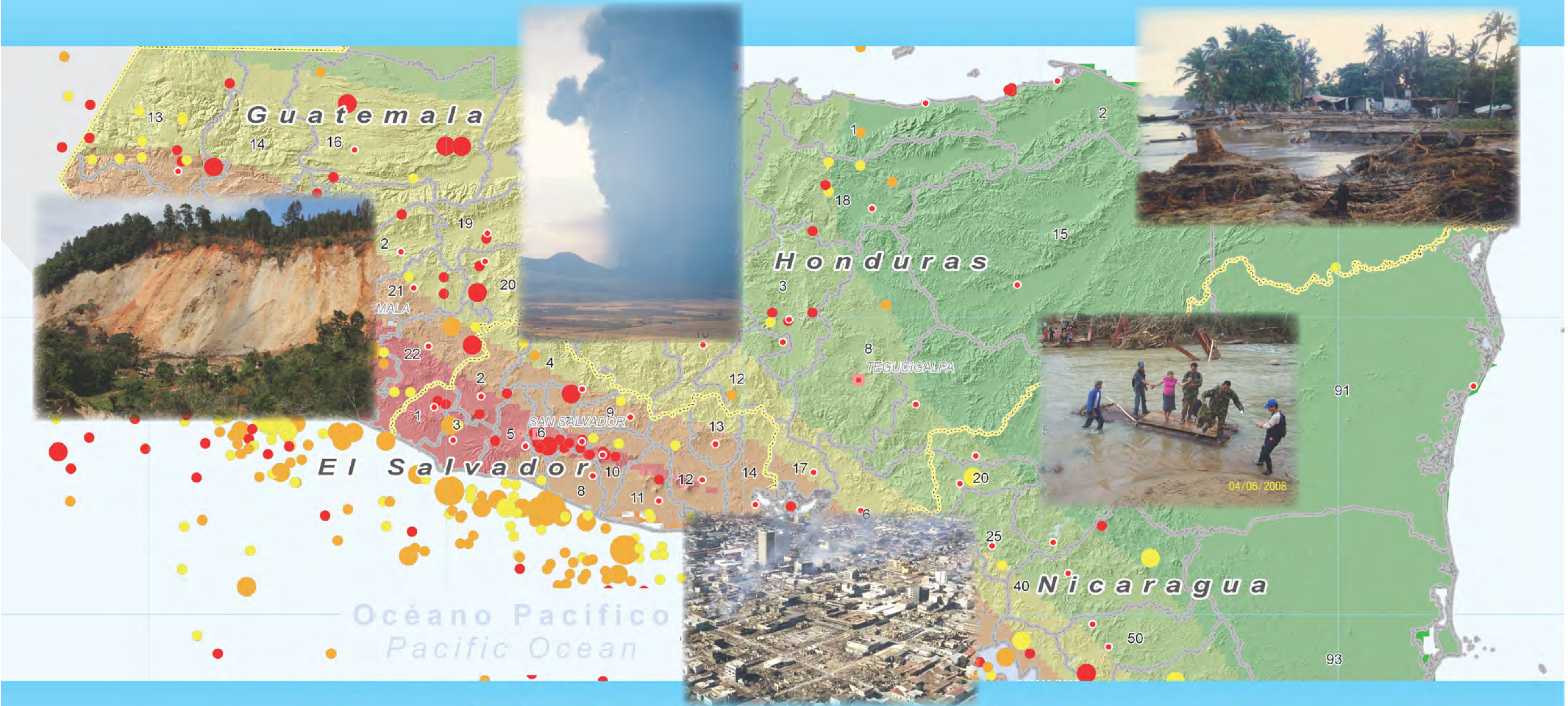
Project
Mitigation of Georisks in Central America



Guidebook for Assessing Risk Exposure to Natural Hazards in Central America
– El Salvador, Guatemala, Honduras and Nicaragua –

SNET
Servicio Nacional de Estudios Territoriales
INSIVUMEH
COPECO HONDURAS
ineter
BGR
On behalf of:
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The

Guidebook for Assessing Risk Exposure to Natural Hazards in Central America

- El Salvador, Guatemala, Honduras, and Nicaragua -

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Project of Technical Cooperation

Mitigation of Georisks in Central America

between the

Servicio Nacional de Estudios Territoriales (SNET), El Salvador

Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH), Guatemala

Comisión Permanente de Contingencias (COPECO), Honduras

Instituto Nicaragüense de Estudios Territoriales (INETER), Nicaragua

and

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Foreword

Central America with its project relevant countries of El Salvador (SV), Guatemala (GT), Honduras (HN), and Nicaragua (NI) covers an area of about 371.500 km² with approximately 34 Mio inhabitants. This central part of the Central America isthmus is situated between longitude 92° 14’ W and 83° 9’ W and latitude 17° 50’ N and 10° 40’ S.

