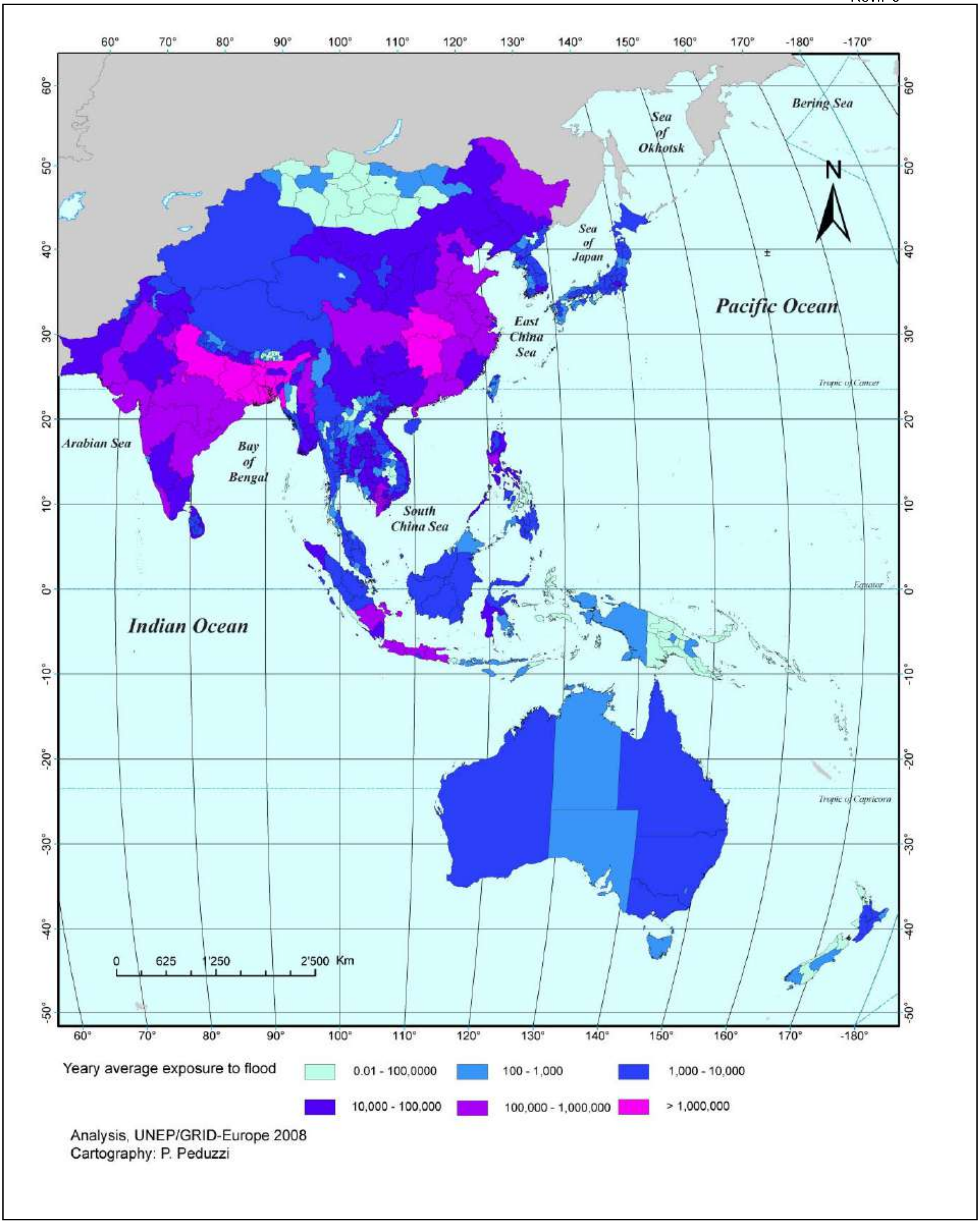

Figure A2 *Flood: average yearly human exposure (at first administrative level).*

A3 Risk

Risk was calibrated using an innovative approach based on approximately 600 satellite recorded events where the number of people killed could be associated with the number of people exposed and vulnerability parameters. By statistical regression, a link could be found among the number of people exposed, different vulnerability parameters and the number of people reported killed. Using such regression it was possible to infer the risk to other areas affected by flooding, and assign a risk index varying from very low risk (1) to extremely high risk (10) (see Figure A3). This follows a methodology developed for the global Risk assessment, which will be published in the Global Assessment Report from the ISDR system in May 2009.

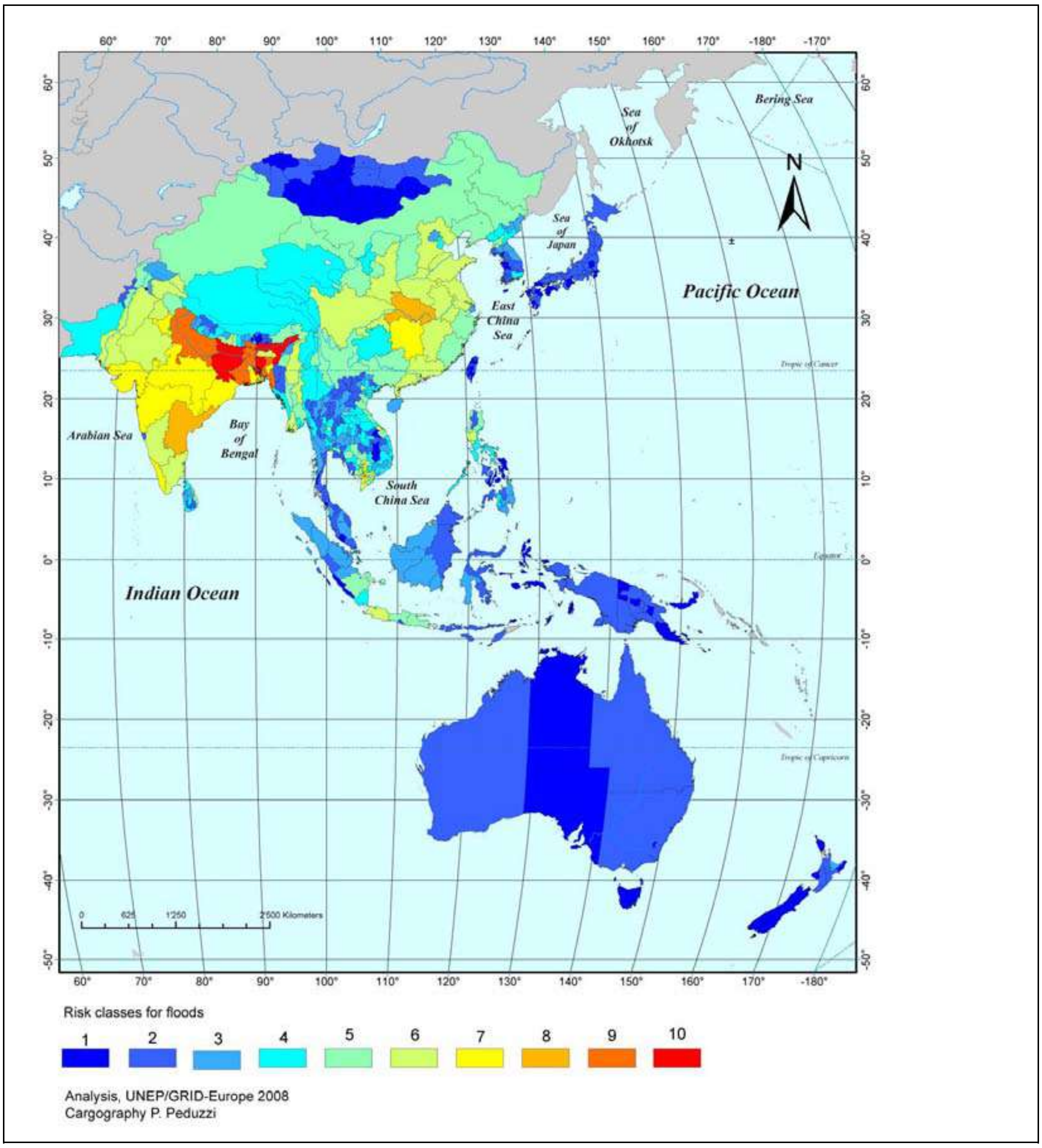

Figure A3 Flood: risk as estimated in category at first administrative level.

A4 Recommendations

For most of the statistical groups regressions were very satisfactory, several were less significant and no regression was possible for one (hot desert). Refining regression equations using a regional approach might be considered for further developments.

Validation of flooded area generated by the model was made using a nine-year record of flood events provided by Dartmouth Flood Observatory. Major differences were identified in special cases: near the coastlines, where surge effect has the most influence; in the large floodplains exhibiting braided streams. As the digital elevation model (DEM) generates only confluences, braided streams are not properly represented and flooded areas are often underestimated in these cases. In some climatic region, processes applied for correcting DEM might generate underestimates of flooded areas. Other cases are probably due to peak flow estimates. As the sample for statistical analysis includes basins of limited size, the regression equations produce less relevant values when used for large drainage areas.

A5 Conclusions

The model achieved provides a fairly detailed identification of flood-prone areas. Despite the detailed resolution, this is still a model based on global datasets and it should not be used at local level (e.g. for land planning purposes). Flood hazards were one of the most troublesome hazards to model in previous global studies. Improvements were possible thanks to the release of new global datasets, such as hydroshed from USGS, based on SRTM 90m resolution, and access to the detailed flood detection data from DFO (previously not available on-line and made available for the Global Assessment Report from ISDR, partner of this project). It was also possible thanks to the improvements in computer performance. Running algorithms at 90m resolution required months of computation on nearly 1 Tb of data.

A6 Acknowledgments

The authors gratefully acknowledge Jim and Kristin Verdin (USGS) for their support in the coding of the flood model, and Robert Brackenridge (Dartmouth Flood Observatory) for providing his dataset on observed flood (as detected by Satellites).

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Appendix B - Tropical Cyclones

Authors:

Tropical Cyclones hazard wind model:
Bruno Chatenoux, (UNEP/GRID-Europe)
Pascal Peduzzi and (UNEP/GRID-Europe)
Dr Hy Dao (UNEP/GRID-Europe)
Based on previous work developed by:
Christian Herold, Dr Frédéric Mouton, Ola Nordbeck and Pascal Peduzzi (UNEP/GRID-Europe)

Tropical Cyclones storm surge model
Dr Andrea De-Bono (UNEP/GRID-Europe)
Bruno Chatenoux (UNEP/GRID-Europe)

Contents

B1 Hazard

Tropical cyclones are powerful hydro-meteorological hazards. Worldwide, more than 78 million people are affected by 50 – 60 tropical cyclone events per year. In the past, such events have led to large disasters such as the 1991 Bangladesh disaster, killing more than 130,000 people. Their uneven distribution around the globe is a consequence of specific climatic and oceanic conditions required for their development.

The improvement of early warning systems helped to achieve disaster risk reduction. Cuba demonstrated that such reduction is not necessarily a question of expense. However, the recent tropical cyclone, Nargis (2008), is a sad reminder that there is still much to do to decrease risk associated with tropical cyclones. Although the number of tropical cyclones world-wide seems to be steady, there are local exceptions, and their severity seems to be increasing. This will be further explain in the upcoming Global Assessment Report from ISDR system.

In this report we treat tropical cyclone hazard as one hazard type, although tropical cyclones are expressed through several distinct attributes, namely:

- Extremely powerful winds
- Torrential rains leading to floods and/or landslides
- High waves and damaging storm surge, leading to extensive coastal flooding.

Mapping the interaction of these different elements would call for a complex model factoring in wind, rain, storm surge and landslides. However, given the limited time available, the priority will be given to modelling winds (see the global sum of wind map in Fig. B1) and storm surge, while flood and landslides hazards will be modelled independently.

Choice of the windspeed model

The proposed global model of tropical cyclones wind hazard is based on the observations of historical cyclone events through an estimation of the radial wind speed profile using a parametric model. The model is developed from an initial equation from G.J. Holland (1980), which was further modified to take into consideration the movement of the cyclones through time. It includes an update of the original data set (Herold et al. 2003) developed by UNEP/GRID-Europe between 2001-2003 (see O. Nordbeck, F. Mouton, P. Peduzzi, 2004 for the detailed methodology). This methodology and the global cyclone dataset were presented at the Fifth WMO International Workshop on Tropical Cyclones in Cairns (IWTC-V, December 2002). The dataset, made available by the United Nations Environment Programme (UNEP) under the name *PREVIEW Global Cyclones Asymmetric Wind speed profiles* (see UNEP PREVIEW Global Risk Data Platform), and other derived products (wind sum, frequency and physical exposure) were used (Peduzzi et al. 2002, Dao and

Peduzzi 2004) to compute the Disaster Risk Index (DRI) published by United Nations Development Programme (UNDP 2004).

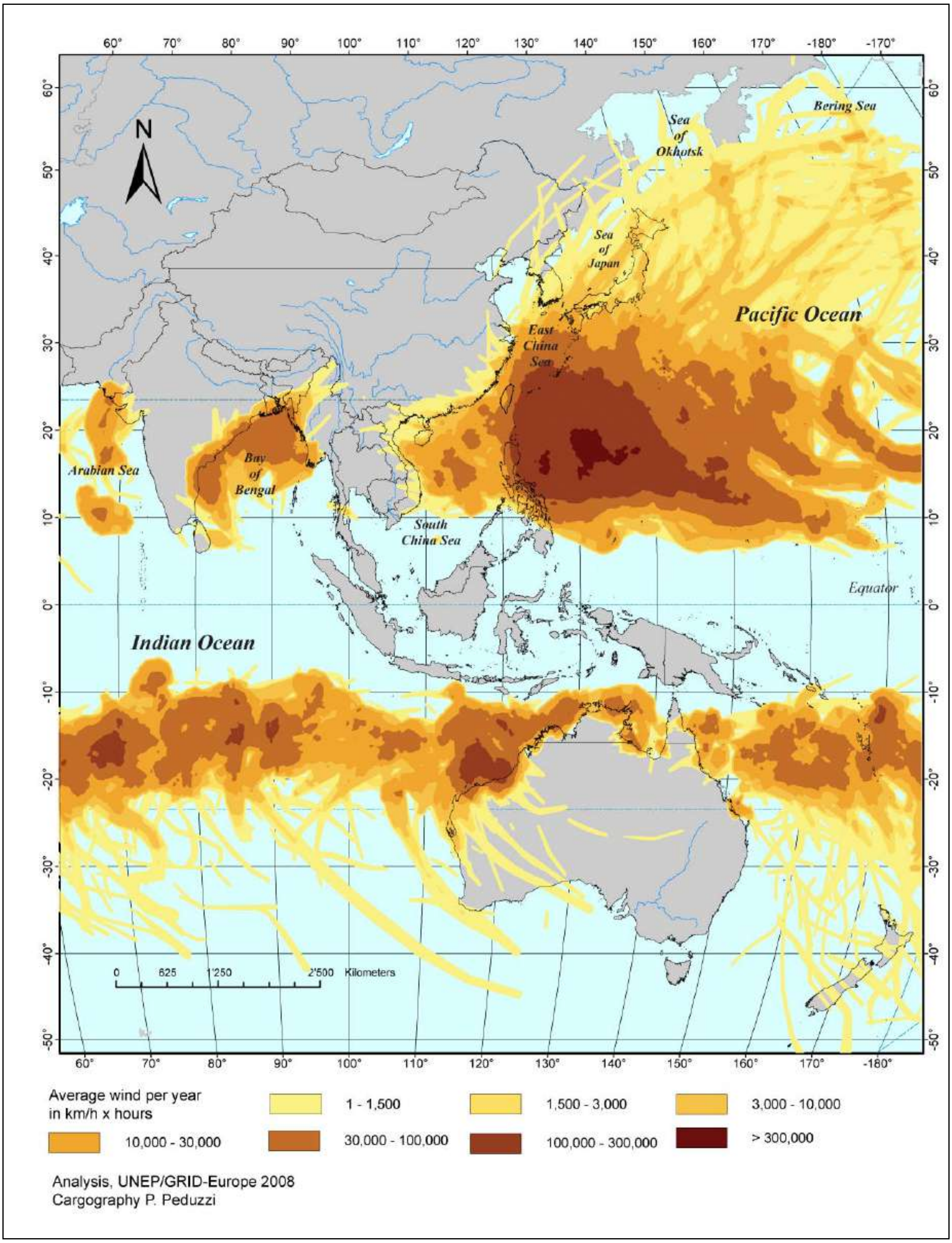


Figure B1 Tropical Cyclones: hazard model

The previous model utilized data from 1980 – 2004 but included only 8 years of data covering the North Indian Ocean's activity. This version was improved by extending the time coverage from 1975 to 2007. It is globally and temporally comprehensive, except over the South India Ocean where two years are missing (1975 and 1976). This is the reason why the study period of 30 years starts in 1977. Practically, the model extrapolates cyclones' tracks (see Figure on the left) into zones affected by a category of windspeed (see Figure on the right). Each category corresponds to a given Saffir-Simpson intensity (see Table).

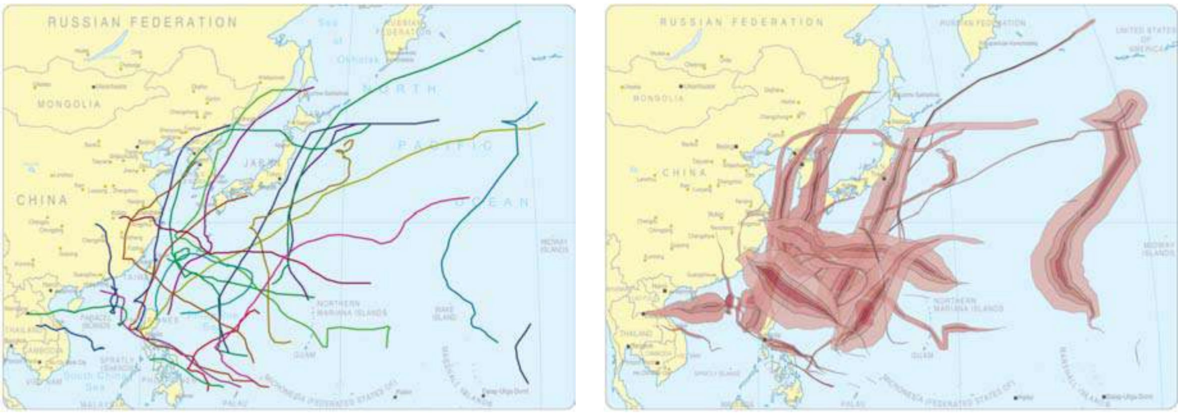


Figure B2 *Conversion of cyclone data from best tracks to Saffir-Simpson buffers.*

Table B1: Saffir-Simpson scale

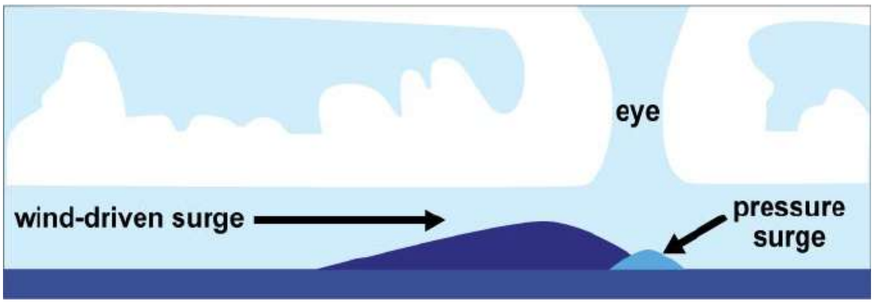
Category	Pressure (kPa)	Winds (km/h)	Surge (meters)
Tropical depression	– – –	– – –	– – –
Tropical storm	– – –	– – –	– – –
Category 1	More than 980	118 – 153	Less than 2
Category 2	965 – 980	154 – 177	2 – 3
Category 3	945 – 965	178 – 210	3 – 4
Category 4	920 – 945	211 – 249	4 – 5
Category 5	Less than 920	More than 259	5 – 10

The methodology was reviewed by a team of experts selected by WMO (see acknowledgements). One of their main recommendations was that the effects of storm surge should be incorporated.

Storm surge

A storm surge is a high flood of water caused by wind and low pressure, most commonly associated with tropical cyclones. The strong winds blowing towards the shore help push water towards shore on the right side of the cyclone's direction of motion. This piling up contributes to most of the coastal flooding.

Also, the central pressure of a tropical cyclone is so low that the relative lack of atmospheric weight above the eye and eye wall causes a bulge in the ocean surface level (Fig. B3). Storm surges are different from tidal surges, which are violent surges caused exclusively by the tidal shift in sea level. Typical storm surge heights vary with the hurricane's intensity, but they can range from only 1 to more than 5 meters. In the United States in 2005, storm surges associated with Hurricane Katrina reached 9m.



Sources: Robert Simmon, NASA GSFC, 2007

Figure B3 Schema of storm surges

The data used to map surge hazard are based on a very detailed elevation model at 90 m of resolution (SRTM). The first 10 km from the coastal line were retained for the analysis. In The Saffir –Simpson scale, each intensity category also specifies the range of amplitude for storm surge waves. The intersection of cyclone tracks on our coastal buffer designates potential regions that can be impacted by a selected cyclone intensity: for example, all the coastal zones having elevation ≤ to 2 meters can be potentially impacted by a storm surge belonging to the S-S category 1.

The model does not take into account the fact that the inland penetration of the storm surge's damage can be dependent on the bathymetry of the continental margin, e.g. for an equivalent storm, the surge can be greater along a gently sloping continental shelf than for a steeply sloping shelf.

B2 Recommendations

Early Warning

Meteorological forecasts in regions where cyclones generally occur are quite effective, but early warning and response remains insufficient in unexpected regions (e.g. Catarina 2004 for South Atlantic Ocean). As a consequence the focus of Early Warning System (EWS) development should take into account climatic changes and/or exceptional behaviours.

Development or revision of 2D models, like the one developed by GRID-Europe, would allow authorities to predict the areas that will be more affected.

Difficulties and limitations
The absence of an official format for archiving tropical cyclone events complicated the compilation of a global data set. Even if special attention was used during this process, missing or duplicated events remain possible.

The 2D model developed by GRID-Europe remains only valid on the ocean and becomes uncertain as soon as landfall happens. As a consequence deep inland data has to be interpreted carefully.

Repartition of victims per Saffir-Simpson categories could improve models.

Next steps
- Inland 2D model to be developed.
- Victim repartition study using high resolution damage data set.
- Integration of surges and precipitations into the model.
- Relation between cyclone intensities and sea surface or sub-surface temperature.

B3 Acknowledgments

This new study would not have been possible without the collaboration of all the WMO Regional Specialised Meteorological Centres (RSMCs) and Tropical Cyclone Warning Centres (TCWCs) who are the providers of the best tracks data collection. Without the raw data none of the following products could have been derived. Hence we are very grateful to Dr. Varigonda Subrahmanyam, Dr. James Weyman, Kiichi Sasaki, Philippe CAROFF, Jim Davidson, Simon Mc Gree, Steve Ready, Peter Kreft, Henrike Brecht and all the persons that have contributed to provide the raw data. We also would like to thanks Nanette Lomarda for facilitating the contacts and a special thanks to Greg Holland and Bruce Harper for their essential advices for the model.

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Data sources:

PREVIEW cyclones asymmetric winds peed profile 2008, UNEP/GRID-Europe

PREVIEW cyclones storm surges, 2008, UNEP/GRID-Europe

Appendix C - Landslide

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Contents

C1 Introduction

Landslides and snow avalanches represent a major threat to human life, property and constructed facilities, infrastructure and natural environment in most mountainous and hilly regions of the world, and the frequency of their occurrence seems to be on the rise. The main reasons for the observed increase in landslide disasters are a greater susceptibility of surface soil to instability as a result of overexploitation of natural resources and deforestation, and greater vulnerability of the exposed population as a result of growing urbanization and uncontrolled land-use. Furthermore, traditionally uninhabited areas such as mountains are increasingly used for recreational and transportation purposes, pushing the borders further into hazardous terrain. Climate change and the potential for more extreme weather conditions may also be a contributing factor.

The major triggering factors for landslides are extreme precipitation events, strong earthquakes, and human activity. The strong correlation between landslides and other natural hazard triggers like hurricanes or earthquakes, has resulted in an underestimation of their socio-economic impact. This underestimation contributes to reduced awareness and concern of both authorities and general public about landslide risk.

Global hazard and risk maps for landslide and avalanche were developed in the Natural Disaster Hotspots project (Dilley et al. 2005, Nadim et al. 2006) to identify the most exposed countries. Based on the global datasets of climate, lithology, earthquake activity, and topography; areas with the highest hazard, or "hotspots", were identified. The applied model was based on classed values of all input data. The model output was a landslide and avalanche hazard index, which was globally scaled into 9 levels. The model results were calibrated and validated in selected areas where good data on slide events exist. More and better input data could improve the model further. In this project the landslide hazard model used in the Natural Disaster Hotspots project was modified and improved to provide a better basis for making more predictions of the global risk associated with landslides.

C2 Model for Landslide Hazard Evaluation

The term "landslide" in this study refers to events involving gravity-driven rapid mass movement down-slope, like rockslides, debris flows, snow avalanches, and rainfall- and earthquake-induced slides; which pose a threat to human life. Slow moving slides have significant economic consequences for constructions and infrastructure, but rarely cause any fatalities.

Landslides involve soil and rock volumes that could vary from tens to millions of cubic metre. Obviously the destructiveness of a landslide is a function of the volume of the masses that are mobilised and their velocity. However, 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, 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, etc. have been used to define landslide intensity. In the present study, all landslides and avalanches capable of causing injury or fatality are considered as “events”. Beyond that, no attempt was made at considering the severity of different landslide events.

To identify the global landslide hazard and risk "hotspots", Nadim et al. (2006) adopted a simplified first-pass analysis method. The scale of their analysis was a grid of roughly 1km x 1km pixels where landslide hazard, defined as the annual probability of occurrence of a potentially destructive landslide event, was estimated by an appropriate combination of the triggering factors (mainly extreme precipitation and seismicity) and susceptibility factors (slope, lithology, and soil moisture). The principles of the method are depicted in Figure C1. The weights of different triggering and susceptibility factors were calibrated to the information available in landslide inventories and physical processes. The general approach used in the present study is a modified and improved version of the approach used by Nadim et al. (2006).

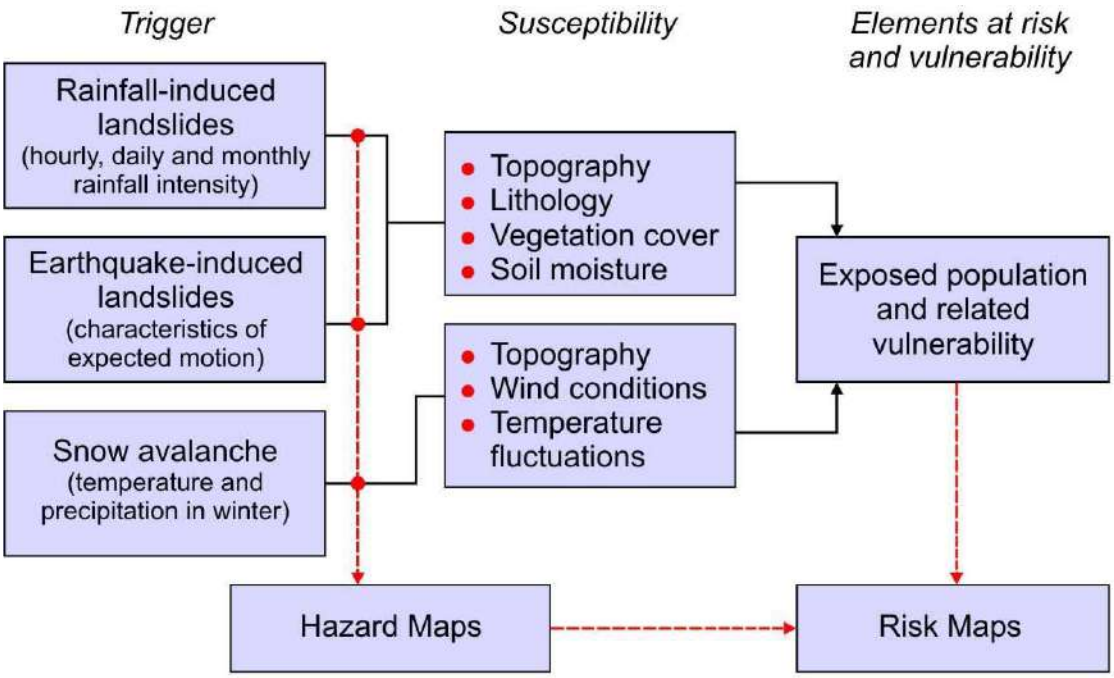

Figure C1 Schematic approach for landslide hazard and risk evaluation.

C2.1 Landslide hazard index $H_{landslide}$

Some of the key improvements in the present model are that the landslide hazard due to earthquakes is differentiated from the landslide hazard due to heavy precipitation, and effect of vegetation cover is included in the model. The landslide hazard indices were estimated using the following equations:

$$H_{landslide, earthquake} = (S_r \times S_l \times S_h \times S_v) \times T_s \quad (1)$$
$$H_{landslide, rainfall} = (S_r \times S_l \times S_h \times S_v) \times T_p \quad (2)$$

where $H_{landslide}$ is landslide hazard index, S_r is the slope factor within a selected grid, S_l is lithological (or geological) conditions factor, S_h describes the soil moisture condition, T_p is the precipitation factor and T_s describes the seismic conditions. The index S_v described the vegetation cover.

C2.1.1 *Slope factor S_r*

The slope factor represents the natural landscape ruggedness within a grid unit. In February 2000, NASA collected elevation data for much of the world using a radar instrument aboard the Space Shuttle. The raw data collected on the mission were processed over three years. NASA has now released a global elevation dataset called SRTM30, referring to the name of the mission and the resolution of the data, which is 30 arc-seconds, or approximately 1 km² per data sample near the equator. The SRTM30 data set covers the globe from 60 degrees south latitude to 60 degrees north latitude. The vertical accuracy is estimated such that 90% of posts are within 16m tolerance of the actual position. Using the SRTM30 data set as the starting point and correcting the anomalies by using other datasets, Isciences (www.isciences.com) derived the grid of slope angles for this study.

Range of slopes angle (unit 1/100 degrees)	**Classification**	**S_r**
0000 – 0100	Very low	0
0101 – 0600	Low	1
0601 – 1200	Moderate	2
1201 – 1800	Medium	3
1801 – 2400	High	4
2401 – 3000	Very high	5
3001 – 3500	Probably stiff soil	4
3501 - 4000	Probably rock	3
4001 - 4500	Probably hard rock	2
> 4500	Stable hard rock	1
No Data	No Data	No Data

In the analyses, the slope data were reclassified on a geographical grid (WGS84). Cells were distributed in the 6 different categories (0 – 5) presented in the category table above.

Note: for slopes which angle is less than 1° (i.e. for flat or nearly flat areas), S_r is set equal to zero because the resulting landslide hazard is null even if the other factors are favourable.

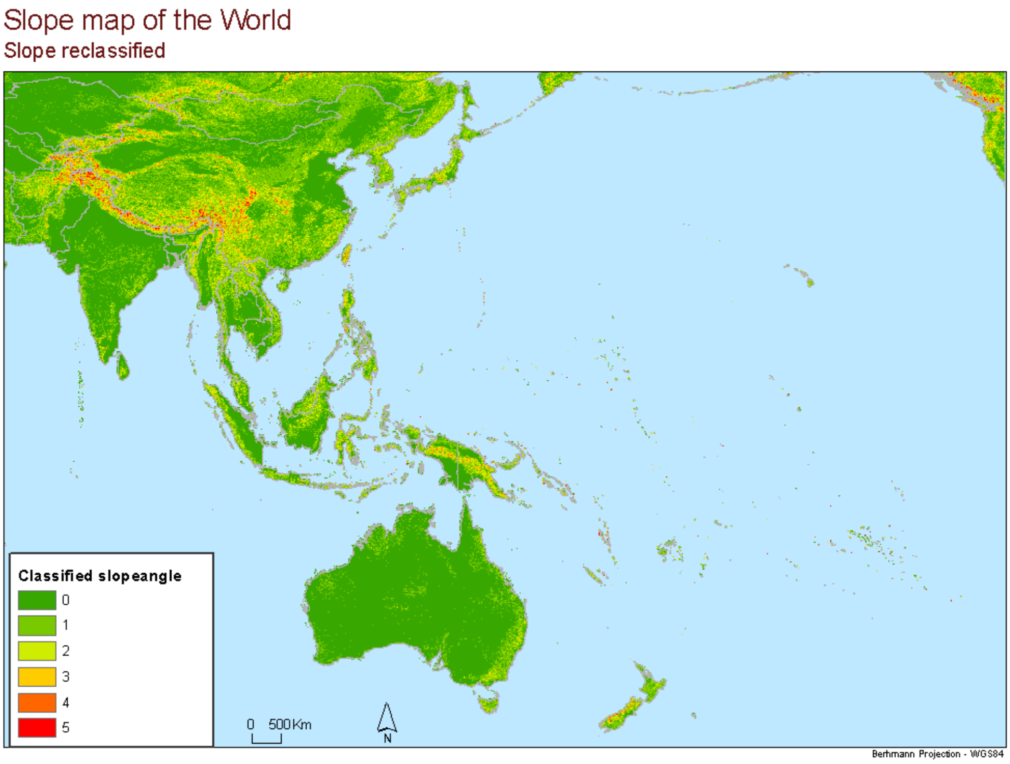

Figure C2 Slope factor S_r for the study area.

C2.1.2 *Lithology factor S_l*

This is probably the most difficult parameter to assess. Ideally, detailed geotechnical information should be used but, at the global scale, only a general geological description is available. Rock strength and fracturing are the most important factors to evaluate lithological characteristics, and these characteristics can vary greatly over short distances.

The dataset used in the study was the Geological map of the World at 1/25,000,000 scale published by the Commission for the Geological Map of the World and UNESCO (CGMW, 2000). The map is available on a CD-ROM. The grid Resolution is 2.5° × 2.5° latitude/longitude. This map is the first geological dataset compiled at a global scale showing the geology of the whole planet, including continents and oceans. In the map, three main types of formation are identified: sedimentary rocks, extrusive volcanic rocks and endogenous rocks (plutonic or strongly metamorphosed).

Lithology and stratigraphy	**Susceptibility**	**S_l (New)**
• Extrusive volcanic rocks - Precambrian, Proterozoic, Paleozoic and Archean. • Endogenous rocks (plutonic and/or metamorphic) - Precambrian, Proterozoic, Paleozoic and Archean.	Low	1
• Old sedimentary rocks - Precambrian, Archean, Proterozoic, Paleozoic. • Extrusive volcanic rocks – Paleozoic, Mesozoic. • Endogenous rocks - Paleozoic, Mesozoic, Triassic, Jurassic, Cretaceous.	Moderate	1
• Sedimentary rocks - Paleozoic, Mesozoic, Triassic, Jurassic, Cretaceous. • Extrusive volcanic rocks – Mesozoic, Triassic, Jurassic, Cretaceous. • Endogenous rocks – Meso-Cenozoic, Cenozoic.	Medium	2
• Sedimentary rocks – Cenozoic, Quaternary. • Extrusive volcanic rocks – Meso-Cenozoic.	High	3
• Extrusive volcanic rocks – Cenozoic.	Very high	3

Three susceptibility classes were used in the analyses, as shown in the table above. Usually old rocks are stronger than young rocks. Plutonic rocks will usually be strong and represent low risk. Strength of metamorphic rocks is variable, but these rocks often have planar structures such as foliation and therefore may represent higher risk than plutonic rocks. Lava rocks will usually be strong, but may be associated with tuff (weak material). Therefore, areas with recent volcanism are classified as high risk. Sedimentary rocks are often very weak, especially young ones.

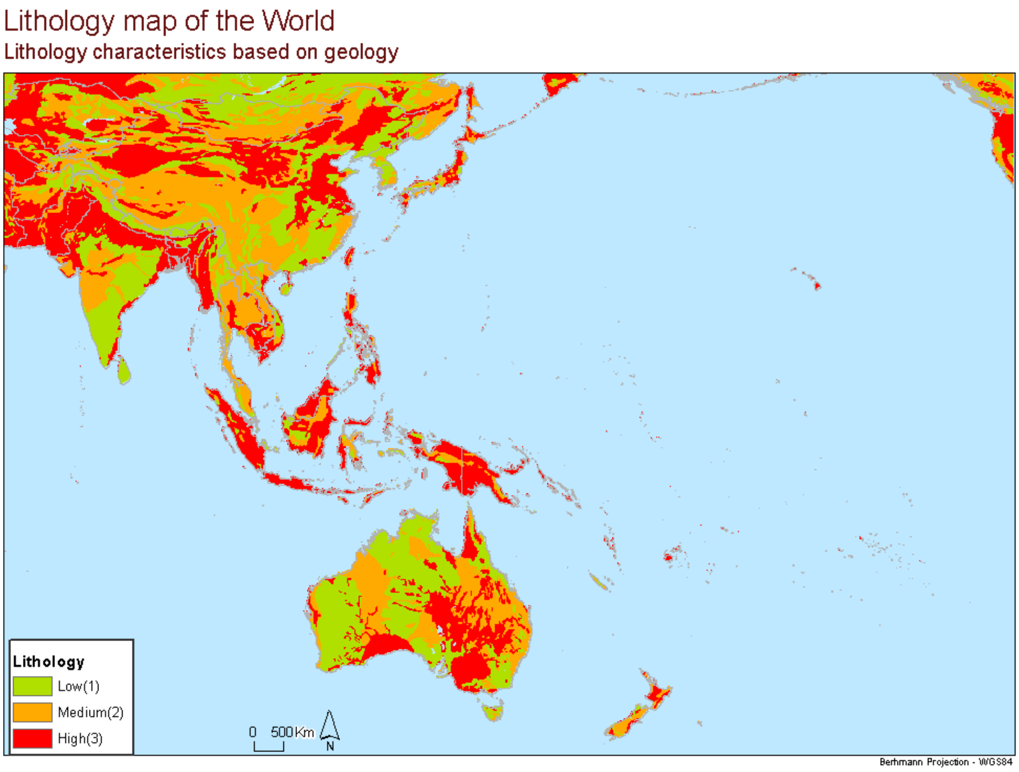

Figure C3 Lithology factor S_l for the study area.

C2.1.3 *Soil moisture factor, S_h*

S_h is a soil moisture index, which indicates the mean humidity throughout the year and gives an indication of the state of the soil prior to heavy rainfall and possible destabilization.

The data for the study were extracted from the Moisture Index by the Climate Prediction Center (CPC; Fan and Van den Dool 2004). The model used to produce the dataset is based on the algorithm of Huang et al. (1996). The data cover the period from 1948 to the present (the data are updated daily in near–real time) and the resolution is 0.5° × 0.5°. The model uses precipitation and temperature as its meteorological inputs and calculates evaporation based on Thornthwaite (1948). Surface run off and base flow are separately parameterised, and parameter calibration for runoff and soil moisture is performed using field data from Oklahoma (Huang et al. 1996).These calibration values are then applied globally.

The CPC data are available for download from:
http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.GMSM/

Three classes for soil moisture index are determined based on NCEP/CPC dataset:

Soil moisture index (NCEP/CPC)	**Susceptibility**	**S_h**
0 → 80	Low to moderate	1
80 → 160	Medium	2
160 → 250	High to very high	3

C2.1.4 *Vegetation cover index S_v*

The GLC2000 database has 22 different classes of vegetation cover, which have been translated into 5 categories (scale 1 to 5) with respect to resistance to landslides. The table below shows the range of S_v for these 5 categories.

Category of vegetation cover w.r.t. resistance to landslides	**Vegetation cover index S_v for rainfall-induced slides**	**Vegetation cover index S_v for earthquake-induced slides**
5	0.8	0.9
4	0.9	0.95
3	1.0	1.0
2	1.1	1.05
1	1.2	1.1

C2.1.5 *Precipitation trigger factor T_p:*

The categorisation of T_p was based on the estimate of the 100-year extreme monthly rainfall (i.e. extreme monthly rainfall with 100 years return period). The source of data was the monthly precipitation time series (1951 - 2004) from Global Precipitation Climatology Centre (GPCC) run by Germany's National Meteorological Service, DWD (Rudolf et al, 2005). The dataset is based on quality-controlled data from a larger number of stations (up to 43,000) with irregular coverage in time. This product is optimised for best spatial coverage and use for water budget studies. The products contain precipitation totals, anomalies, number of gauges and systematic error correction factors. The grid resolution is 0.5°×0.5° latitude/ longitude.

At the time of the study, the monthly values were available for 54 years, from 1951 to 2004. The maximum registered values per annum were used to calculate the expected 100-year monthly precipitation for every grid point assuming a Gumbel distribution. This is done by:

1. Choosing the highest monthly rainfall in the dataset for each year in each pixel.

2. Evaluating the mean μ and the standard deviation σ of the annual maximums.
3. Fitting a Gumbel distribution to the data using the mean and standard deviation computed in Step 2.
4. Finding the 1% fractile of the Gumbel distribution, which corresponds to the 100-year extreme monthly rainfall.

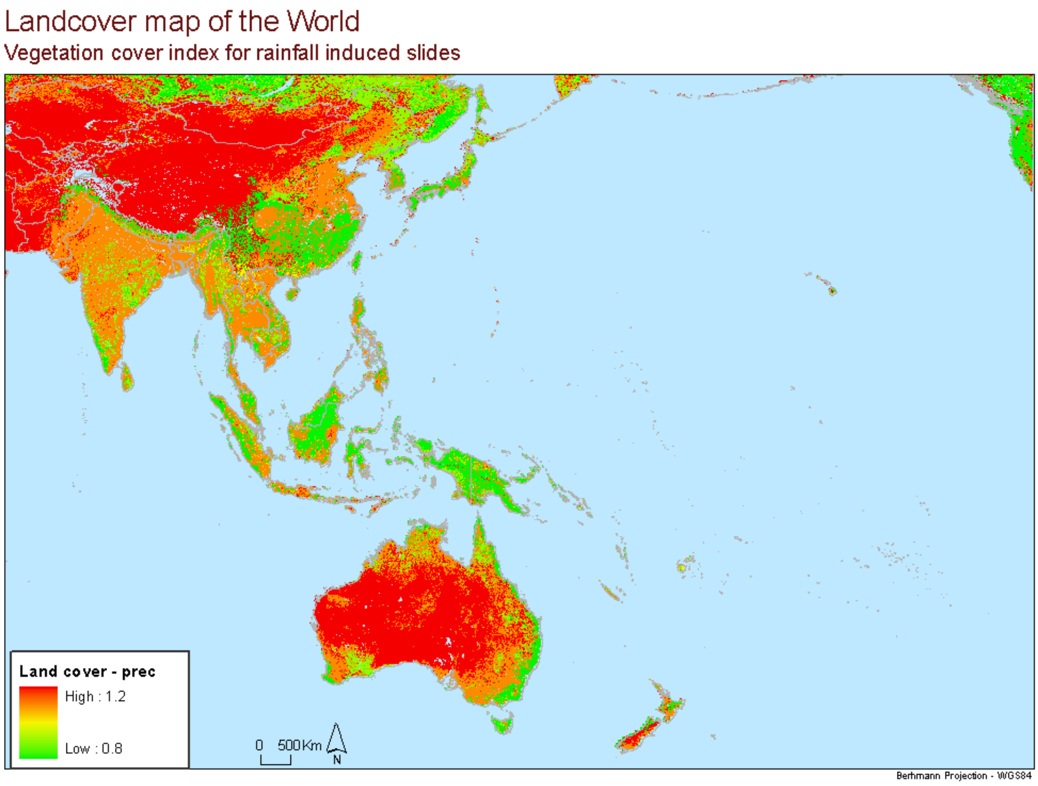

Figure C4 Vegetation cover index S_v for precipitation-induced landslides.

On the basis of the estimated 100-year extreme monthly rainfall, a precipitation index T_{p1} was assigned as listed in the table below.

100-year extreme monthly rainfall (mm)	**Susceptibility**	$\mathbf{T_{p1}}$
0000 – 0330	Low	1
0331 – 0625	Moderate	2
0626 – 1000	Medium	3
1001 – 1500	High	4
> 1500	Very high	5

The precipitation index used by Nadim et al. (2006) in the Global Hotspots study was identical to T_{p1}. Recent research has shown that it is the extreme precipitation events that trigger slides, and the definition of “extreme” depends on what is “normal” at a particular location. In other words, the geometry of natural slopes is adapted to the normal precipitation events at a given location. In order to trigger a slide, anomalously high precipitation is required. In the present study, an anomaly factor in included in the precipitation trigger index. The potential for anomaly was quantified by considering the coefficient of variation (mean divided by standard deviation) of the data obtained in Step 2 of estimation of the 100-year extreme monthly rainfall. The following range for anomaly factor is suggested (in the table below "a" denotes the smallest value of CoV = σ/μ obtained for the whole globe, and "b" denotes the largest value of CoV. The values of "a" and "b" obtained from the calculations were respectively 0.11 and 3.60):

Coefficient of variation of highest monthly annual rainfall, CoV = σ/μ	**Anomaly factor T_a**
a → a + 0.2·(b – a)	0.8
a + 0.2·(b – a) → a + 0.4·(b – a)	0.9
a + 0.4·(b – a) → a + 0.6·(b – a)	1.0
a + 0.6·(b – a) → a + 0.8·(b – a)	1.1
a + 0.8·(b – a) → b	1.2

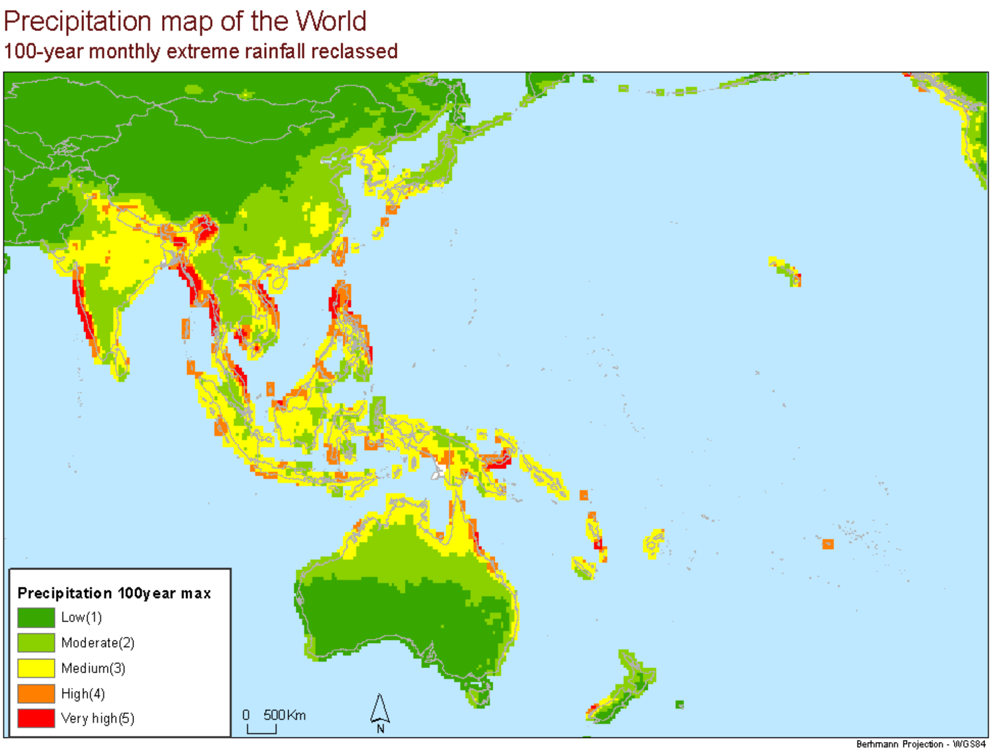

Figure C5 Precipitation index T_{p1} for the study area.