It is located at the interaction between the sea floor tectonic plates, namely Cocos and Nazca to the west and the Caribbean plate to the east. Due to the ongoing subduction at the convergent margin, the Cocos plate bends north-eastward to the Caribbean plate and Central American volcanic arc. This tectonic setting leads to Central America being prone to geohazards, such as earthquakes, tsunamis, volcanic eruptions, and/or subsequent landslides.

To mitigate the impact of natural disasters in Central America caused by geological and associated hydro-meteorological events like hurricanes both a national and a supra-regional risk analysis and a corresponding mapping are imperative. The risk analysis comprises integrating knowledge of topographic and demographic conditions, infrastructure, economic and social aspects, such as the availability of healthcare facilities. The incorporation of this information results in the assessment of risk exposure whose findings can be implemented in spatial development planning processes afterwards. The task of the national line authorities

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involved in the project of ‘Mitigation of Georisks in Central America’ is to carry out research focusing on geohazards, vulnerability and georisks in their own countries, among others.

However, in many cases the impact of natural hazards and resulting disasters in Central America are of supra-regional nature. ‘Lessons learned’ from a disaster like hurricane ‘Mitch’ means to align Disaster Risk Management strategies and policies in a more cross-national context. Therefore, the intention of this guidebook is to point ways out how to tackle risk assessment to geohazards at a supra-regional level as well.

The main purpose of this guidebook is to support national and intergovernmental geoscientific and spatial planning authorities to strengthen their capacities in mapping and assessing risk exposure to geohazards and thus to give support toward a sustainable risk assessment procedure in Central America at all.

The ‘Guidebook for Assessing Risk Exposure to Natural Hazards in Central America’ was published under cooperation between SNET, INSIVUMEH, COPECO, INETER, and BGR through the project of ‘Mitigation of Georisks in Central America’.

We greatly acknowledge all who have contributed to publish this guidebook.

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Content

Introduction

Background

Hurricane 'Mitch', which hit Central America in October 1998, was one of the strongest, deadliest and most destructive Atlantic hurricanes ever. The human and economic losses caused by this event were enormous. More than 11 000 people were killed and the loss provoked by destruction of infrastructure, homes and crops was quantified to be approximately five billion US$ in total (status: 1998). The tangible and non-tangible losses were mostly originated by flooding and mudflows, such as alongside the slope of the Casita volcano in Nicaragua (http://en.wikipedia.org/wiki/Hurricane_Mitch).

The landfall of hurricane 'Mitch' drew international attention to the problem of social vulnerability to natural (hydro-meteorological and/or geological) disasters of this region.

After this unprecedented event and under the impression of the 2001 earthquakes in El Salvador, the Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR) was commissioned by the German Federal Government, represented by the Ministry for Economic Cooperation and Development (BMZ) to implement a joint project of technical cooperation, called 'Mitigation of Georisks in Central America'. This project has been working since 2002 with the collaboration of the governmental line authorities of El Salvador (SNET) and Nicaragua (INETER) and has been geographically and institutionally expanded to the countries of Guatemala (INSIVUMEH) and Honduras (COPECO) in 2005.

The main goal of the project, commonly envisaged by the partners, is the design and the implementation of a supra-regional 'Georisk-Information System' (GRIS) for the collection, management, and evaluation of relevant baseline, hazard, and vulnerability information for assessing and mapping risk and to enable public services making results available for everyone.

Particularly, in the period between June 2009 and June 2010 practical approaches for risk assessment, tailored to the Central American context and need, have been achieved by the project partners. Focusing on geological risks resulting from volcanic eruptions, landslides, earthquakes, and inundations, the aforementioned governmental institutions and the BGR set up project activities to elaborate and to test comprehensible georisk analysis procedures, exclusively based on officially available baseline, hazard, and vulnerability data.

Almost twelve years after the devastations of the region by hurricane 'Mitch' and numerous other disastrous events have been occurred in the last few years (e.g. flooding/landslides: Honduras 2008; El Salvador 2009) the process of analyzing risk and its incorporation into disaster risk reduction activities has not been finished, yet. Quite the contrary, it remains a permanent challenge for national governmental and for intergovernmental authorities in Central America likewise – now and in the future.