The precipitation trigger index, T_p, was obtained by the equation below:

$$T_p = T_{p1} \times T_a \qquad (3)$$

The variation range for T_p is therefore 0.8 – 6.0.

C2.1.6 *Seismic trigger factor T_s*

The data set used for the classification of the seismic trigger factor was the expected Peak Ground Acceleration (PGA) with 475-year return period (10% probability of exceedance in 50 years) from the Global Seismic Hazard Program, GSHAP (Giardini et al, 2003). GSHAP was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU) and in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/IDNDR). The primary goal of GSHAP was to create a global seismic hazard map in a harmonized and regionally coordinated fashion, based on advanced methods in probabilistic seismic hazard assessments (PSHA). Modern PSHA are made of four basic elements: earthquake catalogue, earthquake source characterization, strong seismic ground motion and computation of seismic hazard. For the study, the Peak Ground Acceleration (PGA) with 475-year return period was used as the representative triggering parameter for seismically-induced landslides.

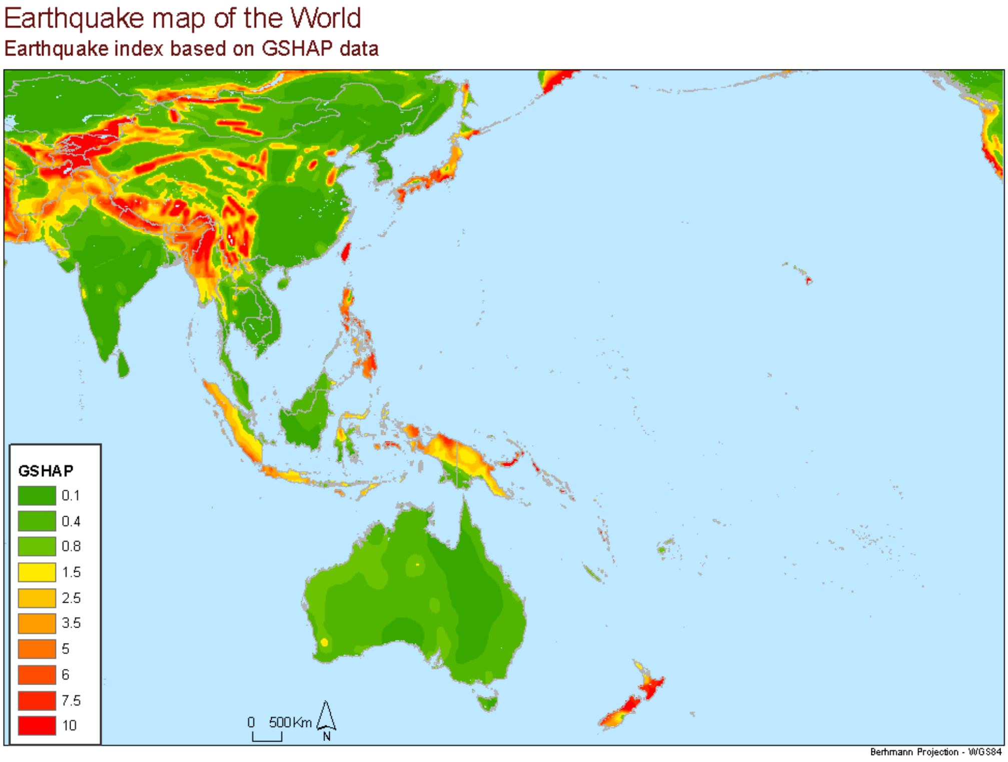

Figure C6 Seismic trigger factor T_s for the study area.

The seismic trigger index, T_s, was evaluated from the GSHAP PGA_{475} data according to the table below.

GSHAP PGA_{475} (m/s^2)	T_s
0.00 – 0.50	0.1
0.51 – 1.00	0.4
1.01 – 1.50	0.8
1.51 – 2.00	1.5
2.01 – 2.50	2.5
2.51 – 3.00	3.5
3.01 – 3.50	5
3.51 – 4.00	6
4.01 – 4.50	7.5
Greater than 4.50	10

C2.1.7 *Categorisation of landslide hazard*

The obtained landslide hazard indices were calibrated against the databases of landslide events in selected (mostly European) countries to obtain the frequency of the events. On the basis of this calibration, the following landslide hazard classifications were established:

Values for $H_{landslide, rainfall}$	**Values for $H_{landslide, earthquake}$**	**Class**	**Classification of landslide hazard potential**	**Representative annual frequency in 1 km^2 grid cell**
≤ 2	≤ 7	0	Negligible	**~ 0**
3 – 9	8 – 24	1	Very low	**~ 0**
10 – 20	25 – 47	2	Low	**0.01 %**
21 – 36	48 – 74	3	Low to moderate	**0.03 %**
37 – 54	75 – 108	4	Moderate	**0.1 %**
55 – 74	109 – 152	5	Medium	**0.3 %**
75 – 99	153 – 205	6	Medium to high	**1 %**
100 – 134	206 – 270	7	High	**3 %**
> 134	> 270	8	Very high	**10 %**

C3 Using the Landslide Hazard Results in Risk Estimation

The intersection of the landslide hazard "hotspots" with population density and infrastructure density maps, and appropriate set of socio-economic indicators (GDP, Human Development Index, etc.) provides a first-pass estimate of landslide risk "hotspots". The risk computations in the Natural Disaster Hotspots project were calibrated according to past human losses recorded by various natural disaster impact databases. The estimation of expected losses was achieved by first combining frequency and population exposed, in order to provide the physical exposure, and then performing a regression analysis using different sets of uncorrelated socio-economical parameters in order to identify the best indicators that were the best proxy for approaching human vulnerability to landslides in a given country (Peduzzi et al., 2002; Nadim et al., 2006).

Since landslides are highly correlated with other natural disasters, one may overestimate the total risk from all natural hazards if one simply adds the individual risks. This is particularly significant for earthquake-induced landslides, where the fatalities due to the earthquake event reported in various databases are inclusive of those caused by landslides. In the new analyses, the landslide hazard due to earthquakes and rainfall are differentiated. This should make it possible to correct for some of the correlations among the risks associated with different natural hazards when the total risk is estimated.

Figures C7 and C8 show the landslide hazard hotspots in parts of the study area.

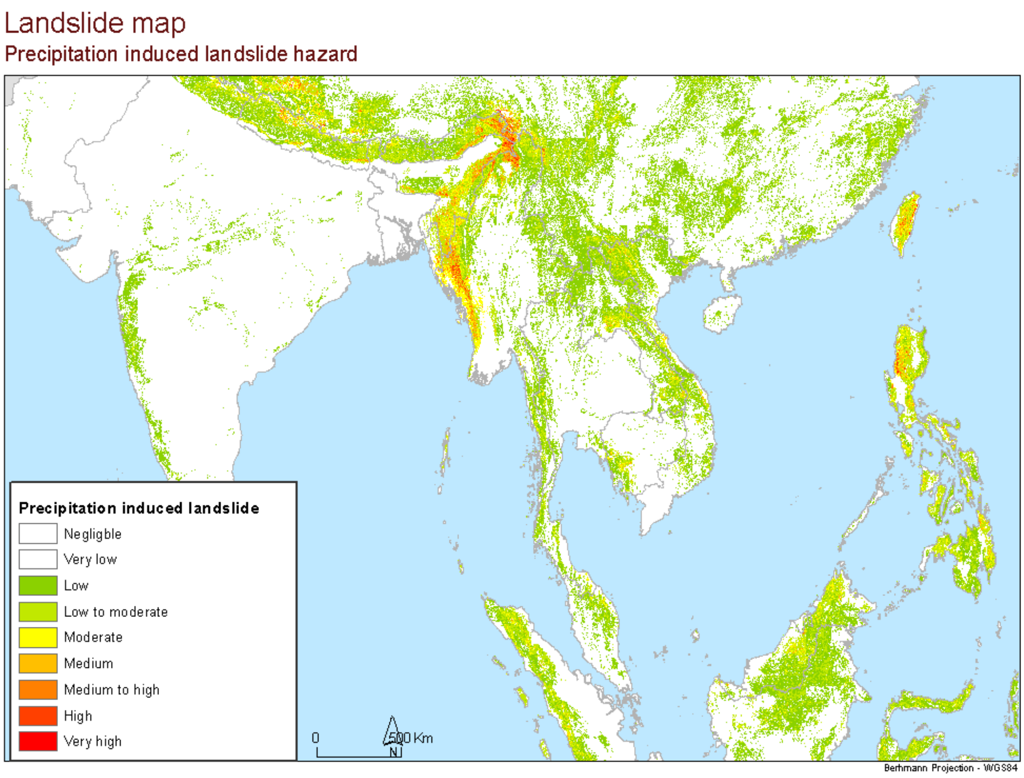

Figure C7 Precipitation-induced landslide hazard hotspots in the study area.

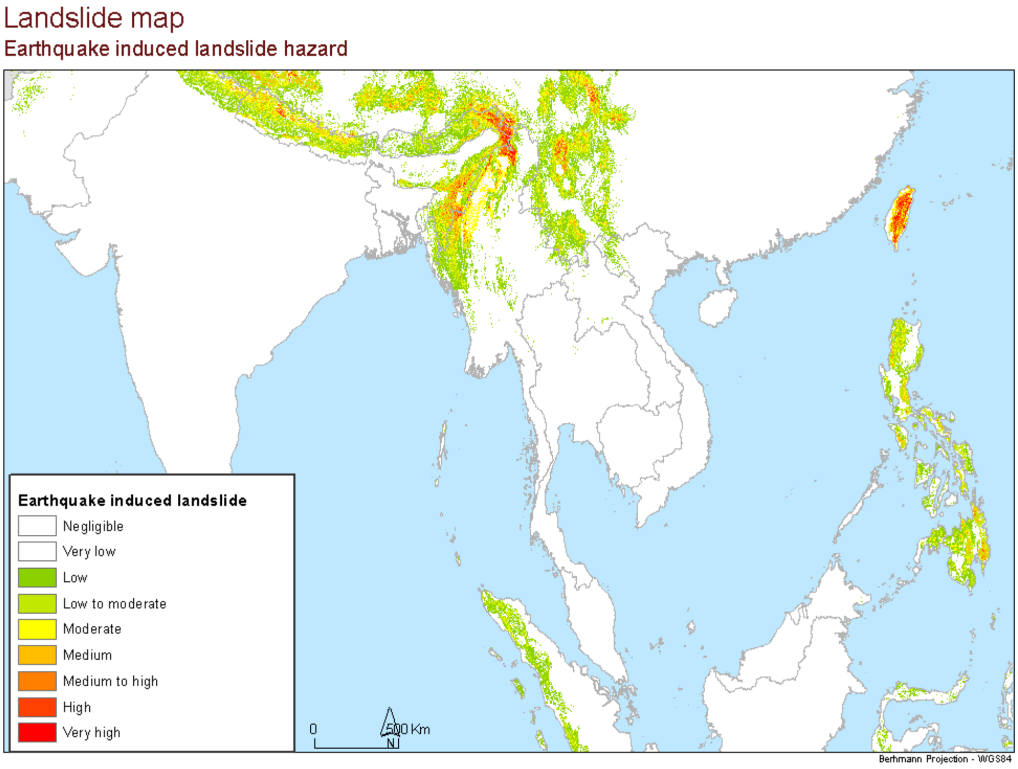

Figure C8 Earthquake-induced landslide hazard hotspots in the study area.

C4 Discussion

In the analyses done in this study, the hazard due to landslides triggered by earthquake and heavy precipitation was dealt with separately because of two reasons. First, the susceptibility factors for the two triggering mechanisms might be different. Second, the risk (to human life) due to earthquake-induced landslides is often included in the earthquake risk, and one should avoid counting the same risk twice in a multi-hazard / multi-risk context.

Human impact is a very important triggering factor for landslides, which was ignored in the model. On a global scale analysis, one could introduce an index that is related to population density and/or infrastructure density. Population density is indirectly accounted for in the risk estimation. Regarding infrastructure density, what is lacking is a good global database. Generally human-induced landslides have very high economic consequences (closing the roads and railways, disruption of daily routines, etc.), but rarely cause large casualties. Since the focus of this study was on the risk to human life, neglecting human-induced landslides may be justified in a first-pass analysis.

Regarding the new vegetation cover index that was used in the model, a relatively small variation range was assigned to the index. This was due to the contradictory opinions of different experts regarding the effects of vegetation cover on slope stability.

The lithology factor is probably the weakest link of the model, mainly because of the coarse resolution of the Geological Map of the World. We are not aware of any other similar database for global geology with a finer resolution. An index that could better describe the soil conditions would have made the model much better. However, we are not aware of any global database of soil conditions (or Quaternary sediment thickness for that matter). It should, however, be noted that when applying the Geological Map of the World, great efforts were made to translate the map into different classes of material (rock and soil) that, from a geological and engineering point of view, are considered susceptible to landslides.

The results of the global landslide hazard assessment (this note) are used as one of the inputs for estimating the landslide risk. Another key input is the data of casualties induced by natural disasters in the EM-DAT database. The EM-DAT database has a number of shortcomings when it comes to landslides, which as described elsewhere (e.g. Nadim et al., 2006). There is not time in this project to establish a “cleaner” database for landslide disasters as the results of the work are to be delivered by mid-June 2008. For future applications, we will look into the global database of landslide news being compiled by the Canadian Geological Survey and the International Consortium on Landslides, and various national databases.

The main focus of the present study is on fast-moving, shallow slides that have a large potential for causing human casualties. The factors governing the susceptibility to deep slides are different from those that are important for shallow slides. Large rock avalanches and submarine slides are also neglected. Therefore both the landslide hazard and landslide risk are likely to be greater than what was estimated in this assessment.

The strategies for the mitigation of risks associated with landslides can broadly be classified in six categories: (1) land use plans, (2) enforcement of building codes and good construction practice, (3) early warning systems, (4) community preparedness and public awareness campaigns, (5) measures to pool and transfer the risks and (6) construction of physical protection barriers.

In many situations where landslides could affect life and property early warning systems (EWS) could be designed to monitor and forewarn of impending danger. EWSs for landslides are monitoring systems specifically designed to detect events that precede a landslide in time to issue an imminent hazard warning and initiate mitigation measures. The key to a successful EWS is to be able to identify and measure small but significant indicators that precede a landslide (so-called precursors). If a landslide occurs or is on the verge of occurring, time is needed for detection through the EWS, notification (authorities -police, -mayor's office, …) and required actions (closure of roads, evacuation, etc.). Societal needs and controls are also a factor. But outmost, communication is the most critical need. The relevant precursor to be monitored depends on the type of landslide. Typical examples of precursors are intense rainfall, ground vibrations and earthquakes, blasting, acceleration or high rate of movement in the slope, rapid increases in pore water pressure or stream flow at the toe of a slope. Typical instruments in an early warning system are rain gauges, geophones, seismographs, piezometers, inclinometers, extensometers and devices for measuring the movement of slopes. Several examples of EWS for landslides are provided in Lacasse and Nadim (2008).

C5 References

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EM-DAT (2003) The OFDA/CRED International Disaster Database - www.em-dat.net - Université Catholique de Louvain - Brussels - Belgium

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Peduzzi P, Dao H, Herold C, Mouton F (2002) Global Risk And Vulnerability Index Trends per Year (GRAVITY), phase II: Development, analysis and results. 56 p. http://www.grid.unep.ch/product/publication/download/ew_gravity2.pdf

(Internet) data sources:

Elevation data (SRTM): Isciences, Michigan, USA
http://www.isciences.com/index.html

Moisture index data: Climate Prediction Center, Maryland, USA
http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.GMSM/.w/

Precipitation data: Global Precipitation Climatology Centre, Deutscher Wetterdienst, Offenbach, Germany

http://gpcc.dwd.de

Seismic trigger factor: Global Seismic Hazard Assessment Program (GSHAP), Geo Forschungs Zentrum, Potsdam, Germany http://seismo.ethz.ch/GSHAP/index.html

Winter precipitation and temperature: International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
http://www.grid.unep.ch/data/index.php

Population data: Gridded Population of the World (GPWv3), Columbia University, New York, USA
http://sedac.ciesin.columbia.edu/gpw/

International disaster database: EM-DAT: The OFDA/CRED International Disaster Database, Université catholique de Louvain, Brussels, Belgium
http://www.em-dat.net/

Land cover database: Institute for Environment and Sustainability, Joint Research Centre, Ispra, Italy
http://ies.jrc.ec.europa.eu/global-land-cover-2000

Appendix D - Drought

Author:

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The following people provided essential contributions to this study:

Gregory Yetman headed all GIS analysis, supported by the efforts of Maria Muniz, Liana Razafindrazay and Vilentia Mara who undertook the geo-referencing of the EM-DAT drought disaster data and assisted in mapping drought hazard and disasters. All are from CIESIN, Columbia University.

Contents

D1 Introduction

Drought is a naturally occurring phenomenon that affects more people globally than any other natural hazard. Unlike aridity, which refers to a semi-permanent condition of low precipitation (desert regions), drought results from the accumulated effect of deficient precipitation over a prolonged period of time. Here "deficient" refers to values being less than the expected, or long-term average value at a particular location. Ultimately, drought refers to a condition of an insufficient supply of water necessary to meet demand, both being highly location-specific. For example, a few months of deficient rainfall can adversely affect rain-fed agricultural systems while several months to a year (or more) of drought may be necessary to impact a water supply system with substantial storage capacity. Given the varying impacts of drought several drought indicators are in use around the world. The "best" indicator is the one that most closely corresponds to the specific drought-sensitive application being considered.

Drought is often described as falling into three main categories: *meteorological*, *agricultural*, and *hydrologic*. Meteorological drought refers to a prolonged period of deficient precipitation that may last from a season to several years. Agricultural drought occurs when soil moisture is depleted to the point where it begins to adversely affect crops, pasture, or rangeland. A reduction in soil moisture is in part related to precipitation but also depends on other meteorological conditions such as temperature and wind as well as non-meteorological factors such as soil type and terrain. Hydrologic drought refers to a condition of persistent, below-average surface water levels in rivers, streams, lakes and reservoirs or subsurface water such as an unusually low water table. These conditions are again partially related to precipitation variability but also to non-meteorological factors. Given the importance of non-meteorological factors, there is often a delay between the onset of meteorological drought and agricultural or hydrologic drought.

Among natural hazards, drought risk is especially difficult to quantify. First, unlike earthquakes, floods or tsunamis that occur along generally well-defined fault lines, river valleys or coastlines, drought can occur anywhere (with the exception of deserts where it doesn't have meaning). Defining what constitutes a drought across the wide range of regional climates around the globe is challenging in its own right, identifying what drought characteristic (its intensity, duration, spatial extent) is most relevant to a specific drought-sensitive sector (agriculture, water management, etc.) poses another layer of complexity. Drought does not destroy infrastructure or directly lead to human mortality. Famines may be triggered by drought but increased human mortality during famine is ultimately linked to a broader set of issues surrounding food security. Thus, once a methodology for defining drought is achieved, evaluating mortality risk from drought remains a region-specific challenge.

Despite these challenges, in contrast to other natural hazards drought is a slow onset phenomenon making it particularly amenable to the development of early warning systems. In addition to its slow onset, a major climate factor leading to drought, particularly in tropical locations, is the El Niño-Southern Oscillation (ENSO) phenomenon. Generally speaking, El Niño events are associated with drought across much of Indonesia, India, the Philippines and eastern Australia while also affecting many other regions of the globe. Advances in climate science have made possible skillful seasonal predictions of both ENSO and its associated seasonal rainfall variations with three or more month lead-time. Thus, the combination of real time drought monitoring and availability of seasonal rainfall forecasts constitutes a solid foundation for a drought early warning system.

Figure D1 shows the number of geo-referenced drought disasters recorded in EM-DAT during the period 1974-2004.

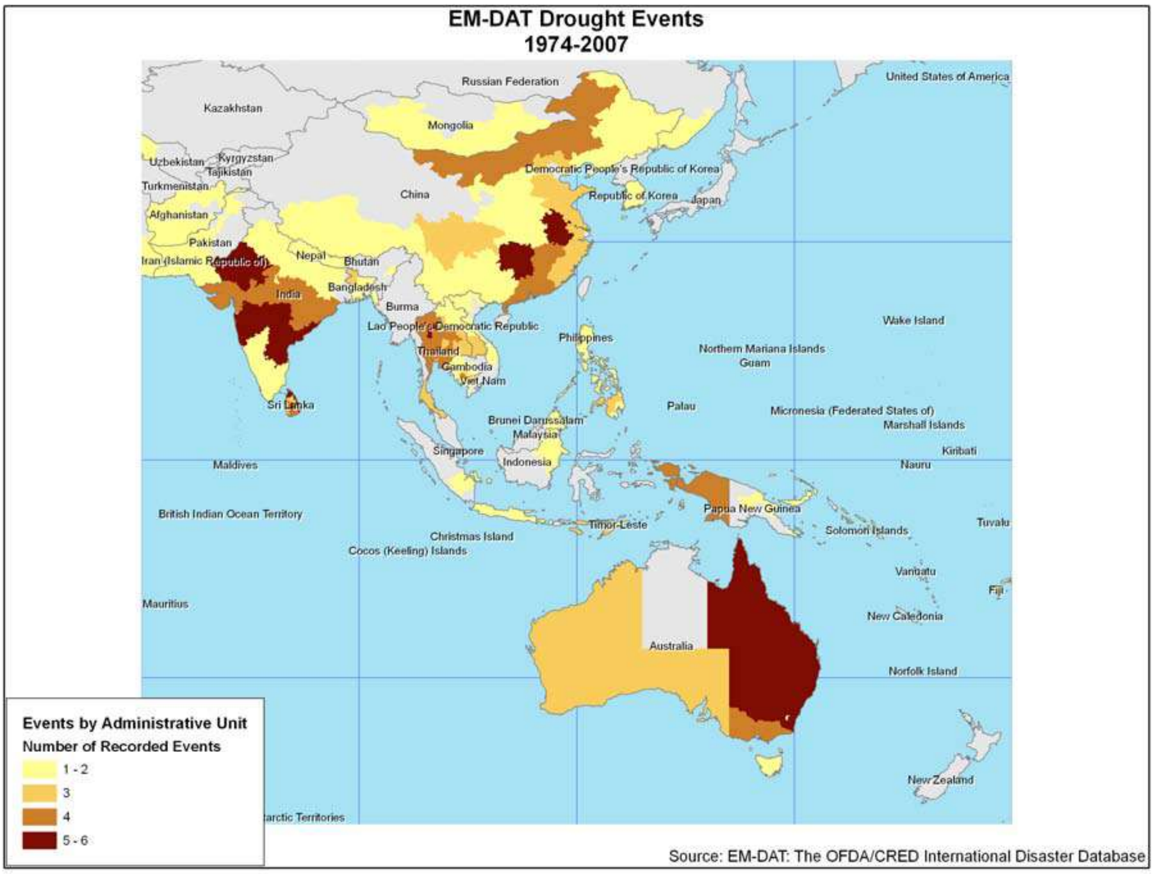

Figure D1 Number of geo-referenced drought disasters recorded in EM-DAT 1974-2004.

D2 Drought Impacts, Vulnerability, and Early Warning

Unlike other natural hazards, drought does not result in damage to infrastructure nor does it directly cause human fatalities. Rather, the impacts of drought are associated with the myriad ways in which reduced water supplies affect human populations and the natural environment. Drought affects crops, pasturelands, drinking water supplies, water quality, and various types of industry. Rain-fed agricultural systems, particularly those in regions of high precipitation variability, are especially vulnerable to drought as are public water supplies having small storage capacity. Famines and increased human mortality, while often directly linked with drought, more accurately result from complex issues surrounding food security. Drought may reduce crop yields but the availability of food is affected by many non-climate factors as well including civil conflict, economic shocks and the ability to buy food, the lack or mismanagement of governmental or institutional policies that affect access to food, etc. In this sense drought is not a natural disaster, it is a natural event that may trigger human disaster. And famine is not an event it is a process, the collective consequences of largely human factors.

Since drought fundamentally refers to an imbalance between water supply and demand, increasing water use can also increase vulnerability. In addition, it is generally believed that a warming climate will serve to enhance the hydrologic cycle including an increase in surface evaporation which will exacerbate drought conditions regardless of their underlying cause, particularly during the warm season.

Drought early warning capabilities vary substantially around the globe. However, a key element to any successful drought warning system is the ability to monitor the hydrometeorological variables most relevant to drought-sensitive sectors in a timely fashion. Robust ground-based observing systems are therefore crucial to drought early warning as is timely access to remotely sensed data from satellites, which ultimately needs to be calibrated using observations if it is to provide the most utility. In addition, quantifying the relationship between physical indicators of drought and drought impacts is a necessary step in building an early warning system for any location and for specific applications (Wilhite and Buchanan-Smith 2005; Lyon et al. 2008).

D3 Quantifying Drought, its Severity, and Probability of Occurrence

Numerous indicators have been developed to monitor drought many based solely on precipitation. These meteorological drought indicators were often designed for monitoring drought in a specific location, or climate type, and for a specific sector such as agriculture (Hayes et al. 2005). During the 1960s an attempt was made to include variables other than precipitation in order to develop a simple index which mimics the water balance at the earth's surface.

In this model precipitation increases moisture supply and estimated evaporation from the surface reduces it, the difference leading to changes in the estimated soil moisture. More sophisticated land surface modeling approaches have subsequently been developed and are beginning to be used in drought monitoring and forecasting efforts. In many locations, however, precipitation-based drought indices are found to be highly correlated with output from these more sophisticated water balance models.

To be applicable across varying climate regions of the globe the approach in the current study is to look at standardized drought indices. Standardizing allows comparisons of drought index values across regions with different average annual rainfall, for example. Specifically, we will examine the Standardized Precipitation Index (SPI; Mckee et al. 1993). The SPI compares an accumulated precipitation amount for a given time interval (e.g., the past 3, 6 or 12 months) with historical values for the same period. The difference between the observed and historical value is then expressed in terms of a standardized (normal) distribution having a mean of zero (indicating no difference from the historical average). Increasingly negative values of the SPI indicate increasingly drier-than-average conditions, with values less than -1 generally considered to indicate the threshold of drought. Since it is a standardized index, the probability of a given drought level (e.g., SPI = -1.5) is the same at all locations even though the climatological rainfall across locations may vary. See Figure D2 below.

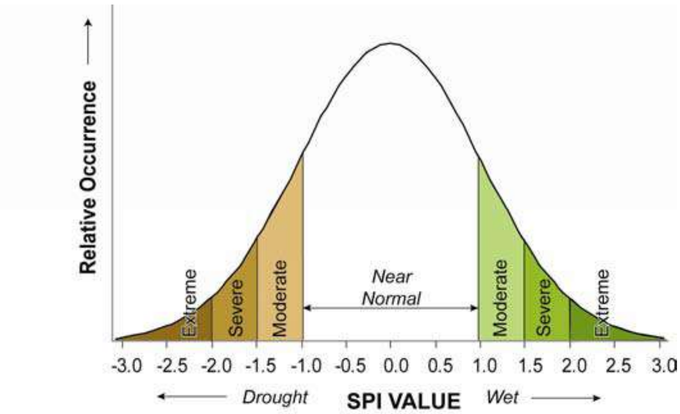

Figure D2 The relative occurrence versus value of the SPI. Index values < -1.0 are associated with drought conditions. Moderate drought occurs < 16% of the time, severe drought < 7%, and extreme drought < 3 %.

Using the SPI to evaluate regional variations in drought characteristics is accomplished by considering runs (i.e. counting the number of consecutive months) when the index remains below a given intensity threshold. This is shown schematically in Figure D3.

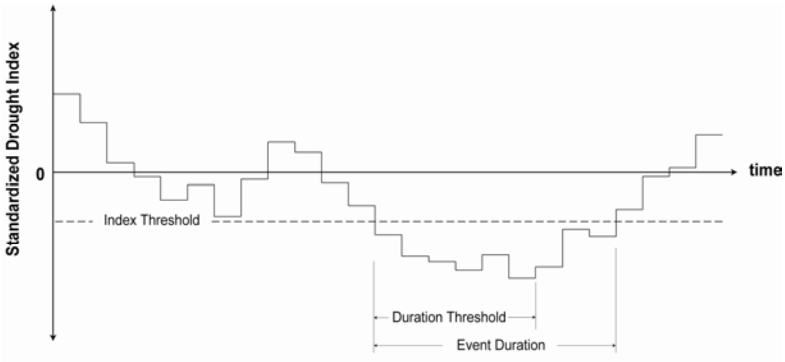

Figure D3 A drought event is identified when the magnitude of the standardized drought index value remains below a prescribed threshold for a minimum, prescribed duration.

For the analysis here, monthly gridded precipitation analyses for the globe were obtained from the Global Precipitation Climatology Centre (GPCC, Rudolf and Schneider 2005). Monthly values of the SPI were then computed for precipitation accumulations over the 3, 6 and 12 month periods. In addition, data representing model estimates of soil moisture were used being obtained from the US Climate Prediction Center (Fan and van den Dool 2004). The soil moisture data were standardized using the same methodology as for the SPI and runs below different indicator intensity thresholds were performed as shown in Figure D3.

Some caveats relating to data quality need to be considered here. The gridded precipitation analyses used are based solely on station observations which are relatively sparse in some regions of the globe leading to greater uncertainty of the precipitation in those locations. In addition, the number of stations used in generating the monthly precipitation grids can vary over time and with location. Observed precipitation is also a key input to the model used to estimate soil moisture making the soil moisture estimates used here subject to similar uncertainties in data sparse regions. Despite these concerns, however, the data sets used here represent a substantial improvement over those utilized in the Global Hotspots drought analysis as they a) are at a much higher spatial resolution, b) are for a longer analysis period, and c) include both precipitation and soil moisture drought indicators).

D4 Quantification of Drought Hazard

D4.1 Overview

The primary goal of this activity is to enhance the drought hazard and impact analysis from that which was done in the Natural Disaster Hotspots project. As outlined below, the primary improvements will be made through 1) enhanced spatial resolution of drought hazard indicators, and 2) geo-referencing of drought disaster information.

This section describes the overall methodology to be used in this effort. The specific datasets to be employed are also briefly described. Analysis of drought exposure and mapping of geo-referenced drought disasters and drought indicators was undertaken at CIESIN, Columbia University.

D4.2 Methodological Approach

D4.2.1 *Drought Indices*

Given that no universal definition of drought exists, no single drought index can successfully capture the characteristics of the phenomenon most relevant to a particular application (e.g., agriculture, water management, etc.). Given this need for flexibility, the approach here was to analyze drought hazards using multiple indicators that are based on the Standardized Precipitation Index (SPI; Mckee et al., 1993). The SPI is computed using only monthly precipitation. An advantage of the SPI is that it can be used to examine different time scales of interest, for example, a season (3 months) to annual (or longer). The same routine used for computing the SPI was also applied to model estimates of monthly soil moisture (SM) from a land surface model (Fan and van den Dool 2004) to generate standardized indices of that variable, which hereafter will be referred to as the SMI.

D4.2.2 *Characteristic Time Scales for Drought*

Both the SPI and SMI indices were evaluated for different time periods (3, 6, and 12 months). These varying time scales allowed for an analysis of the sensitivity of impacts (based on drought disaster information in the EM-DAT database, 1975-2004) to different characteristic timescales of drought. The SPI and SMI were computed for the full range of available precipitation and soil moisture data namely, 1951-2004.

D4.3 Comparative Drought Characteristics

To examine the relative occurrence of drought "events" across the globe, run statistics of various drought indices were assessed. This analysis was performed at the grid point level and runs in the SPI and SMI time series when index values fell below different truncation levels (thresholds) were evaluated. The duration (D) of a drought was indicated by the length of time (in months) that the index remained below the truncation level (e.g., SPI < -1.0), while the severity (S) of the drought was defined as the sum of the departures from the truncation level over the duration. A measure of average drought Intensity (I) is obtained from the simple relationship $I = S / D$. This approach is widely used in the analysis of hydrometeorological time series and drought frequency analysis (Dracup et al. 1980; Clausen and Pearson 1995; Fernández and Salas 1999; Keyantash and Dracup 2002; Sirdaş and Şen 2004; among many others). A schematic of the relevant quantities is shown below in Figure D4.

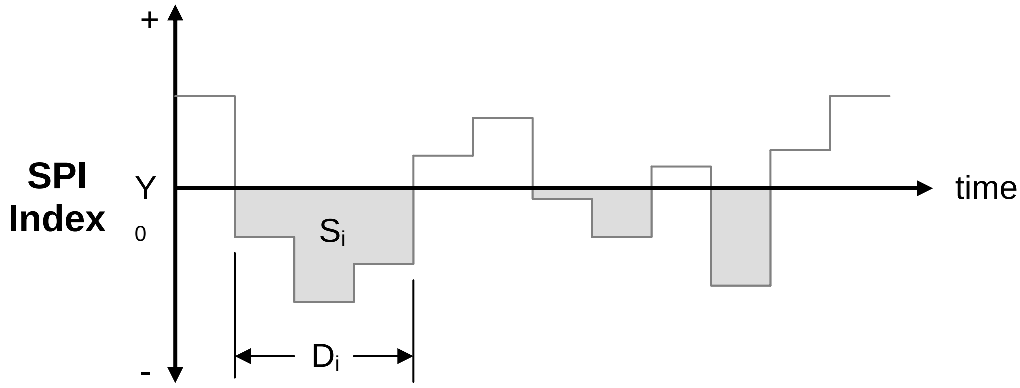

Figure D4 *Time series of the SPI at a given grid point. Here Y_0 represents the truncation level for defining drought events (which could be set at SPI = 0, -1, -1.5, etc.), D_i is the duration of the i^{th} drought event, and S_i indicates its severity (the sum of index values below the truncation level). The average intensity, I_i, of the drought is given by $I_i = S_i / D_i$.*

By design, the SPI and the SMI have standard normal distributions (zero mean and unit variance) and as such, the frequency of occurrence of the index being below a specified truncation level is essentially the same at all grid points. For example, the SPI will have values below zero (below minus one) 50% (16%) of the time period over which the index is calculated (here 1951-2004), at all locations. Therefore the relative frequency of SPI index values below a given threshold are known *a priori* and will not provide useful information on relative occurrence of drought across different regions. However, the duration, D, of individual drought "events" (i.e., runs below threshold) is not similarly constrained and will exhibit spatial variability from one location to another when there are local differences in the persistence characteristics of the SPI. For example, a run below threshold of duration D = *n* months is more likely to persist to D = *n* + 1 months at locations where the monthly autocorrelation of SPI is high (e.g., Schwager 1983; Fernández and Salas 1999). In this part of the analysis, different SPI indices and truncation thresholds were used to examine the relative occurrence of associated droughts exceeding specified durations. In addition, the relative severity, S, of drought events so identified was also considered. The specific analyses are detailed below:

D4.4 Summary Statistics

1. Using global precipitation and soil moisture datasets time series of different SPI and SMI indices (3, 6, 12-month) were generated at all global land area grid points (excluding Antarctica), 1951-2004.

2. Based on the above indices and varying truncation levels of SPI and SMI (-1.0, -1.5) the relative frequency of occurrence of drought events exceeding specified durations (e.g., 3, 6, 12 months) were examined across global land areas. A seasonal mask was applied to the drought indicator data fields such that they were not analyzed during climatological dry seasons. The dry season was defined as a string of at least 3 consecutive months with average monthly precipitation (in each month) that was less than 5% of the total annual precipitation.

D4.5 Drought Events and EM-DAT Drought Disasters

1. All drought disasters within the EM-DAT database were geo-referenced to identify, to the extent information is available within the database, the geographical region (e.g., province or provinces) within a country that were most closely associated with the drought disaster. For the globe, there are roughly 400 drought disasters in EM-DAT over the period 1975-2004 that were geo-referenced.

2. Time series of monthly values of the SPI and SMI indices (for different integration times as described in item (1) of the previous section) were then used for comparison of individual drought events with drought disasters in EM-DAT (1975-2004). The objective here was to examine whether threshold values of drought indices (severity, duration) can be identified that are most closely associated with drought disasters. This included analyzing the fraction of the region having drought index values below threshold, area-average drought index value for the region, etc.

3. Since the EM-DAT data typically contains disaster information for only the most severe drought cases the sample size can be quite limited for many countries making robust statistical comparisons impossible for an individual country. However, we are considering a global analysis to see if common characteristics of drought emerge in terms of their relationship to disasters.

D4.6 Data

D4.6.1 *Precipitation Data*

Monthly, gridded precipitation analyses for the globe were obtained from the Global Precipitation Climatology Center (GPCC). These analyses are based on station observations which have been spatially interpolated to generate gridded analyses at a 0.5 x 0.5 deg. lat/long resolution. The available data covered the period Jan 1951 to Dec 2004. Although gridded to a nominal 0.5 x 0.5 deg. lat/lon. grid, the precipitation analyses are likely to contain larger errors in data sparse regions. Another caveat in using these data in the context of precipitation-only drought indices such as the SPI is that other parts of the surface water balance such as infiltration, runoff, and evaporation are not considered.

D4.6.2 *Modeled Soil Moisture for the Globe*

The soil moisture (SM) data used were obtained from the US Climate Prediction Center (CPC). The soil moisture data are monthly values gridded to a 0.5 x 0.5 deg. lat/long spatial resolution. These are estimated values of SM, as they are output from a hydrologic model which utilizes monthly, global precipitation analyses and surface temperature data as inputs. Based on these input variables, the model calculates other terms in the water balance, including soil moisture. Again, though nominally gridded to 0.5 x 0.5 deg. spatial resolution, these data are only as reliable as the inputs which are based on station observations which have varying spatial coverage. For more details on the soil moisture data see Fan and van den Dool (2004).

D4.7 Limitations

The global scale analysis undertaken in this study has some important limitations. First, variations in regional climate which are associated with small scale topographic features, such as rain shadows, will likely not be well captured in the drought analysis. More generally, the issue of data quality in regions with sparse precipitation observing stations needs to be kept in mind. Using the calendar year as the period in which drought events are identified may obfuscate the occurrence of events that develop near the start, or end, of a given year. These factors limit the applicability of the results reported here to the scale of individual countries or sub-national regions. For such cases a finer scale analysis, using higher density observations as input to the drought indicators is required. In addition, the drought disaster data in the EM-DAT database emphasize only the most severe droughts making it likely that many drought impacts, particularly at the sub-national scale, are not included. This is particularly true for countries with comparatively low vulnerability to drought and therefore are much less likely to have a drought disaster recorded in the EM-DAT database.

D5 Results

The various drought indictors were first compared with the occurrence of drought disasters within the EM-DAT database. Drought events identified (on a grid point and calendar year basis) when the SPI and SMI remained below -1.0 and -1.5 for at least 4 and 2 months, respectively were first flagged in a binary fashion (1 = drought event, 0 = no event). The area of intersection between these drought event regions and the geo-referenced drought disaster events in EM-DAT was then computed for each event within a given year (1975-2004). Two criteria were then considered in determining which drought indicator showed the closest correspondence with drought disasters: 1) the "hit rate" indicating at least some overlap between a drought event and a disaster and 2) the area of intersection between the drought disaster and drought event indicators when there is a "hit". The idea behind the second criterion is that a minimal intersection between a drought indicator and disaster region may not be indicative of a real cause and effect relationship, so the greater the area of intersection, presumably the better. The hit rates and area of intersection were computed for each indicator and ranked (highest to lowest). The sum of the ranks for the two criteria provided the indication of the best overall drought indicator.

Based on the combined ranking the best overall drought indicator was found to be the 6-month SPI used to identify drought events that met the thresholds of SPI < -1.5 for 2 or more consecutive months. This result indicates the more severe the drought the better the association with a disaster in EM-DAT. That the 6-month SPI shows the best relationship also suggests that it is the character of the full rainy season in monsoon regions (areas which dominate the disasters in EM-DAT) that is most relevant in terms of having the most severe impacts.

D6 Relating Drought Indicators and Geo-referenced Disaster data in EM-DAT

For the period 1975-2004 there are **(???)** drought disasters recorded in the EM-DAT global database. Within the EM-DAT records many of these disasters have information indicating their geographic location (typically some administrative region) within a particular country. All available information within the EM-DAT data was therefore used to geo-reference the drought disasters. Of the **(???)** drought disasters in EM-DAT, **(???)** were geo-referenced to the sub-national scale. For a given calendar year, the location of individual drought events (identified using the standardized indicators) was then overlaid on the geo-referenced locations of recorded drought disasters using GIS software. This allowed for an examination of what drought indicators were most closely associated with disasters and, using global population data, to assess the human population exposed to drought events over the period of study.

D7 Next Steps

Hydrologic modeling is advancing rapidly and global analyses of several output variables (estimated soil moisture, runoff, evaporation) are being developed for estimating historical conditions and in real time monitoring. While there are caveats concerning the calibration of these models they provide information at fairly high spatial resolution and represent the next generation of modeled soil moisture products from those used here. In future efforts these data can be compared with precipitation-based drought indices and with drought impacts reports.

For future work it is recommended that drought impacts research be conducted on a regional (or national) versus global scale where sufficient high quality and high spatial resolution data exist. Data with high spatial resolution are necessary for both the drought indicators and for quantifying application-specific impacts (agriculture, water supplies, etc.).

The potential effect of global warming on the physical characteristics of drought (intensity, duration, spatial extent) represents another important area of research that clearly has implications for human impacts.

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For Further Information

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Helpful URLs:

Early Warning Systems for Drought Preparedness and Drought Management. Workshop summary from the US Drought Mitigation Center, University of Nebraska, Lincoln. http://drought.unl.edu/monitor/EWS/EWS_WMO.html

Appendix E - Tsunami

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Contents

E1 Introduction

Tsunamis are waves set in motion by large and sudden displacements of the sea water, having characteristics intermediate between tides and swell waves. Although tsunamis are infrequent (ca. 5-10 events reported globally pr. year), they do represent a serious threat to the coastal population in many areas, as demonstrated by the devastating effects of the 2004 Indian Ocean tsunami. Tsunamis are often generated by submarine earthquakes. However, submarine landslides are becoming increasingly recognized as important triggers as well. Other sources of tsunamis include collapsing/exploding volcanoes, and asteroid impacts. Tsunamis generated by large earthquakes in subduction zones (area where one continental plate moves beneath another) along the major plate boundaries contribute most to the global tsunami hazard.

When the tsunami is generated, it propagates in the open sea with speeds of several hundred kilometers per hour, and may hence reach coastlines distant from the earthquake within a relatively short time. The wave slows down when it reaches the shoreline, and its height increases. Because of its relatively large wave-length, the tsunami may travel far inland compared to wind waves and swells, and because of its relatively short period, it inundates much faster than tidal waves and storm surges. When the tsunami inundates land, flow velocities become large, enabling the tsunami able to carry very large objects, erode the landscape, and destroy buildings. The tsunami becomes lethal both due to possibilities of being impacted by structures and flotsam, as well as drowning. Generally, tsunamis may cause damage to most coastal structures; however, buildings of poor quality are particularly vulnerable. The tsunami is most destructive close to the shoreline where the flow velocity and wave load are largest.

E2 Objectives and outline

This appendix presents a synthesis of completed and ongoing studies of tsunami hazard and risk, utilizing reports obtained from leading international organisations on tsunami hazard, as well as results from regional projects on tsunami hazard and risk conducted by NGI. In addition, results from a number of journal papers are included in the analyses. The above mentioned results are also supplemented by a limited number of scenario computations for selected hotspot areas. The literature sources are listed in Table E1, and the list of scenario simulations are listed in Table E2.

The different tsunami risk and hazard studies compiled herein are conducted by different organisations, and for different clients and purposes. As a consequence, the reported tsunami hazard and risk is a patchwork of those methods. However, the results are unified to present the tsunami surface elevation at the shoreline for a 475-year tsunami (10% probability of occurrence in 50 years).

Owing to the need for investigating a large portion of the globe, the quantification of the tsunami hazard is crude and focuses on overall trends rather than details. The results of the study is therefore a first-pass assessment of the tsunami hazard and risk based on today's knowledge, and should therefore not be considered as complete. The study will focus only on earthquake generated tsunamis, and mostly on tsunamis caused by megathrust earthquakes, as the largest events will often contribute more to the risk than the smaller events (Nadim and Glade, 2006). It is stressed that non-seismic sources (landslides, sub-aerial slides, and asteroids) are not included in this study, and that such sources may contribute to the total risk.

This appendix is organised as follows: In the main body of the report, we first present some key terminology and definitions needed for the subsequent chapters and appendices. We then give a brief description of the methodology used for producing the hazard data as well as the exposure. Examples of the resulting hazard data and exposure are then presented. A discussion of the limitations of this study is then presented, and finally the main findings are summarised. The work leading up to the tsunami hazard and risk study described in this appendix, is closely linked with the Global Risk Update (NGI 2009a, NGI 2009b). For more details on the tsunami scenarios, methods, and literature review, we therefore refer to NGI (2009a) and NGI (2009b) for more details.

Table E1: Literature sources for tsunami hazard maps

Region	Method	Reported metric	Reference
Indonesia - Banda Ache	Credible worst case	Run-up	Sengara et al. (2008)
Western Thailand	Credible worst case	Shoreline surface elevation	Løvholt et al. (2006)
Western Australia and southern Java	Probabilistic	Surface elevation at 50m water depth	Burbidge et al. (2007)
South China and Taiwan	Probabilistic	Run-up	Liu et al. (2007)
Indonesia - Makassar Strait	Probabilistic	Run-up	Prasetya et al. (2001)
Japan – East coast	Probabilistic	Run-up	Annaka et al. (2007)
Japan – West coast	Historical records	Run-up	Rikitake and Aida (1998) - from Shimazaki (1984)
New Zealand	Probabilistic	Run-up	Berryman et al. (2006)

Table E2: Scenario simulations

Fault	Location	Moment magnitude M_w
Western Sunda Arc	Along Andaman Islands	8.5
Western Sunda Arc	From Great Nicobar to Little Andaman	8.6
Western Sunda Arc	From northern Sumatra to Great Nicobar	8.6
Western Sunda Arc	Along Midwestern Sumatra	9.2
Western Sunda Arc	Along the South-western Sumatra	9.1
Burma Fault	From the Ayeyarwady delta (Myanmar) to Chittagong (Bangladesh)	8.9
Makran Fault	Along the Pakistan coast	8.4
Bali Thrust	North of Bali/Sumbawa	7.9
Flores Thrust	North of Flores Island	7.8
Western Sunda Arc	Deep Java Trench north of Bali	8.4
Western Sunda Arc	Deep Java Trench north of Flores	8.4
Banda Sea	South of Kepulauan Sula	8.2
Banda Sea	Weber Basin	8.1
Banda Sea	South of Ambon Island	8.1
North Sulawesi Fault	North of Sulawesi	7.9
North Sulawesi Fault	North of Sulawesi	7.9
New Guinea Trench	Western Irian Jaya, north of Biak Island	8.6
New Guinea Trench	Eastern Irian Jaya	8.5
New Guinea Trench	Western Papua New Guinea	8.6
Philippine Trench	South East Mindanao	8.4
Philippine Trench	North East Mindanao	8.4
Manila Trench	West of Luzon Island, northern Philippines	8.2
Tonga Trench	Northern part of Tonga trench	9.0
Tonga Trench	Southern part of Tonga trench	9.0
Kermadec Trench	Northern part of Kermadec trench	9.1
South-Solomon Trench	Eastern Solomon Islands	8.3
South-Solomon Trench	Mid Solomon Islands	8.2
South-Solomon Trench	Western Solomon Islands	8.4
South-Solomon Trench	Bougainville Island - Papua New Guinea	8.2
South-Solomon Trench	New Britain Island - Papua New Guinea	8.3
New Hebrides Trench	Southern Vanuatu	8.6
New Hebrides Trench	Northern Vanuatu	8.6

E3 Terminology

Here, we list some definition of terms that apply to this appendix. The list is by no means meant to be complete, but rather a help for improving the readability of this report, as well as avoiding confusion.

- **Moment magnitude** (M_w): Based on the seismic moment and computed directly from source parameters or from long period components in the earthquake record.

- **Return period** (T): The mean (average) time between occurrences of an event of a given moment magnitude or wave-height. The wording recurrence rate is also used.
- **Surface elevation** (η): Water level above equilibrium (mean sea).
- **Shoreline wave-height** (η_C): Here defined as the water level above equilibrium (mean sea) at the shoreline. The definition applies to the tsunami models used in this report, which does not include inundation. For non-breaking waves, this quantity equals the run-up.
- **Inundation length**: Maximum horizontal distance reached by the tsunami inland from the equilibrium shore line.
- **Run-up**: The vertical level reached by the wave at the inundation limit on land above equilibrium (mean) sea level.
- **Danger (*Threat*):** Natural phenomenon that could lead to damage, described by geometry, mechanical and other characteristics. Description of a threat involves no forecasting.
- **Hazard** (H): Probability that a particular danger (threat) occurs within a given period of time. Here, the tsunami hazard is defined as the probability of the shoreline wave-height or run-up exceeding a critical level.
- **PTHA :** Probabilistic Tsunami Hazard Assessment.
- **Exposure** (E): Here defined as the population living within a potentially affected area.
- **Vulnerability** (V)**:** The degree of loss to a given element at risk, or set of such elements, usually expressed on a scale from 0 (no loss) to 1 (total loss). An example of the vulnerability for tsunamis is the mortality.
- **Risk** (R): Measure of the probability and severity of an adverse effect to life, health, property, or the environment. Quantitatively, $R = H \times E \times V$. This can be also expressed as "Probability of an adverse event times the consequences if the event occurs".
- **Longitude** (ψ)**:** Longitude, defined as positive East and negative West. In some figures transformation of the longitude is applied for convenience, when computational domains cross the date line.
- **Latitude** (φ): Latitude, defined as positive North and negative South.

E4 Method for tsunami hazard and exposure quantification

E4.1 Quantification of tsunami hazard

The results quantify the tsunami hazard as the maximum surface elevation at shoreline with probability of exceedance of 10% in 50 years (i.e. nominally 475 years return period). Due to the large return periods as well as the large geographic extents investigated, a so called "credible worst case scenario" approach was applied. Nadim and Glade (2006), argues that the most rational approach for estimating the risk associated with future tsunamis is to consider scenarios of plausible extreme, tsunami-generating earthquake (and/or tsunami-generating submarine slide) events, compute the tsunami wave heights triggered by these events, and estimate the upper and lower bounds on the annual probability of occurrence of these scenarios.

E4.2 Earthquake source modelling

The megathrust earthquake scenarios considered are confined to those with the potential for tsunami generation due to co-seismic dip-slip motion, as strike-slip fault movement is generally less important for wave generation. For the study areas, earthquakes of given width, length and slip are established, and in turn converted to seabed displacement using standard analytical formulas like Okada (1985). These earthquake widths, lengths, and slip values are either established based on information available in literature or selected to a certain extent to comply with the parametric relations of Wells and Coppersmith (1994). However, it is noted that Wells and Coppersmith (1994) are based on earthquake data of moment magnitudes up to about 8. Our scenarios generally involve larger magnitudes with a few exceptions. The predefined sources are used as initial conditions for numerical tsunami simulations.

E4.3 Scenario return period

Return periods for sections of fault zones are inferred from literature where available. Otherwise, we establish them based on fault zone convergence rates, with a few exceptions using the study of Bird (2003) as the source. Assuming that the slip rate D_t equals the convergence rate, we find the return period T from the slip D by assuming that the earthquake slip $D=D_t \cdot T$ over the duration of the return period. We also assume that the earthquake fault zone is so called "memory free", meaning that the probability of a future event is independent of the occurrence past or recent events. However, it is noted that one exception is made to the "memory free" assumption, namely in the area close to the 2004 Indian Ocean tsunami.

E4.4 Wave propagation modelling

Near field and regional tsunami propagation are be modelled using a linear dispersive wave models (Pedersen and Løvholt, 2008), on publicly available computational ETOPO2 grids. For convergence, the grids are refined to the desired resolution by bi-linear interpolation. The wave heights are extracted at near shore control points, normalized to a small reference depth, where the further amplification to the shoreline is roughly computed using the method described below.

E4.5 Amplification from to control points to the shoreline

The amplification of the wave-height from the control points to the shoreline is obtained a numerically based database of simulations of very fine grids near the shoreline. The simulations are performed employing linear hydrostatic waves simulations along two-dimensional transects. The procedure is based on the findings of Carrier and Greenspan (1958), showing that for non-breaking waves, linear hydrostatic models with a vertical wall at the shoreline produces the correct run-up. The method for obtaining the near shore amplification is verified both by comparing samples of the linear hydrostatic wave simulations with the TSUNAMICLAW run-up model along the same transects, as well as conducting some few three-dimensional run-up simulations using the ComMIT model. However, it is stressed that due to the extent of large geographical regions, run-up simulations incorporating local effects are not conducted.

E4.6 Calculating the exposed population

Based on the shoreline wave-heights, rough inundation maps were computed for the purpose of counting the population exposed to the tsunami. The inundated area was first computed by interpolating the shorelines wave-heights at the different points along the shoreline, thereby covering all the topography below the shoreline wave-height. As mentioned above, the dataset for global sea-level rise were utilized for this purpose. However, it turned out that for some very flat near shore locations, the inundation distance could turn out to be unreasonably high. A simple formula for the maximum inundation distance I_{max} given by

$$I_{\max} = \sqrt{g\eta} \cdot T / 4$$

was therefore used to limit the inundation distance. The formula is assuming that the wave travels inland with a propagation speed of $(g\eta_C)^{1/2}$ for a quarter of a predefined wave period, and therefore give a rough upper bound of the inundation length.

For the production of the population exposure maps, all the layers used in the map have been projected to the Berhmann Projection (WGS 84). The boundary layers follow the United Nations Cartographic protocol concerning the disputed territories. The global inset map has been projected into Lambert Azimuthal Equal Area at a 100° central meridian origin. The regional population density has been defined manually in ArcGIS in order to display coherently the different affected regions. The extent of tsunami inundation do not define the actual length of inundation, a buffer of 25km has been used only for a visual purpose. Local maps focus on the main impacts of tsunami inundation in the project areas of interest, and the scale used has been chosen manually as the angle that best represents the inundation areas. The breakdown density of population used for classification is based on natural breaks at a country basis. It is noted that there is a discrepancy in the shoreline reference and the exposure data in the visual display. The offset between the shoreline and the exposure data is therefore artificial.

E4.7 Extension to risk

In this appendix, the vulnerability *V* is not computed as it involves factors as lethality as a function of flooding levels, the arrival time of the event, early warning systems, awareness of local population, and structural design of buildings. Computing the risk associated with tsunamis is a challenging task, especially when the aim is to quantify the tsunami risk in terms of the expected number of annual fatalities. Catastrophic tsunamis are relatively rare events and reliable data to establish models for quantitative risk estimation are currently not available. The tsunami risk is not only a function of the number of exposed people, it is also function of when the tsunami happens (time of day, season of the year, weekend or week day, …), the travel time of the tsunami, whether or not an effective tsunami warning system is in operation, awareness of the exposed people about the tsunami phenomenon, availability of escape routes and “safe” grounds, etc.

E5 Results

E5.1 The tsunami hazard

Important areas of tsunami generation in Asia Pacific includes the following major subduction zones, namely the Sunda Arc ranging from western Indonesia to the Philippines, the Philippine trench, the Manila trench, Makran south of Pakistan, and the New Guinea trench. Moreover, the coastlines facing the Pacific are all exposed to far-field tsunamis generated along the so-called “Ring of Fire” located along the perimeter of the Pacific Ocean.

The overall tsunami hazard map for Asia Pacific is shown in Figure E1. A more dense hazard datasets were available for eastern Indonesia, a close up of the tsunami hazard map for this region is displayed in Figure E2. Indonesia is the country exposed to the largest wave-heights found in this study, ranging from 5 to 20m over large parts of the country.

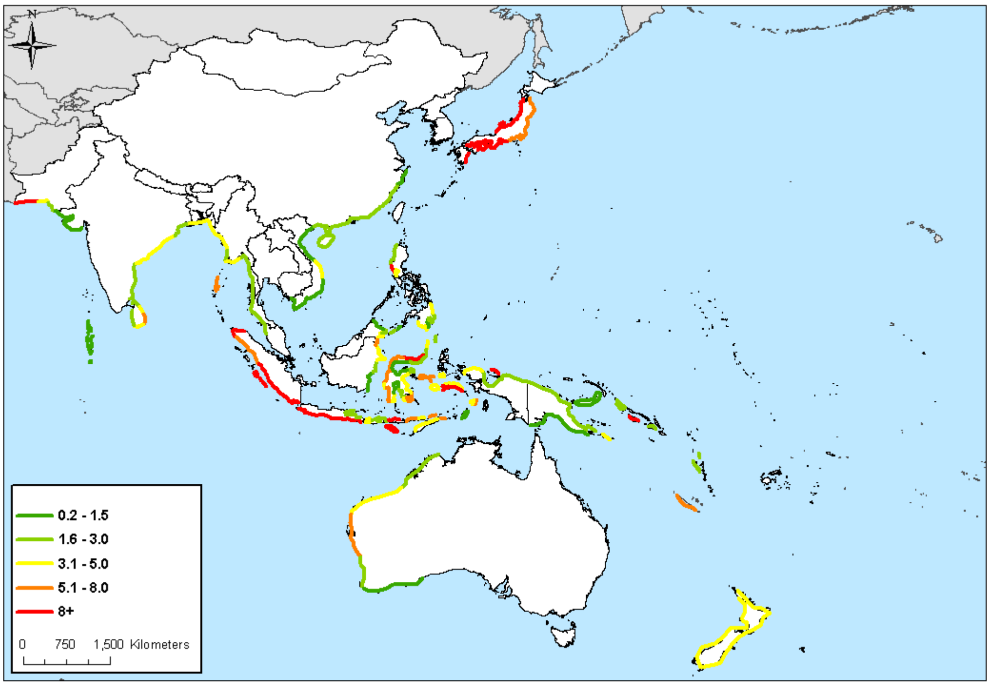

Figure E1 *Tsunami hazard map for Asia-Pacific. Note: The coastal areas with no tsunami hazard indicated on map mostly represent areas where no data are available.*

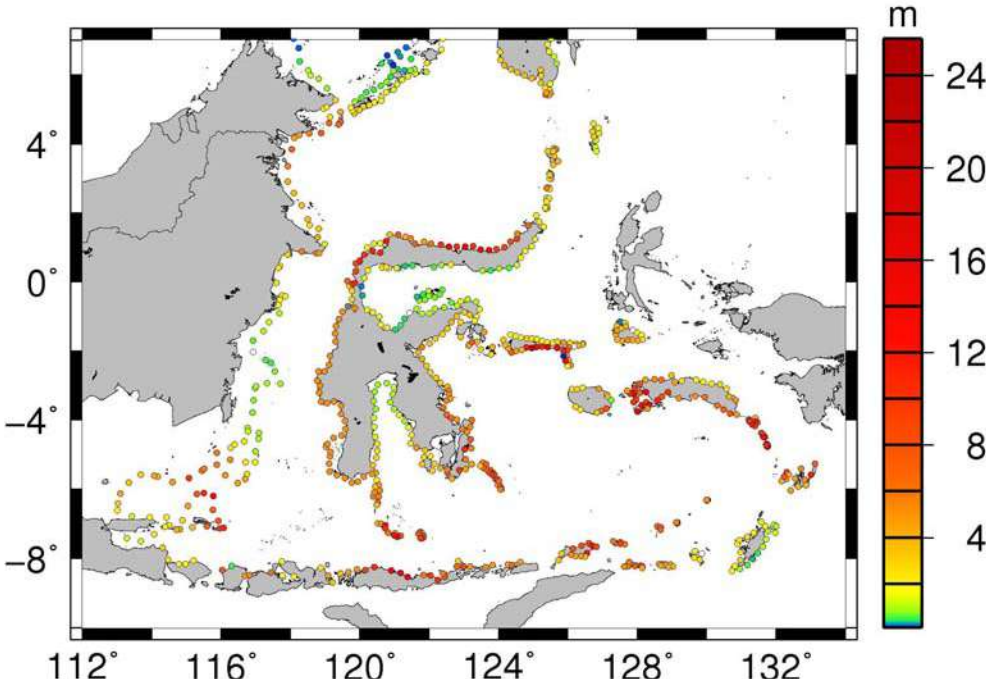

Figure E2 *Maximum shoreline elevation map for parts of eastern Indonesia. Note that results for some areas (for instance Irian Jaya and coastlines facing the Indian Ocean), the hazard data are omitted in this plot.*

In addition to the shoreline wave-height, we have computed the arrival time of the tsunami. The arrival time is important, as the possibility for successful warning of the tsunami is increasing with the arrival time. Examples of results of the shoreline wave-height and the arrival time are shown in Figure E3. Table E3 shows the symbols used to display both the wave-heights and arrival times. Note that for all results, the date line indicates directions of east and west. This might sometimes be counterintuitive, particularly when referring to the eastern and western parts of the Pacific. For instance, short travel times are often associated with tsunami impact in Indonesia, which makes tsunami early warning difficult.

Table E3: Symbols used to display maximum shoreline wave-heights and arrival time.

Wave height → / Arrival time ↓	< 2 m	2-4 m	4-10 m	>10 m
< 30 min				
30-60 min				
> 60 min				
Not available				

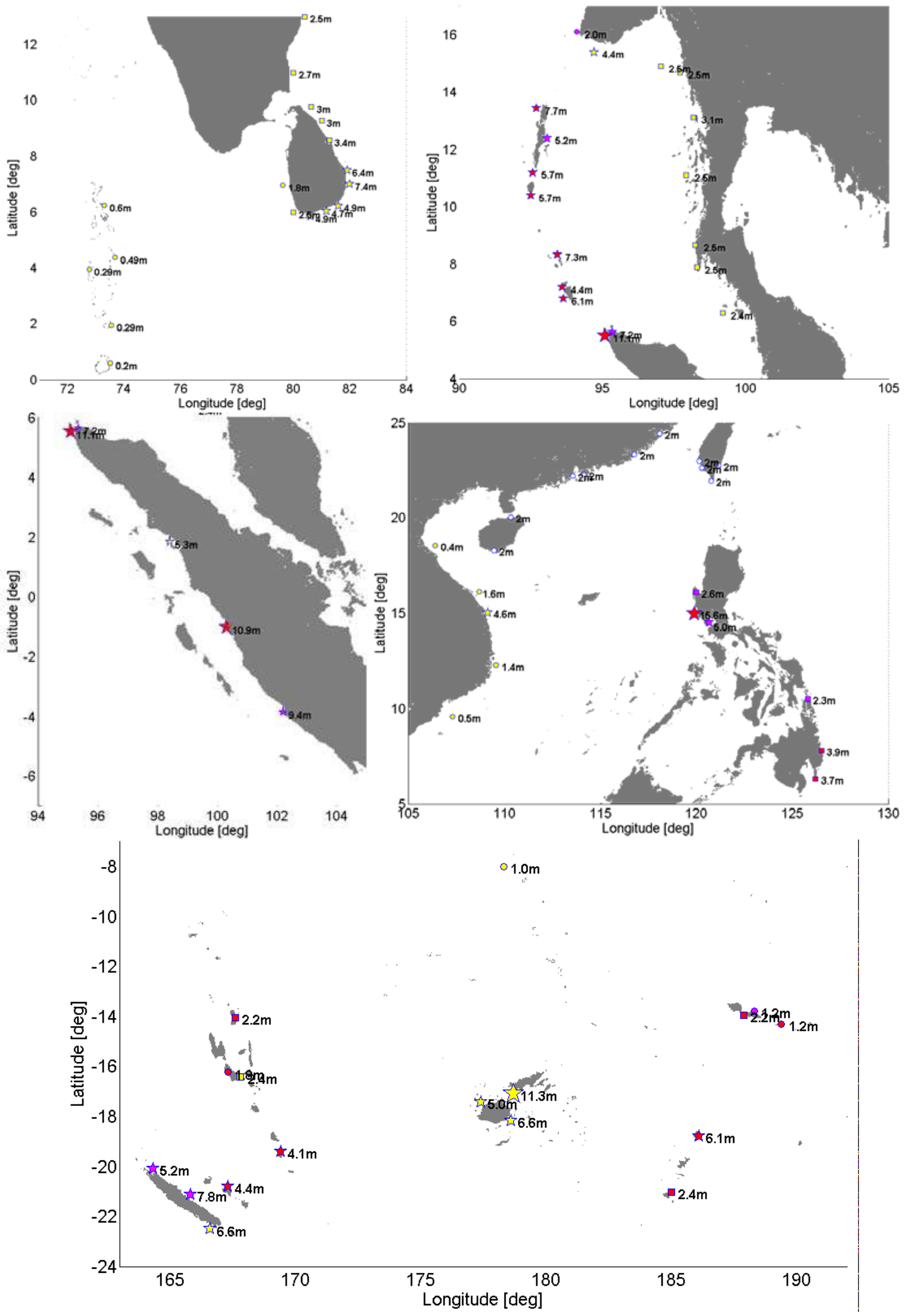

Figure E3 *Maximum shoreline wave-heights and arrival times at control points. Upper left, Sri-Lanka, Southern India, and the Andaman Islands. Upper right, Andaman Sea area. Mid left, Western Sumatra. Mid right, South China Sea and The Philippines. Lower panel, New Caledonia, Vanuatu, Fiji, Tonga, Samoa, and Kiribati.*

E5.2 Tsunami exposure

The density of the population exposed to tsunamis for Asia-Pacific is shown in Figure E4, whereas a close up of the population density for some selected locations are shown in Figure E5. The total number of people exposed to tsunamis are listed in Table E4, and also indicated in Figure E4.

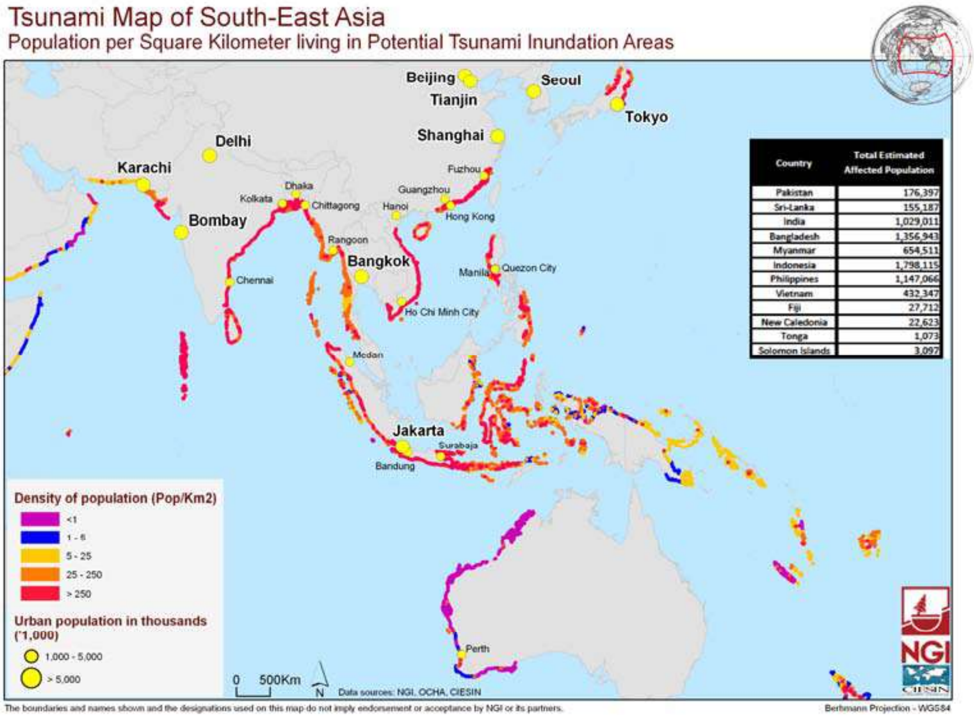

Figure E4: Density of exposed population in inundated areas.

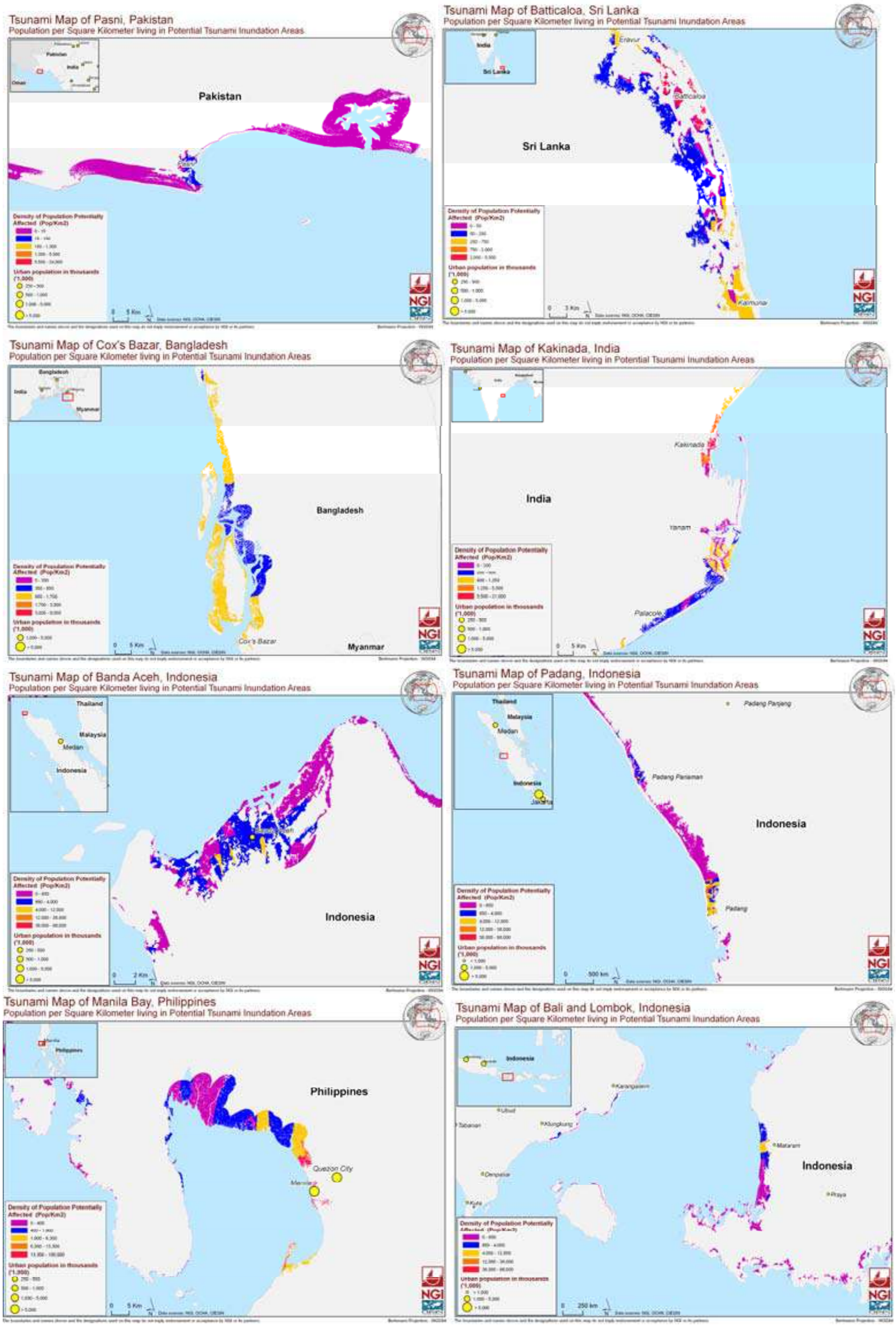

Figure E5 Tsunami exposure in selected locations. The legend indicates the population densities in people/m^2. Upper left, Pashni, Pakistan. Upper right, Batticaloa, Sri-Lanka. Mid-upper left, Cox's Bazar, Bangladesh. Mid-upper right, Kakinada, India. Mid-lower left, Banda Aceh, Indonesia. Mid-lower right, Padang, Indonesia. Lower left, Manila Bay, Philippines. Lower right, Lombok and Bali, Indonesia.

The exposed population in Indonesia exceeds 1.5 million. Similarly, a large number of people could be exposed to large waves in the Philippines. Large population exposure is also found for Vietnam and China, but in these countries the tsunami risk is lower, both because of the smaller waves expected and longer travel times and hence increased possibilities of early warning. The exposed population in Japan is the largest one found within the study region. However, the analysis conducted for Japan was not as extensive as the analysis for the countries in South Asia. With the exception of New Zealand, an order of magnitude smaller population exposure was generally found for the Pacific countries compared to the larger countries in Asia. However, the smaller island countries generally have a similar or higher percentage of the exposed to the total population.

Table E4 : Exposed population to tsunami in Asia-Pacific.

Country	Exposed population in Year 2000	Percent of total population
Australia	13,300	0.07
Bangladesh	1,400,000	1.00
China	720,000	0.06
Fiji	28,000	3.5
Indonesia	1,600,000	0.76
India	1,030,000	0.10
Japan	3,600,000	2.8
Sri Lanka	155,000	0.85
Maldives	22,000	8.0
Myanmar	650,000	1.4
New Caledonia	23,000	11
New Zealand	73,000	1.9
Pakistan	180,000	0.12
Philippines	1,150,000	1.5
Papua New Guinea	1,300	0.02
French Polynesia	850	0.36
Solomon Islands	3,100	0.75
Thailand	11,500	0.02
Tonga	1100	1.1
Vietnam	430,000	0.54
Vanuatu	1,100	0.6
Western Samoa	1,400	0.8

E6 Limitations

Uncertainty in establishing the return periods
The largest and most destructive tsunami events like the 2004 Indian Ocean tsunami are generally posing larger risk to human lives than the smaller and more frequent events. For this first pass analysis, the tsunami hazard maps are focusing on extreme events only, that is, tsunamis generated by large earthquakes of return periods of approximately 500 years. It is noted that establishing the size of infrequently occurring earthquakes are uncertain due to the lack of a reliable long term history in monitoring them. Hence, the return periods for the future tsunamis are not to be interpreted as precise estimates. We also remark that the assumption of a "memory free" fault is somewhat conservative, as areas of recent large earthquake events may actually have a lower probability than the ones interpreted here.

Interpretation of hazard maps and population exposure
Due to the extensive task of covering the whole world, emphasis is given to producing regional hazard maps for less developed countries rather than for countries clearly able to cope with tsunami risk themselves. The methods for establishing the global tsunami hazard maps and population exposure are established based on approximate and simplified methods for covering large geographical areas. These hazard maps are not to be used for detailed local analyses, but rather for comparative and regional studies. In the hazard maps, differences in the reference height of the coastline sections are sometimes encountered. These differences may cause slight offsets between the affected zones and coastlines. We also note that for countries, the total exposed populations may be too low, as there are sections of the coastline that are not investigated. This is particularly the case for large countries, for instance Indonesia and USA.

Non-seismic sources
It should also be noted that tsunamis generated by volcanoes, submarine landslides, rockslides and smaller earthquakes are not addressed in the present study. Non-seismic sources contributes to the generation of about one fifth of all tsunamis globally, and t there are several examples of such tsunamis causing devastation, a recent example is the 1998 Papua New Guinea tsunami caused by a submarine landslide, killing 2182 people (source, http://www.emdat.be).

E7 Summary

Based a combination of findings from tsunami hazard literature and numerical simulations, a the tsunami hazard and exposure for a 475-year tsunami (10% probability of occurrence in 50 years) is established for the most hazard prone areas in Asia Pacific. At this stage, only megathrust and large earthquake events are identified as possible triggers. We identify both the height of the wave (probability of exceeding a shoreline wave-height or run-up) and in addition the arrival-time (the latter only from the numerical simulations). Inundation maps are then created for the purpose of computing the population exposure.

From the hazard analysis, areas of significant or large parts of the coastlines having wave-heights exceeding 5 m includes Pakistan, Sri-Lanka, Andaman and Nicobar Islands (India), large parts of Indonesia, Western Australia, north-western Philippines, Japan, and a number of the Pacific Islands. With a few exceptions, these coastlines are exposed to tsunami generated in the vicinity of the coastlines, giving little time for warning and evacuation.

Based on the hazard analysis, the population exposed to tsunamis are quantified country by country. Moreover, some selected hotspot areas of high population density combined with potentially high run-up are given. Whereas the risk is not computed, a brief discussion on the possibility on how to extend this study to include the risk is briefly given.

It is noted as priority has been made to countries may have lack of resources to deal with tsunami risk, some areas susceptible tsunamis are still not covered or at least only poorly covered. Areas that are included in the analysis include most of the Japan Sea, North China, a few parts of Indonesia, Philippines, Malaysia, and Eastern Australia, as well as a number of the smaller Pacific Islands. In addition, Japan is poorly covered in this analysis.

E8 Acknowledgements

A number of leading international organisations shared their reports on tsunami hazard and risk, and their help was crucial for the quality of this work. For their contributions with respect to sharing their work, we thank, Geoscience Australia, SOPAC (South Pacific Applied Geoscience Commision), GNS (New Zealand), and CEA (France).

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Appendix F - Conflict Hazard and Population at Risk in Asia-Pacific

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Contents

F1 Introduction

The aim of this project has been to develop a methodology of conflict hazard and risk assessment and present results of such an analysis for countries of concern to the UN OCHA's regional office in Bangkok. The project is limited to state-based internal armed conflict; other forms of political violence, including international conflict and communal violence, are not covered. Armed intrastate conflict is understood as armed violence between a state and an organized non-state actor over a clearly stated issue of incompatibility which causes at least 25 battle-related deaths pr calendar year (see UCDP/PRIO Armed Conflict Dataset; Gleditsch et al., 2002). The assessment consists of three parts. First, a country-level model of conflict hazard is developed, which serves to identify the countries most likely to host armed intrastate conflict within the next year. Next, a sub-national conflict hazard assessment is conducted, which highlights where, within the conflict-prone countries, violence is most likely to take place. Finally, a simple model of population at risk is presented, combining the estimated sub-national conflict hazard with population density statistics. The resulting map displays areas with the highest maximum number of people potentially affected by conflict in the high-hazard provinces.

F2 National Conflict Hazard

While all armed conflicts have idiosyncratic traits, there are also a limited set of generic factors that correlate with the frequency of conflict. Armed intrastate conflict outbreak occurs disproportionately in countries with large and ethnically diverse populations, low national income, inconsistent and unstable political systems, and with a recent history of conflict (Hegre & Sambanis, 2006). In this analysis, we estimate the probability (hazard) of conflict *occurrence* ('what is the probability of observing armed conflict in country *i* in year *n*?'), which is analytically distinct from most conflict studies that focus on conflict outbreak ('what is the probability of observing a new armed conflict in country *i* in year *n*?'). However, as most of the important explanatory factors for conflict outbreak also influence occurrence, we apply a benchmark statistical model of conflict onset to evaluate the conflict propensity among the countries in the study region.

To establish the prediction model we first run a logit regression with corrections for temporal trends on empirical data for all countries in the world, 1950–2004 (Table F1). The results correspond well to Hegre & Sambanis's (2006) analysis of conflict outbreak, though a different operationalization of political system to handle a possible endogeneity problem (see Gates, et al, 2006; Vreeland, 2008) returns weaker results for democracy.

The most influential country characteristic is conflict history – the number of years since the last active conflict. This is expressed as a decaying function to account for a non-linear healing effect of time, $decay = 2^{-(\frac{T}{\alpha})}$ where α is the half-life (in years) and T is the duration of peace until the time of observation. Several iterations revealed that a half-life parameter of just one year generated the strongest results. Aside from conflict history, irregular regime change, poverty, population size, and ethnic diversity are found to systematically increase the likelihood of conflict occurrence, while the severity of recent natural disasters has little effect.

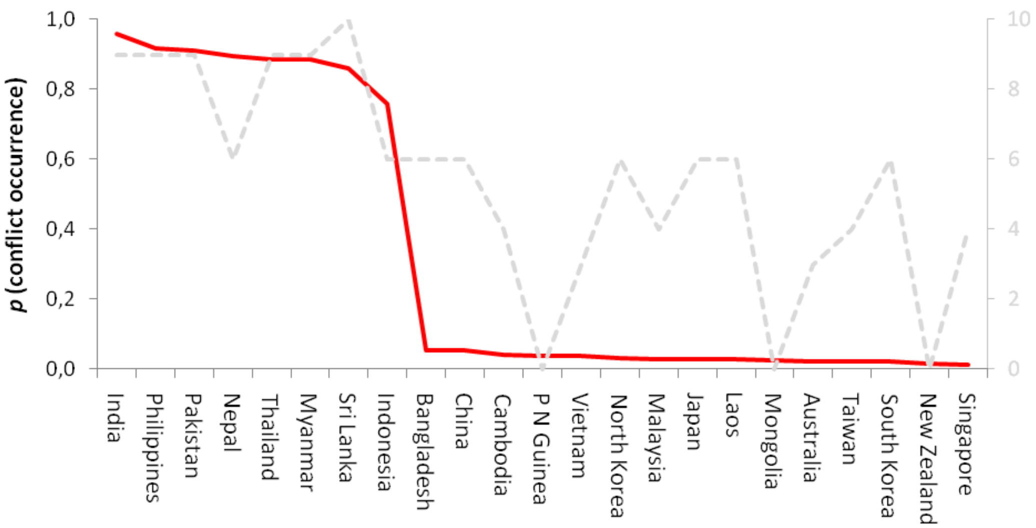
Table F1 Determinants of armed intrastate conflict occurrence, 1950–2004

	β	SE β	p value
Democracy index[a]	.262	.274	.338
Democracy squared[a]	.540	1.037	.603
Regular regime change	.078	.188	.678
Irregular regime change	.929	.373	.013
GDP capita[a, b]	-.197	.094	.037
Population[b]	.197	.063	.002
Ethnic fractionalization	.556	.314	.076
Disaster deaths[a, b]	.023	.032	.474
Conflict history decay	5.168	.238	<.001
Time squared	.005	.002	.004
Intercept	-23.212	6.114	<.001

Note: Global logit regression model with robust standard errors clustered on countries, N=6,656;
[a] data lagged one time period; [b] natural logarithm.

The parameter estimates from this global analysis are then used in combination with the most recently available data (in this case, 2007) on the selected parameters. The result is a set of conflict hazard estimates, interpreted as the probability of observing conflict by country during the following year (2008). The countries in the study region, Asia-Pacific, can then be ranked according to conflict likelihood (Figure F1).

As Figure F1 demonstrates, the region is essentially split in two in terms of conflict hazard. The top eight countries are estimated to have a probability of armed conflict that is more than ten times higher than the next country on the list. This significant divide is driven largely by the countries' previous conflict history. Six of the top eight countries hosted one or more armed conflict in the last year of observation (2007), while the remaining two countries had just emerged from conflict (Nepal in 2006 and Indonesia in 2005). In contrast, the most recent armed conflict in the sample of low-risk countries ended eleven years ago, in 1998 (Cambodia). A large population and low per capita income are other factors that explain the variation in conflict hazard, although the inertia of these features implies that they are better at estimating base-line hazard than predicting the timing of conflict outbreak. One factor that does increase the short-time hazard is irregular regime change (coups, assassination of executive). While this effect is less pronounced than that of conflict history, it nonetheless constitutes a non-trivial hazard that frequently precedes armed intrastate conflict. In the case of China, the predicted probability of observing conflict during 2008 more than doubles (from 5% to 13%); for Indonesia, the change is measured at 13 percentage points (from 76% to 89%). As a means of forecasting the onset of new armed conflict, irregular regime changes serve as good early warning indicators.



Note: the dotted line, plotted against the right vertical axis, displays the scores from OCHA's own assessment of conflict hazard, which also accounts for the intensity of earlier violence (OCHA *Global Focus*, August 2007).

Figure F1 Estimated probability of observing armed intrastate conflict in 2008 by country.

Figure F2 shows the geographic distribution of conflict hazard in the study region. It effectively highlights areas of high concern, but it can be misleading. Most active conflicts in this region are geographically limited, so for large countries such as India, Indonesia, and Thailand, the majority of the territories are unaffected by the violence and may not be considered particularly exposed.

F3 Sub-National Conflict Hazard

In order to provide a more realistic hazard map, we next estimate conflict likelihood at the first-order administrative level for twelve countries in the region. For some other countries, crucial socio-economic and demographic data were unavailable or inconsistent (e.g. China, Myanmar, North Korea, small island states in the Pacific), while a high-resolution hazard assessment was deemed irrelevant for democracies with no recent history of armed intrastate conflict (e.g. Australia, Japan, New Zealand).

Four complementary factors were assumed to affect the local conflict propensity: Socio-economic status, ethnic inclusion/exclusion, distance from the capital, and conflict history. A number of country-specific sources (such as national bureaus of statistics and human development reports), as well as international data providers (e.g. CIESIN, Columbia University), were consulted before creating the indices.

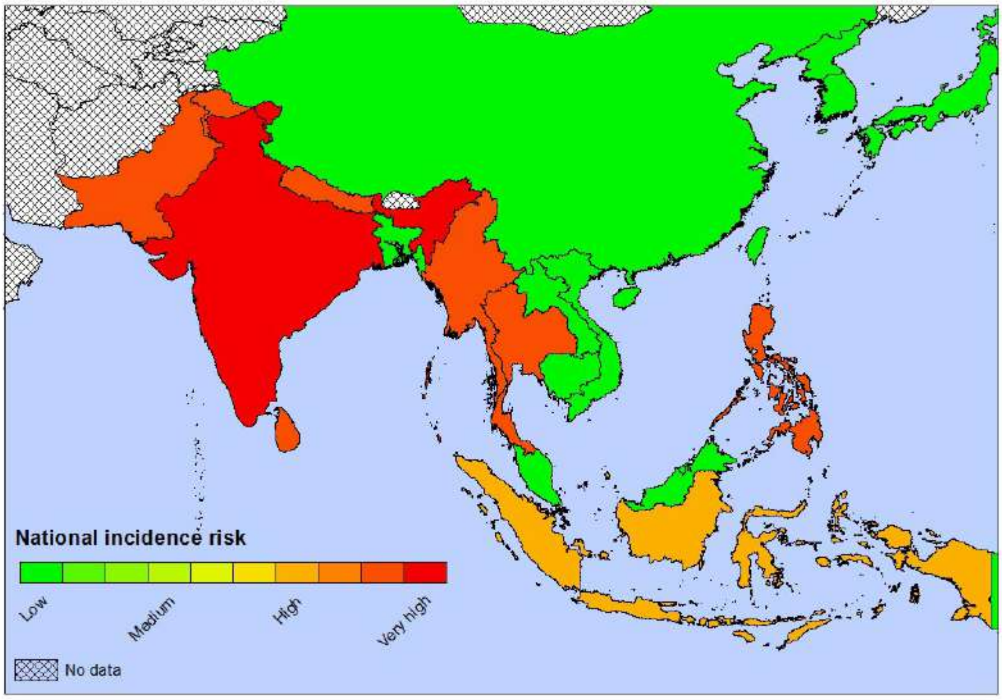


Figure F2 Hazard map of armed intrastate conflict in the Asia region, 2008.

A. Socio-economic status

This index varies between 1 (relatively wealthy) and 5 (relatively poor) and is generated from 4–5 country-specific indicators of socio-economic status. Because the data sources differ between countries, the values on the index are expressed in relative terms (i.e. relative to the most well-off district) and are thus not immediately comparable between cases. However, most of the country indices contain local estimates of GDP per capita, infant mortality, and HDI scores from national Human Development Index reports. The sources and characteristics of the specific socio-economic indicators can be found in the appendix.

The 5-point scale for the socio economic variables gives the measured difference between each district and the district with the highest score on the given socio-economic indicator (this is normally the capital district, but not always). The values are given as standard deviations (0–1 SD = *1*, 1–2SD = *2*, 2–3SD = *3*, 3–4SD = *4*, 4>SD =*5*). Finally the scores for the socio economic variables are added together to create the socio economic hazard indicator. We take the max total added score a district can get and dived this by 5 and use this as the cut off point for the indicators.

B. Ethnicity

The ethnic indicators consist of two variables:

- A dichotomous indicator on whether the main ethnic group in the sub-national region has access to national power according to the ETH Zurich Ethnic Power Relations (EPR) data (0 if in power, 2 if not in power).
- An indicator of the composition of ethnic groups in the the sub-national region, measuring whether the region is dominated by the group(s) in power (EGIP) or by a marginalized group (MEG):
  Size of largest MEG/(Size of largest MEG + Size of EGIP(s)).

  The ratio values are divided in two three groups and given a score:
  0–0.33 = 1
  0.34–0.66= 2
  0.67–1 = 3

When summing the exclusion and ratio indicators, a joint ethnicity scale is created, ranging from 1-5.

C. Conflict history

The variable indicates whether the province has been in conflict in previous years, and if so, how long ago. We use 5 time periods.

1 = 1946–1989
2 = 1990–1997
3 = 1998–2002
4 = 2003–2006
5 = 2007

Sub-national regions with no previous conflict are assigned a value of 0.

D. Distance from the capital

The indicator of center vs. periphery consists of two dichotomous variables that jointly form a 3-point scale (0–2):

- Dummy variable indicating whether the sub-national region is situated on a different island than the capital city or along an international border (1 if yes, 0 otherwise).

- Dummy variable indicating whether the sub-national region is situated further away from the capital city than the average distance for all sub-national regions in country (1 if further away than the average; 0 otherwise).

From these indicators a relative conflict hazard index is constructed. The first three components (socioeconomic status, conflict history, and ethno-political exclusion) are assigned equal weight (all have maximum values of 5) while the fourth component, geographic location, is considered less important (the maximum value is 2). A summarized relative hazard index of the four components ranges between 2 and 17. Since the index for each country is relative to the least conflict-prone region the hazard scores are primarily suited for comparing with other districts in the same country. To offer a more objective, cross-sectional consistent indicator of conflict likelihood, we join the local hazard scores with the country-level conflict incidence hazard estimated from Table F1. However, to maintain reasonable sub-national variation within countries, we multiply the national conflict incidence hazard by 10 for those regions that score higher than 4 standard deviations above the minimum value on the sub-national index, and then multiply the national conflict incidence hazard by the sub-national hazard. By multiplying the national hazard with the highest subnational scores only, we avoid inflating the local hazard for regions in conflict-ridden countries that do well on the sub-national indicators (e.g. central Thailand).

Figure F3 shows the results and provides a more nuanced picture of where armed conflict is more likely, compared to the cross-national analysis presented in Figure F2. Most of the twelve countries have considerable sub-national variation in conflict likelihood. India, in particular, displays high internal variation in conflict hazard, with violence being very likely in the northwest and northeast but much less so in central parts of the country. This reflects the long-lasting separatist conflicts in Kashmir, Assam, Manipur, and Nagaland, as well as the Naxalite rebellion around Chhattisgarh, Jharkhand, and Andra Pradesh. Recent conflict history, peripheral location, and local dominance of minority groups also explain the high likelihood of violence in the predominantly Muslim southern provinces of Thailand. In Nepal, the conflict hazard is highest among the border districts, most of which are economically marginalized and contain politically excluded populations.

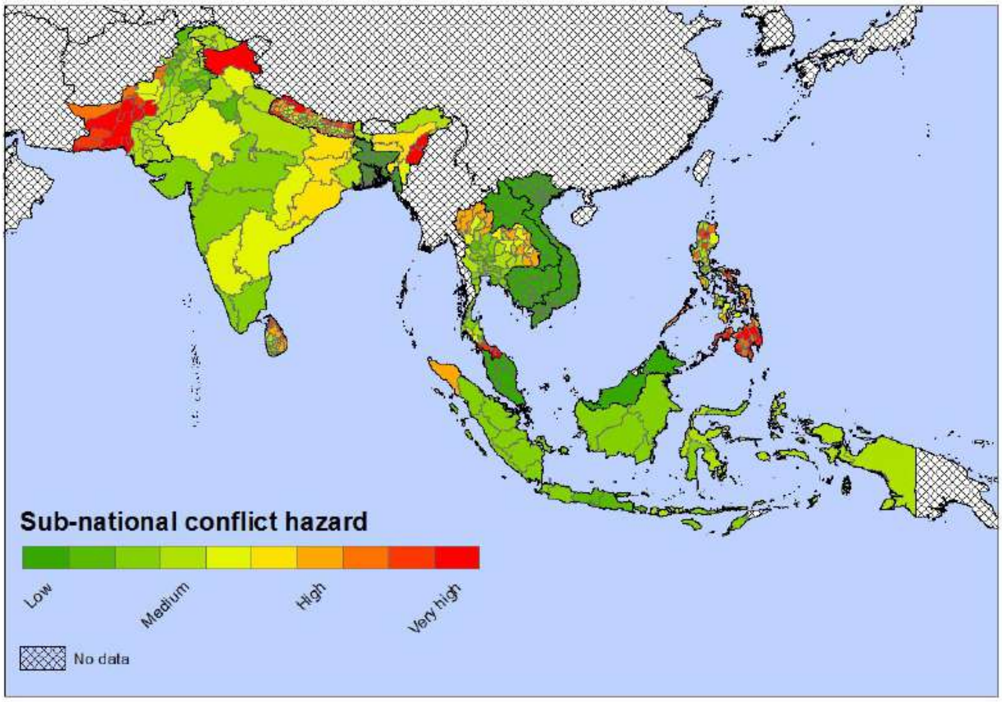


Figure F3 Sub-national distribution of conflict hazard, 2008.

F4 Sub-National Conflict Risk

Finally, the size of the exposed population in the medium-to-high hazard regions is considered (gridded population data from CEISIN). While population density is a poor indicator of likely casualty levels if a conflict occurs, it gives some indication of the number of people potentially affected by the conflict. For simplicity, Figure F4 distinguishes merely between regions with above-average population density and those that are less densely populated, but the underlying data can be displayed in various fashions depending on purpose. Orange regions represent medium to high conflict hazard and below-average population density, whereas red denotes high conflict hazard and high population density. This procedure limits the number of high-hazard (red) provinces compared to Figure E3, and can be an effective means to single out high-priority areas where more people are at risk.

The difference between Figure F3 and F4 is clearly illustrated by the case of Nepal. Most rural border districts have high conflict hazard due to adverse socioeconomic and cultural characteristics and a recent history of conflict. However, many of these districts, in particular those in the northern Himalayan region, are sparsely populated so the number of high-risk areas is substantially lower.[1] A similar result is evident for the relatively sparsely populated Indian states of Kashmir, Naga-land and Manipur, all of which have a high conflict likelihood but with comparably low numbers of maximum potential people at risk.

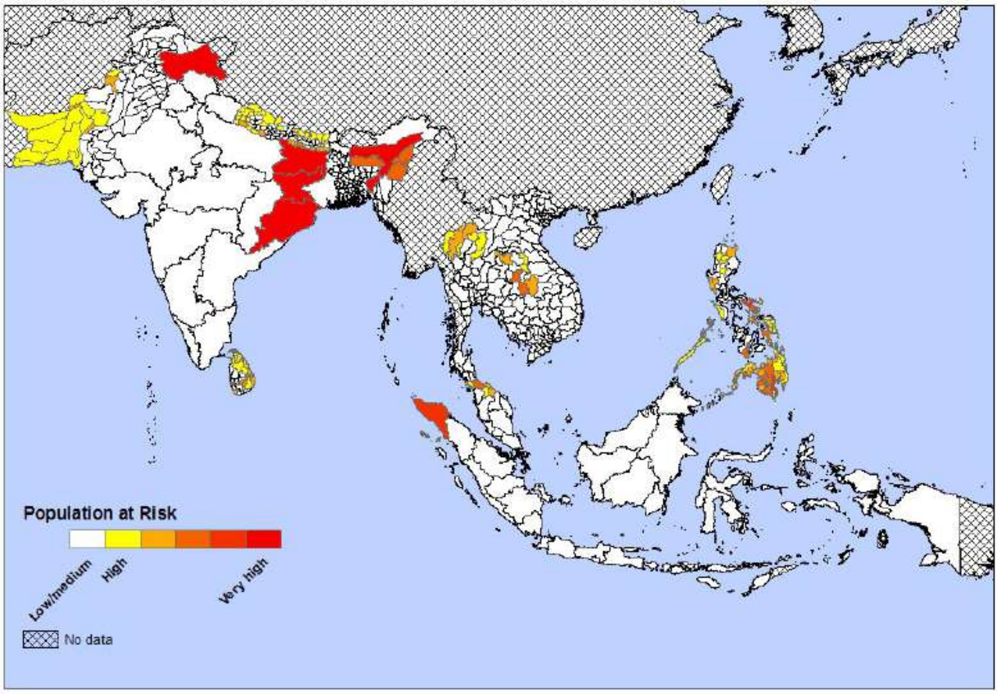


Figure F4 Population-weighted hazard map in high-to-very-high conflict hazard regions, 2008.

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Gates, Scott; Håvard Hegre, Mark Jones & Håvard Strand. 2006. 'Institutional Inconsistency and Political Instability: Polity Duration, 1800–2000', *American Journal of Political Science* 50(4): 893–908.

[1] When conflict casualty estimates become available in a geo-referenced format, the sub-national population at risk model should be modified to account for severity levels of prior violence, which arguably is a better indicator of future casualties than population density. This would probably contribute to marking off parts of Sri Lanka and Kashmir as high-risk areas while e.g. southern Thailand (Pattani) might be downgraded.

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Sources of Socio-Economic Data:

Indonesia

a. **Human Development Index 2005** (Source: Statistics Indonesia, http://www.bps.go.id/sector/ipm/table1.shtml)
b. **Life Expectancy** 2005– Life expectancy varies from 62.1 to 72.5 (Source: Statistics Indonesia, http://www.bps.go.id/sector/ipm/table1.shtml)
c. **Adjusted per capita riil expenditure 2005:** The data rage from 584 - 638 (Source: Statistics Indonesia, http://www.bps.go.id/sector/ipm/table1.shtml)
d. **Infant Mortality Rate** – The data range from 24 – 81 (Source: Center for International Earth Science Information Network (CIESIN))

Nepal

a. **Human Development Index 2000** – The data rage from 0.304-0.652. (Source: Nepal Human Developing Report 2004: http://hdr.undp.org/xmlsearch/reportSearch?y=*&c=n%3ANEPAL&t=*&k=&orderby=year)
b. **Human Poverty Index 2000** – The data rage from 24.9 – 63.8 (Nepal Human Developing Report 2004)
c. **GDP per Capita:** The data rage from 679 - 3438 (source: Nepal Human Developing Report 2004)
d. **Infant Mortality Rate** – The data range from 60.1 – 112.2. (Source: Center for International Earth Science Information Network, CIESIN)
e. **Composite Index from District Survey** – Including variables concerning electricity, health, education, and nutrition. The survey can be found on: http://www.cbs.gov.np/Others/District%20level%20development%20indicators.pdf (060308) (source http://www.cbs.gov.np/)

The Philippines

a. **Human Development Index 2000** – The data is divided into 5 categories. (Source: Philippines Human Development Report)
b. **Poverty Incidence 2006** –The data rages form 3.4 to 64.6. (Source: National Statistical Coordination Board, www.nscb.gov.ph)
c. **GDP per Capita - Per Capita Gross Regional Domestic Product at Constant 1985 prices (in pesos).** The data rage from 37855 to 3486. (Source: National Statistical Coordination Board, www.nscb.gov.ph)

d. **Infant Mortality Rate** – The data rage from 23.6 to 60.8. (Source: Center for International Earth Science Information Network, CIESIN)

Sri Lanka

a. **GDP/cap by province (2005):** The data rage from 0.07 to 0.2. (Source: Sarvananthan 2007 Economy of the Conflict Region in Sri Lanka: From Embargo to Repression, p 6: Central Bank of Sri Lanka).
b. **Road Density (2005)** – The data rage from 0.28 to 1. (Source: Sarvananthan 2007 Economy of the Conflict Region in Sri Lanka: From Embargo to Repression, p 28).
c. **Borrowing (2003)** – Borrowing as percentage of total household income. The data rage from 14.2 to 43.6 (Source: Sarvananthan 2007 Economy of the Conflict Region in Sri Lanka: From Embargo to Repression, p 41).
d. **Infant Mortality Rate (200)** – The data rage from 4.1 to 27.8 (Source: Center for International Earth Science Information Network, CIESIN) However, the data for the following districts have been replaced by data from the World Health Organization: Ampara, Butticaloa, Tricomalee, Jaffna, Kilinochchi, Mannar, Mullaitivu, Vavuniya. (Source: Sarvananthan 2007 Economy of the Conflict Region in Sri Lanka: From Embargo to Repression, p 32).

Pakistan*

a. **Literacy Ratio % (1998):** The data rage from 11.1 to 72 (Source: Pakistan Human Developing Report 2004)
b. **GDP per capita (1998):** The data rage from 640 to 3350. (Source: Pakistan Human Developing Report 2004: http://hdr.undp.org/en/reports/nationalreports/asiathepacific/pakistan/name,3174,en.html)
c. **Enrolment Ration% (1998)** The data rage from 6.9 to78.3 (Source: Pakistan Human Developing Report 2004)
d. **Human Development Index** The data rage from 0.332 to 0.624 (Source: Pakistan Human Developing Report 2004)

*There exists no socioeconomic data for Azad Kashmir, F.A.T.A and Northern Areas – these have been assigned a value of 5 (relatively least developed) on the socioeconomic scale.

Cambodia

a. **Infant Mortality Rate (2004):** Data ranging from 42 to 122 (Source: Cambodia Human Developing Report 2007: http://hdr.undp.org/xmlsearch/reportSearch?y=*&c=n%3ACambodia&t=*&k=&orderby=year)
b. **Temporary Housing (2004):** Data ranging from 3.1 to 45.1 (Source: Cambodia Human Developing Report 2007)
c. **Human Development Index (2004):** Data ranging from 0.3 to 0.83 (Source: Cambodia Human Developing Report 2007)

d. **Human Poverty index (2004):** Data ranging from 14.3 to 46.2 (Source: Cambodia Human Developing Report 2007)

Thailand

a. **Infant Mortality Rate (2005):** Data ranging from 3.6 to 14.8 (Source: Thailand Human Developing Report 2007: http://hdr.undp.org/xmlsearch/reportSearch?y=*&c=n%3AThailand&t=*&k=&orderby=year)
b. **GDP per capita (2004):** Data ranging from 17083 to 691093 (Source: Thailand Human Developing Report 2007)
c. **Household debt (2004):** Data ranging from 29.1 to 86.2 (Source: Thailand Human Developing Report 2007)
d. **Poverty incidence (2004):** Data ranging from 0 to 33.97 (Source: Thailand Human Developing Report 2007)

Laos

a. **Life Expectancy (2002):** Data ranging from 54 to 63 (Source: Laos Human Developing Report 2006: http://hdr.undp.org/xmlsearch/reportSearch?y=*&c=n%3ALao&t=*&k=&orderby=year)
b. **GDP per capita (2002):** Data ranging from 889 to 2516 (Source: Laos Human Developing Report 2006)
c. **Human Development Index (2002):** Data ranging from 0.458 to 0.652 (Source: Laos Human Developing Report 2006)
d. **Poverty Head Count Ratio (2002)** Data ranging from 17 to 54 (Source: Laos Human Developing Report 2006)

Bangladesh

a. **Infant Mortality Rate** – The data rage from 64.5 to 126. (Source: Center for International Earth Science Information Network, CIESIN)
b. **Percentage of households with electricity supply** – 6.69% to 74.27% (source: Bangladesh Bureau of Statistics, December 2005, Bangladesh Case Study: http://gisweb.ciat.cgiar.org/povertymapping/)
c. **Average years of schooling of adult (> 15 years of age) household members** – 1.84 to 5.3. (source: Bangladesh Bureau of Statistics, December 2005, Bangladesh Case Study: http://gisweb.ciat.cgiar.org/povertymapping/)
d. **The Squared Poverty Gap Index: measures of the severity of poverty for each area** – 2.66 – 17.01 to (source: Bangladesh Bureau of Statistics, December 2005, Bangladesh Case Study: http://gisweb.ciat.cgiar.org/povertymapping/)
e. **Gini coefficient based on per capita income** – 33.84 to 44.67. (source: Bangladesh Bureau of Statistics, December 2005, Bangladesh Case Study: http://gisweb.ciat.cgiar.org/povertymapping/)

a. **India**

a. **Per Capita Consumption Expenditure 1999-2000 –** The data range from 413.71 to 1382.87 (source: National Human Development Report 2001)*

b. **Percentage of Population below the poverty line 1999-2000 -** The data range from 3.48% to 47.15% (source: National Human Development Report 2001)*

c. **Per capita net state domestic product at current prices 2004-05 -** The data range from 5606 to 60787 (source: Indian Public Finance Statistics 2007-08, Ministry of Finance, department of Economic Affairs, Economic Division)

d. **Literacy rate 2001 -** The data range from 47% to 90.86%. (source: http://indiabudget.nic.in)

e. **Infant Mortality Rate –** The data rage from 28 to 133. (Source: Center for International Earth Science Information Network (CIESIN))

***** Chhattisgarh is assigned the same value as Madhya Pradesh, to which it belonged until 2000.
* Uttaranchal is assigned the same value as Uttar Pradesh, to which it belonged until 2000.
* Jharkhand is assigned the same value as Bihar, to which it belonged until 2000.

Vietnam

a. **GDP in capita PPP (US$)*** - The data range from 5209 to 542 (Source: National Human Development Report 2001: Doi Moi and Human Development in Vietnam: http://planipolis.iiep.unesco.org/upload/Viet%20Nam/Viet%20Nam%20HDR%202001.pdf)

b. **Adult literacy rate -** The data range from 96.9 to 51.3 (Source: National Human Development Report 2001: Doi Moi and Human Development in Vietnam: http://planipolis.iiep.unesco.org/upload/Viet%20Nam/Viet%20Nam%20HDR%202001.pdf)

c. **Education index -** The data range from 0.86 to 0.54 (Source: National Human Development Report 2001: Doi Moi and Human Development in Vietnam: http://planipolis.iiep.unesco.org/upload/Viet%20Nam/Viet%20Nam%20HDR%202001.pdf)

d. **Human Development Index -** The data range from 0.835 to 0.486 (Source: National Human Development Report 2001: Doi Moi and Human Development in Vietnam: http://planipolis.iiep.unesco.org/upload/Viet%20Nam/Viet%20Nam%20HDR%202001.pdf)

e. **Infant Mortality Rate –** The data rage from 10.5 to 82.6. (Source: Center for International Earth Science Information Network, CIESIN)

*GDP in Ba Ria-Vung Tau is assigned the average GDP for the high human development states, because the GDP is very high and skewed due to oil and gas. This would have affected the standard deviation as an outlier.

Malaysia

a. **% of children starting primary 1 reaching 5 primary 2001 –** The data range from 88% to 100% (source: Malaysia - Achieving the Millennium Development Goals Successes and Challenges: http://www.undp.org.my/index.php?option=com_content&view=article&id=104&Itemid=63)
b. **% of households under the poverty-line 2002 -** The data range from 1% to 16% (source: Malaysia - Achieving the Millennium Development Goals Successes and Challenges: http://www.undp.org.my/index.php?option=com_content&view=article&id=104&Itemid=63)
c. **Infant Mortality Rate 2000 -** The data range from 7% to 14% (source: Malaysia - Achieving the Millennium Development Goals Successes and Challenges: http://www.undp.org.my/index.php?option=com_content&view=article&id=104&Itemid=63)

Appendix G - Measuring the Capacity to Cope with Natural Disasters

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Contents

G1 Definitions

Broadly defined, the coping capacity is the ability of a group of individuals to address the risks related to an adverse event, be it before, during or after its occurrence[1].

Obviously, this ability has a strong influence on the eventual impact of natural disasters. The purpose of this paper is to propose a method for its evaluation, so that a measure of coping capacity can be combined with the usual components of risk, i.e. hazard characteristics, exposure and vulnerability, and provide a better understanding of the actual level of risk that people are facing.

To this aim, however, there needs to be a clear-cut distinction between the coping capacity and the other components of risk, to avoid any double-counts[2]. Because of its broadness, the above definition of coping capacity does not allow for such a distinction, and needs to be restricted. More precisely, the *informal* means of protection and support available to individuals and communities at the various stages of a disaster, such as mutual help relations, or cultural traditions conveying knowledge of natural hazards, are usually incorporated (as elements of social and human capital) in the notion of vulnerability.

Leaving aside such informal assets, our working definition of coping capacity will therefore cover *all institutional means to protect and support individuals and communities facing the risk of a disaster*. This "institutional coping capacity" is not covered by common measures of vulnerability.

The institutions dealing with disaster risks and disaster situations can be classified under the following four policy fields[3]:

- Risk assessment and communication, i.e. the identification, evaluation and possibly quantification of the hazards affecting the country and their potential consequences, and exchange of information with and awareness-raising among stakeholders and the general public;
- Risk mitigation, i.e. laws, rules and interventions to reduce exposure and vulnerability to hazards;
- Disaster preparedness, warning and response, i.e. procedures to help exposed persons, communities and organisations be prepared to the occurrence of a hazard; when hazard occurs, alert and rescue activities aimed at mitigating its immediate impact;
- Recovery enhancement, i.e. support to disaster-stricken populations and areas in order to mitigate the long-term impact of disasters.

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[1] According to the United Nations International Strategy for Disaster Reduction, for instance, coping capacity is "the means by which people use available resources and abilities to face adverse consequences that could lead to a disaster" (http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm).
[2] It is important to note that this distinction does not mean that the coping capacity should not be *correlated* to other components of risk.
[3] The risk management terminology can considerably vary from one source to the other. The terminology used in this paper is consistent with the definitions of the International Organization for Standardization (ISO, 2002).

- In each of these fields, institutions can operate at local, regional, national or international level, and a rigorous assessment of coping capacity should consider all these levels. However, as a first step, this paper will address only the national level institutions, and as a consequence, it will not account for sub-national differences. Other levels could be integrated in the same methodological framework at a later stage. However, data availability might prove a major challenge to this end.

The following sections briefly discuss how criteria can be selected for evaluating a country's coping capacity, how information relative to each of these criteria can be collected and interpreted, and finally how the resulting data can be aggregated into a synthetic indicator.

It should be emphasized that very few attempts have been made in the past to consistently measure the capacity of institutions dealing with disaster risks to effectively protect and support people. Two notable exceptions are the Inter-American Development Bank's project "Risk Indicators for the Americas" (IADB, 2005) and the Organisation for Economic Cooperation and Development's project "Risk management policies" (OECD, 2003, 2006, 2007 and forthcoming). The present paper builds on the methodological approaches of these projects.

G2 Evaluation criteria

The evaluation method consists in using a limited number of components to map a country's performance in each of the mentioned policy fields. The first annex to the paper lists these components.

In principle, the coping capacity depends on the specific circumstances of a risk. For instance, a country can be well equipped to address frequent medium-sized events, but totally unprepared to face a low-probability large-scale event. Or it can have particular instruments (international agreements, warning mechanisms, etc.) to face one type of disaster and none for other types.

Each component of coping capacity should therefore be estimated for each natural hazard separately, e.g. the quality of hazard monitoring for earthquakes, for floods, and so on. However, it seems reasonable to assume that some of the components are constant across hazards. The quality of the legal and regulatory framework, for instance, is probably a reliable gauge of a country's ability to prevent and mitigate all disaster risks through the law. We will therefore consider a number of all-hazard components, together with hazard-specific components.

Tables G1 lists the policy fields and data sources used in the evaluation criteria, while Table G2 provides the list of indicators used in the coping capacity analyses.

G3 Data collection and processing

To estimate the components of coping capacity, one can then either use existing indicators and data, or set up field surveys. Choosing one option rather than the other is a matter of weighing the loss of accuracy related to the use of proxies against the cost and limitations of collecting information *ad hoc*. From a careful review of publicly available datasets, it appears that for about one-third of the proposed components, estimations can be built on the basis of existing indicators. The last column of Table G1 indicates the data source used for each of those components, and Table G2 lists the relevant indicators. For the others components, field surveys have been conducted using the questionnaires presented in Section G4 of this appendix.

The final step consists in normalising all the estimates to a common scale, and then aggregating the normalised estimates in order to obtain a synthetic indicator:

$$I = \Sigma_i \, \alpha_i . I_i^{all} + \Sigma_i \, \Sigma_j \, \beta_i . \gamma_j . I_i^{hazard\ j}$$

where the α_is are the weights of all-hazard indicators I_i^{all}, the β_is are the weights of hazard-specific indicators $I_i^{hazard\ j}$ and the γ_js represent the relevance of hazard j for the country, calculated in terms of exposure:

α_i and β_i are determined by the analyst and should satisfy the following conditions:

$$\sum \alpha_i = 1$$

$$\sum \beta_i = 1$$

γ_j = exposure hazard j / exposure all hazards

$$\sum \gamma_j = 1.$$

Table G1 – Evaluation criteria

Policy fields	All-hazard components	Hazard-specific components	Data sources
Risk assessment		Hazard monitoring and evaluation	Questionnaire
		Consequence and vulnerability assessment	Questionnaire
Risk mitigation		Awareness-raising activities	Questionnaire
	Legal and regulatory framework: - general governance - law enforcement Environmental sustainability		Governance indicators
		Sectoral regulations	Questionnaire
		Structural defences	Questionnaire
Preparedness, warning and response	Infrastructure equipment: - telecommunications - transportation - health and sanitation		Development indicators
	Continuity plans in public and private organisations		Questionnaire
		Early warning mechanisms	Questionnaire
	Emergency response		Questionnaire
Recovery	Macroeconomic capacity - balance of payments - government finance - per capita income		National accounts Balance of payments statistics
	Social safety net		National Accounts, Development indicators
		Insurance mechanisms and disaster funds	Questionnaire
	Reconstruction and rehabilitation planning		Questionnaire

Table G2 – List of indicators

Policy fields	Component	Indicators	Sources
Risk mitigation	**General governance**	Property rights and rule-based governance	World Bank CPIA Ratings
		Quality of public administration	
	Law enforcement	Transparency, accountability and corruption in the public sector	World Bank CPIA Ratings
	Environmental sustainability	Environmental Performance Index	Columbia and Yale universities
Preparedness, warning and response	**Telecom infrastructures**	Fixed and mobile phone subscribers per 1,000 people	World Bank Development Indicators
		% households with television	
	Transport infrastructures	% of paved roads rail	World Bank Development Indicators
		Travel on roads per capita (kms)	
		Travel on railways per capita (kms)	
	Health and sanitation infrastructures	Hospital beds per 1,000 people	World Bank Development Indicators
		Physicians per 1,000 people	
		% population with access to improved sanitation facilities	
		% population with access to improved water sources	
Recovery	**Balance of payments**	Current account balance as % of GDP	World Bank Balance of Payments Statistics
		Workers' remittances received as % of GDP	
		Net inflows of FDI as % of GDP	
		External debt as % of GDP	
	Government finance	Surplus or deficit as % of GDP	World Bank National Account Statistics
		Central government debt as % of GDP	
	Per capita income	GDP per capita (in current USD)	
	Social safety net	Social protection rating	World Bank CPIA Ratings
		Public and private health expenditures as % of GDP	World Bank Development Indicators
		Out-of-pocket health expenditure as % of health expenditure	

G4 Coping capacity questionnaires

G4.1 Explanatory note

This section presents a procedure for building a synthetic indicator of a country's capacity to cope with natural disasters4. For this, the notion of coping capacity is broken down into 14 components (see methodological annex). Some of these will be estimated for each country using existing data and indicators, others through field surveys. The latter will be based on the questionnaires presented in the following pages.

The questionnaires concern ten components of coping capacity:

- Hazard evaluation
- Consequence and vulnerability assessment
- Awareness-raising activities
- Sectoral regulations
- Structural defences
- Continuity planning
- Early warning
- Emergency response
- Insurance and disaster funds
- Reconstruction and rehabilitation planning.

For each component, five levels of achievement are considered and briefly described. Some components have to be evaluated for each hazard type separately (hazard-specific components), others for natural hazards in general (all-hazard criteria). Irrelevant columns of the table are coloured in grey accordingly. Field officers are asked to rank the country by a cross in the relevant cell, or possibly on the line between two cells, based on their evaluation of the action of all institutions dealing with disaster risks, whether public, non-governmental or private. They should consider only those policies and measures that are already in place, and not those that are considered or planned, so that a repetition of the survey through time can give an idea of the country's progress related to new policies and reforms.

[4] Earthquakes, floods, landslides, typhoons, droughts, volcanoes, tsunamis, avalanches and wildfires are considered in this project.

G4.2 Coping capacity questionnaires

	Rating	Earthquakes	Floods	Landslides	Typhoons	Droughts	Volcanoes	Tsunamis	Avalanches	Wildfires	All hazards
Hazard evaluation	1. Basic inventory of past events; no monitoring; no forecasting										
	2. Some event catalogues; basic instrumentation; basic maps										
	3. Advanced observation networks and research, with gaps										
	4. Comprehensive hazard maps; use of probabilistic forecasting										
	5. Detailed hazard mapping and analysis										
Consequence and vulnerability assessment	1. Incomplete assessment of exposed people and assets										
	2. Some evaluation of the vulnerability of physical structures										
	3. Evaluation of the direct impact of reference events										
	4. Some assessment of the vulnerability of lifelines and of indirect consequences										
	5. Integrated risk assessment covering health, environment, social, economic and cultural impacts										
Awareness-raising activities	1. Sporadic information on risk and appropriate behaviour during emergencies										
	2. Communication on risk and disasters through the media, leaflets, exhibitions										
	3. Large, coordinated campaigns on risk and disasters; guidelines on vulnerability reduction										
	4. Education of children; frequent organisation of drills										
	5. Systematic dialogue with communities on their exposure to and perception of risk; involvement of private actors and NGOs										

Coping capacity questionnaires (continued)

	Rating	Earthquakes	Floods	Landslides	Typhoons	Droughts	Volcanoes	Tsunamis	Avalanches	Wildfires	All hazards
Sectoral regulations	1. No consideration of risk in construction, planning and land use regulations										
	2. Some consideration of risk, inadequate enforcement										
	3. Fairly effective regulations for new constructions and development, problem with older constructions and settlements										
	4. Consistent approach to the regulation of construction and land use on the basis of exposure to hazards										
	5. Sustained effort to weigh the costs and benefits of exposure to hazards and gradually reduce vulnerability through the adoption and updating of laws and regulations										
Structural defences	1. Incomplete mitigation, stabilisation, reinforcement and control measures in the most hazard-prone areas										
	2. Effective structural defences in large cities regarding fairly frequent events (more than 1 in 50 years)										
	3. Existence of a national framework and significant resources for developing hazard control structures in widespread locations, in partnership with local government										
	4. Widespread interventions throughout the territory to control hazards and mitigate risks										
	5. Systematic approach to protecting livelihoods and assets from low frequency-high consequence events (less than 1 in 100 years)										
Continuity planning	1. Continuity plans do not exist or are not operational (no trained personnel, no updating, etc.)										
	2. Basic contingency plans are in place in ministries, large hospitals, public utilities, large municipalities, major corporations										
	3. Legal requirements and/or incentive mechanisms (e.g. use of certification) for public and private organisations to adopt extensive continuity plans										
	4. Some coordination of continuity plans among ministries, local government and operators of lifelines; occasionally, joint simulation exercises										
	5. Widespread continuity planning in public and private organisations; frequent updating of plans in larger organisations based on the results of joint exercises										

Coping capacity questionnaires (continued)

	Rating	Earthquakes	Floods	Landslides	Typhoons	Droughts	Volcanoes	Tsunamis	Avalanches	Wildfires	All hazards
Early warning	1. No early warning system										
	2. Basic early warning systems available for decision-makers and risk managers										
	3. Adequate early warning systems coupled with media announcements, reaching a majority of the population ahead of an event										
	4. Advanced early warning systems coordinated with emergency response in essential government services and lifelines										
	5. Advanced early warning systems, integrated with preparedness and emergency response plans throughout the country										
Emergency response	1. Fragmented organisation and scattered resources; predominance of voluntary responders										
	2. Professional search and rescue services, evacuation possibilities, temporary shelters and central operations centres available in the most hazard-prone areas										
	3. Existence of a national organisation of emergency response, with coordination authority; adequate supplies of medical, transport, communications and other specialised equipment in all important cities										
	4. Clear definition of roles and responsibilities at local, regional and national level, according to the size of events; proportionate allocation of resources										
	5. Permanent coordination between responders in national agencies, local government, NGOs and communities; specialised equipment and well-trained rescue services available throughout the country										
Insurance and disaster funds	1. Little or no insurance (or other cost-sharing) mechanism available for households, corporations and local governments										
	2. Ad-hoc mechanisms to support the victims of past disasters by transferring a significant share of financial losses to the national community										
	3. Insurance against natural disasters is gradually developing on the basis of probabilistic risk evaluations										
	4. Insurance coverage for a significant share of public and private buildings; limited cost-sharing mechanisms at local government level										
	5. Widespread coverage for private and public buildings; substantial insurance penetration for plants, equipments, and business interruption; existence of government-sponsored disaster funds and legislation to support disaster-stricken municipalities										

Coping capacity questionnaires (continued)

	Rating	Earthquakes	Floods	Landslides	Typhoons	Droughts	Volcanoes	Tsunamis	Avalanches	Wildfires	All hazards
Reconstruction and rehabilitation planning	1. No organisation and legislation addressing the planning of rehabilitation or reconstruction of disaster-stricken areas										
	2. General principles exist at national level regarding the conduct of reconstruction after a disaster: needs assessment, consultation of stakeholders, investment decisions, financing, etc.										
	3. Reconstruction plans have been adopted in some of the country's major urban centres exposed to natural hazards										
	4. In most hazard prone areas, municipal commissions or discussion groups have developed or are developing plans to address the consequences of the natural disasters that might occur										
	5. Risk considerations (regarding structural defences against natural hazards, sheltering and evacuation, reconstruction in the event of a disaster, etc.) are systematically integrated into urban development plans, with the involvement of local stakeholders										

G5 Conclusion on coping capacity

In this report, coping capacity was defined as the ability of institutions at national and local level to deal with the risks of natural disasters. This leaves aside coping capacity at individual, household and societal levels, which is largely redundant with the notion of vulnerability and was therefore addressed in the chapter on vulnerability assessment.

Disaster risk management consists of risk assessment, risk prevention and mitigation, emergency management and recovery enhancement. There have been very few attempts to systematically evaluate disaster risk management policies at national level. To our knowledge, the two main exceptions are the aforementioned projects from the IADB and the OECD.

The assessment of coping capacity in this report draws on the methodologies of these two projects. Like the IADB project, it uses a mix of economic, social and policy indicators and ad hoc surveys to rate national disaster management capabilities. Like the OECD project, it aims at covering the entire range of risk management policies. A country's performance can therefore be broken down into its specific results in risk assessment, risk prevention, emergency management and recovery enhancement, and even further into components of each of these policy fields. Likewise, aggregate results for managing natural hazards in general can be decomposed into the various hazard types that the country is exposed to. This makes the coping capacity ratings relevant for both monitoring the overall situation of countries and advocating targeted policy measures.

There are two directions in which this report's coping capacity assessments could be tested, improved and consolidated: first, by conducting surveys and computing the rankings for more countries; and second by looking at how well the rankings explain the ability with which countries have actually managed the natural hazards that they have faced in the recent past.

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Appendix H - Categorisation of hazards and calculation of risk index

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Contents

H1 Background

Each of the natural hazards considered in this project, as well as the conflict hazard, is assessed in a different manner. This cannot be avoided because the spatial and temporal scales and the frequency of occurrence vary over several orders of magnitude for the different hazards considered. However, it does make it a challenge to compare the risk associated with the different hazards, and to compare the risk profiles of countries that are exposed to different typs of hazard.

This appendix presents the methodology used for mapping of the hazard and exposed population in the project. The procedure outlined below will probably not work very well for “very low probability – extremely high consequence” events, like the December 2004 Indian Ocean tsunami or exceptionally large earthquakes that might occur at “seismic gaps” along major faults. This type of events should be handled separately.

H2 Hazard mapping

For each of the hazards considered in the study, 4 classes or categories were defined on the basis of the computed hazard intensity and frequency, or on the basis of an estimated hazard category:

- 0: Non-existent or negligible (white)
- 1: Low (green)
- 2: Medium (amber)
- 3: High (red)

For some of the natural hazards all the information is condensed into a single index. For example for earthquakes, the Modified Mercalli Intensity (MMI) with a return period of 475 years was used. For these hazards, it is relatively straightforward to classify the hazard into 4 categories. For others, for example river flood and tropical cyclone, two parameters (intensity and frequency) were used to define the hazard. For these hazards, the matrix shown in Figure H1 was used to obtain the categories.

H2.1 Example: hazard categories for cyclone and storm surge

The tropical cyclone and storm surge data were originally produced by UNEP/GRID-Europe in five different layers (raster data files) representing the five different intensity classes (see Appendix B). The original raster data files represented the annual yearly frequency (multiplied by 1000) for the five intensity classes.

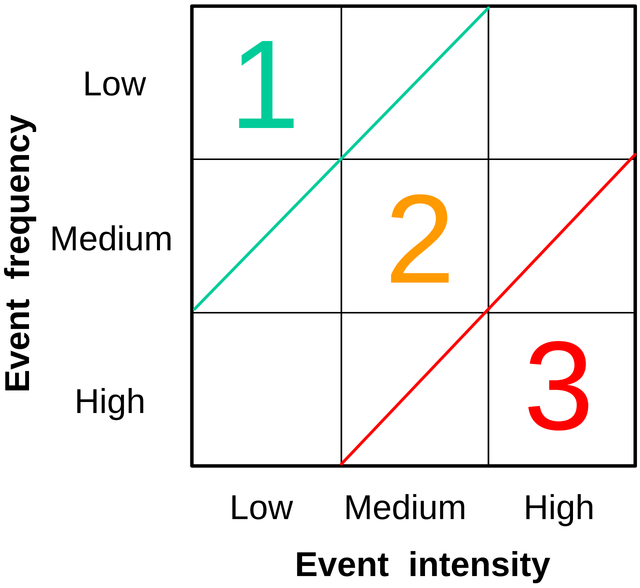

Figure H1. Conversion of hazard categories defined by two parameters to three hazard classes.

To convert these data into 4 hazard categories, the five original raster files for each intensity class were merged into one data set by weighting and adding them together as follows:

Cyclone intensity class	Weighting factor
1	1
2	1.5
3	2
4	2.5
5	3

The results from this weighting were added together to produce one single hazard raster file:

$$\text{Total\_Hazard\_Index} = \sum_{i=1}^{5} Weighting\_factor_i \cdot Freq_i$$

where $Freq_i$ is the annual frequency of intensity i cyclone (multiplied by 1000) in a pixel. The values Total_Hazard_Index for cyclone wind speed and storm surge were then reclassified in to four classes according to the following re-classification tables:

Cyclone wind speed

Total_Hazard_Index		**New hazard category**
From	To (including)	
0	0	0
1	300	1
301	1000	2
1001	2500	3

Storm surge

Total_Hazard_Index		**New hazard category**
From	To (including)	
0	0	0
1	120	1
121	550	2
551	1950	3

H3 Calculation of exposed population and Risk Index

For each country in the study area, the equivalent population exposed to each hazard was defined as 100% of the population living in Hazard Category 3, plus 30% of the population living in Hazard Category 2, plus 10% of the population living in Hazard Category 1. For landslides, which have a limited spatial extent even within a pixel of 30 arc_sec ×30 arc_sec, and for civil conflict, which is impossible to resolve spatially to the same resolution as natural hazards, a correction factor of 0.10 was applied to the equivalent exposed population.

An attempt was made to develop a global risk index for ranking the countries in the study area. In general, it is logical for the risk index to have the following format:

$$\text{Risk Index} = \text{function of } [\sum_{i=1}^{7} w_i y_i \cdot f(\frac{z_i}{x_i}) \text{ , Coping Capacity Index}]$$

where w_i are weighting factors that designate the relative importance of different hazards, x_i is the equivalent population exposed to hazard “i”, y_i is the ratio of x_i to the total population, z_i is the number of fatalities caused by hazard “i” within a reference time frame, and $f(\frac{z_i}{x_i})$, which is a vulnerability indicator, is some function of the number of fatalities divided by the equivalent exposed population.

As discussed in Appendix G, the Coping Capacity Index for a given country is different for the different hazards. However, it was not possible to gather enough data in this study to come up with meaningful coping capacity indices for different hazards and the aggregate index for all hazards was used in the calculations.

The following equation for Risk Index was used in the study:

Risk Index =

$$1000 \cdot \left[\sum_{i=1}^{7} w_i y_i \cdot (0.01 + \frac{z_i}{x_i}) \right] / \left[(\sum_{i=1}^{7} w_i) \cdot (10 + Coping\ Capacity\ Index) \right]$$

The seven hazards considered in the calculation of the risk index were river flood, earthquake, tropical cyclone (including storm surge), drought, precipitation-induced landslide, tsunami and civil conflict. The following points should be noted about the calculated risk index:

- The fatality data for different natural hazards were obtained from the EM-DAT database for the time period 1980-2007.
- Fatalities due to civil conflict were based on PRIO Battle Death data 1980-2005, and UCDP Battle Death data 2006-07. Battle death data for Pakistan are not available and were roughly guessed for the calculations.
- The weighting factors w_i in the equation for the Risk Index are specified by the user.
- The aggregate Coping Capacity Index described in Appendix G and presented in Table 3 of the main report varies from 2.06 to 4.83 (higher values indicating higher coping capacity). These values were rescaled for use in the Risk Index equation as follows:

  Rescaled Coping Capacity Index = $\frac{10 \cdot (Coping\ Capaicty\ Index - 2)}{3}$

- The value of $(\frac{z_i}{x_i})$ was reset equal to 0.02 if it exceeded 0.02.
- The factor “1000” used in the Risk Index equation is purely for scaling purposes.
- The values of exposed population to tsunami hazard listed in Table 2 of the main report are based on the population data from the Year 2000.

The calculation of the Risk Index involves assigning weighting factors (importance factors) by the user to the different hazards. Tables H1 and H2 show the values of the Risk Index computed for the countries in the study area using two different sets of weighting factors. For the values shown in Table 4, the same weighting factor was applied to all natural hazards and civil conflict. Table 5 shows the results for the following weighting factors: flood = 1, earthquake = 2, drought= 1, tropical cyclone = 3, landslide = 1, tsunami = 2 and conflict = 2.

Table H1. Risk Index with same weighting factor for all hazards

Country	Risk Index
Bangladesh	9.7
Philippines	9.3
Indonesia	7.2
Myanmar	6.4
Nepal	6.2
Papua New Guinea	5.3
Japan	5.2
Pakistan	5.1
Bhutan	3.8
Sri Lanka	3.6
Malaysia	3.5
New Zealand	3.5
Viet Nam	3.1
Dem People's Rep of Korea	2.6
Cambodia	2.5
Thailand	2.2
India	2.1
China	2.0
Timor-Leste	1.9
Lao People's Democratic Republic	1.9
Brunei Darussalam	1.8
Republic of Korea	1.7
Australia	1.2
Maldives	1.2
Singapore	0.9
Mongolia	0.8
Island nations of the Pacific	**Risk Index**
Micronesia (Federated States of)	10.7
Vanuatu	7.8
Solomon islands	6.0
Samoa	4.7
Palau	4.5
Tonga	4.4
Fiji	4.2
Nauru	3.2
Kiribati	2.3
Tuvalu	2.3

Table H2. Risk Index with varying weighting factor for different hazards

Country	Risk Index
Bangladesh	11.0
Philippines	10.9
Myanmar	8.0
Nepal	6.5
Indonesia	6.3
Japan	5.9
Papua New Guinea	5.1
Pakistan	5.1
Bhutan	4.0
New Zealand	3.2
Sri Lanka	3.0
Dem People's Rep of Korea	2.9
Viet Nam	2.9
Malaysia	2.4
India	2.1
Timor-Leste	2.1
Republic of Korea	2.0
Lao People's Democratic Republic	2.0
Thailand	1.9
China	1.8
Brunei Darussalam	1.5
Cambodia	1.5
Marshall Islands	1.4
Maldives	1.3
Australia	1.1
Singapore	0.9
Mongolia	0.8
Island nations of the Pacific	**Risk Index**
Micronesia (Federated States of)	13.0
Vanuatu	10.1
Solomon islands	7.2
Palau	7.0
Fiji	5.9
Samoa	5.8
Tonga	5.5
Nauru	3.5
Kiribati	2.5
Tuvalu	2.5

The computed Risk Index is not very stable for the island nations of the Pacific because of their small size and population. These island nations should not be directly compared with the other nations in the study area.

Tables H3 through H7 summarise the spatial extent, exposed population and recorded fatalities for different natural hazards and civil conflict in Nepal, Sri Lanka, Pakistan, Indonesia and the Philippines. The following points should be noted about these tables:

- Except for tsunamis, the equivalent exposed population to risk from natural hazards was computed as 100% of people living in high hazard areas, plus 30% of people living in medium hazard areas, plus 10% of people living in low hazard areas.
- For tsunami, the exposed population was defined as all people living in the coastal areas inundated by the tsunami heights shown on Figure 29.
- It should be noted that the resolution of hazard maps for conflict are at the first-order administrative level.
- For landslides, only precipitation-induced landslides were considered. The fatalities (and risk) caused by earthquake-induced landslides are included in earthquake. To account for the limited spatial extent of a landslide, only 10% of the total population living in the slide-prone regions were considered in the calculations.
- The fatality data for natural hazards are taken from the EM-DAT database.
- Fatalities due to civil conflict are based on PRIO Battle Death data 1980-2005, and UCDP Battle Death data 2006-07. Battle death data for Pakistan are not available.

Table H3. Nepal – Hazard and exposure profile (Total population: 28,278,000 – Total area: 147,900 km^2)

Threat	**No. of people exposed**		**Areal extent of high & med. hazard categories, km^2**	**% of total country area**	**Fatalities (1980 – 2007)**
	Equivalent exposed population	% of total population			
Cyclone	0	0	0	0	97[1]
Flood	97,300	< 1	2,000	1.4	5481
Earthquake	8,515,000	30.0	147,900	100	809
Landslide	40,585	< 1	116,700	79	1578
Drought	709,500	2.50	26,500	18	0
Tsunami	0	0	-	-	-
Armed conflict	10,294,000	36	87,200	59	11,228
Coping Capacity: Low					

[1] Fatalities caused by storm events are included in this value.

Table H4. Sri Lanka – Hazard and exposure profile (Total population: 19,076,500 – Total area: 66,000 km²)

Threat	No. of people exposed		Areal extent of high & med. hazard categories, km²	% of total country area	Fatalities (1980 – 2007)
	Equivalent exposed population	% of total population			
Cyclone	290,700	1.5	27,830	42	754
Flood	28,800	< 1	1,730	3	1,695[1]
Earthquake	0	0	0	0	0
Landslide	4,170	< 1	10,420	16	119
Drought	2,882,000	15	25,900	39	0
Tsunami	158,000	< 1	-	-	35,399
Armed conflict	4,345,000	23	42,000	64	64,271
Coping Capacity: Low					

[1] Includes fatalities due to storm surge.

Table H5. Pakistan – Hazard and exposure profile (Total population: 163,350,000 – Total area: 879,200 km²)

Threat	No. of people exposed		Areal extent of high & med. hazard categories, km²	% of total country area	Fatalities (1980 – 2007)
	Equivalent exposed population	% of total population			
Cyclone	2,246,000	1.4	59,500	7	1,446
Flood	292,000[1]	< 1	23,200[1]	3	10,336[1]
Earthquake	36,253,000	22	879,000	100	78,812
Landslide	23,850	< 1	94,200	11	579
Drought	15,071,000	9.2	198,500	22	143
Tsunami	203,700	< 1	-	-	0
Armed conflict	6,357,000	3.9	315,900	36	No data
Coping Capacity: Low					

[1] Includes storm surge.

Table H6. Indonesia – Hazard and exposure profile (Total population: 219,465,000 – Total area: 1,903,600 km²)

Threat	**No. of people exposed**		**Areal extent of high & med. hazard categories, km²**	**% of total country area**	**Fatalities (1980 – 2007)**
	Equivalent exposed population	% of total population			
Cyclone	47,300	< 1	2,100	0.1	1,692
Flood	469,000	< 1	4,850	0.3	6,919[1]
Earthquake	58,652300	27	1,847,100	97	13,435[2]
Landslide	216,620	< 1	899,000	47	1,816
Drought	47,043000	20	526,500	28	1,329
Tsunami	1,660,000	< 1	-	-	166,000[2]
Armed conflict	433,000	< 1	57,170	3.0	6,597
Coping Capacity: Low					

[1] Includes storm surge.
[2] EM-DAT lists 179,435 fatalities for earthquakes, which includes tsunamis. It is estimated that about 166,000 are due to tsunamis.

Table H7. The Philippines – Hazard and exposure profile (Total population: 88,323,000 – Total area: 297,200 km²)

Threat	**No. of people exposed**		**Areal extent of high & med. hazard categories, km²**	**% of total country area**	**Fatalities (1980 – 2007)**
	Equivalent exposed population	% of total population			
Cyclone	15,658,000	18	193,500	65	29,054
Flood	773,000[1]	< 1	5,400[1]	2	31,885[1]
Earthquake	25,748,000	29	297,200	100	8,569
Landslide	126,240	< 1	199,800	67	2,646
Drought	9,490,000	11	143,000	48	8
Tsunami	1,333,000	1.5	-	-	102
Armed conflict	24,116,000	27	188,800	64	47,297
Coping Capacity: Average					

[1] Includes storm surge.

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