The compilation of this guidebook within a very short period of time was only possible by incorporating the lessons of comprehensive experiences from comparable technical cooperation activities of the BGR, especially from the Indonesian-German cooperation project 'Mitigation of Georisks' (http://www.georisk-project.org/) carried out between 2003-2009. In full conformity with the partners, BGR pursues the strategy to establish comparative guidelines in risk mapping, independent from any country. On this account, the structure of this document is similar to the 'Guidebook for Assessing the Risk to Natural Hazards - Case study: Province of Central Java' (PROJECT MITIGATION OF GEORISKS IN INDONESIA, 2009).

Risk Assessment and Mapping

Risk assessment is an initial step toward the development and implementation of disaster risk reduction strategies and consequently of highest relevance for planners and decision makers to adopt sustainable disaster reduction policies and to define counter measures to reduce the exposure to risk. In view of the disaster management cycle (see figure below), it is part of the pre-disaster sector (prevention and mitigation) with the aim to mitigate the impact of potential disasters and to be adequately prepared in case of an imminent hazardous event.

Risk assessment can be briefly defined as 'a methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihood and the environment on which they depend' (UNDP, 2004).

With reference to this definition the practical implementation of risk assessment undertaken in this project/document encompasses following principal steps:

1. *Baseline Data:* Comprises the acquisition and preparation of information regarding administrative entities, land use, topography, demography and other socio-economic data.
2. *Hazard/Susceptibility Data:* Comprises the acquisition and preparation of information regarding the spatial occurence, intensity (magnitude) and time dimensions of hazards. The result of this assessment is a map showing hazard zones. Alternatively, so called susceptibility maps refer merely to *where* hazardous events could potentially occur, that is without any information about the time dimension (probability).
3. *Vulnerability and Capacity Data:* Pursues the question of whom and what is at threat? Vulnerability can refer to specific elements at risk, such as population, infrastructure or economic potential of a region. Capacity describes how a society is prepared (organized) to resist the impact of a natural disaster. This may for example refer to coverage of a region with healthcare facilities or the percentage of buildings adhering to earthquake design codes.
4. *Exposure and Risk.* Exposure shows how a vulnerability parameter, such as population, is affected by a certain hazard or a combination of hazards. In map format this is displayed by an intersect overlay of hazard (s) with the vulnerability (map). At this stage technical input ends. All further stages of assessment of risk involve decision making by governmental authorities in charge. It has to be estimated and determined, which level of risk is acceptable for a certain region or which type of risk (exposure) map is the most suitable to consider for the future development of an area.
5. *Implementation of Findings.* Risks identified through the assessment could subsequently be mitigated by elaboration of scenarios and by taking appropriate counter measures. Accordingly, this can be established by adjusting spatial development planning of a region or by measures to increase the coping capacities of a society could be envisaged.

Purpose of risk mapping on national / supra-regional level in Central America

Compared to the sub-national administrative levels (Departamento/Municipio), where mitigation of disaster risk usually involves regulations on land use, application of building codes or explicit building and construction measures (e. g. reinforcement of roofs to better resist volcanic ash fall), risk mapping on a national, and on a supra-regional level covers a much broader scale.

In Central America, the main purposes of risk mapping on a national level are:

- To identify priority areas at national level where special public attention and concentration is needed to mitigate the risk caused by natural hazards;
- To ensure comparability of the assessment of risk exposure throughout a country, in order to facilitate fair and balanced political and financial support to regions in need; this is particularly important for the allocation of governmental budgets for disaster management and mitigation counter measures;
- To increase the awareness/perception of the population and policy makers regarding the threats they are exposed to nationwide;
- To identify regions at threat, where inter-local cooperation at sub-national/national level in disaster management is logistically and economically rational.

In Central America, the main purposes of risk mapping on a supra-regional (transnational) level are:

- To strengthen the Central American integration process by increasing the awareness/perception of the population and policy makers regarding threats they are exposed to occurring across national boundaries and to support the implementation of Disaster Risk Management strategies and policies in a supra-regional context;
- To identify cross-national regions at threat, where transnational cooperation in disaster risk management logistically and economically prudential;
- To ensure comparability of risk exposure outcomes tailored to the Central America context and needs between neighbouring countries, in order to streamline a political and financial decision support to regions in need by transnational political institutions, especially Sistema de la Integración Centro-américana (SICA), with its body Centro de Coordinación para la Prevención de los Desastres Naturales en América Central (CEPREDENAC, http://www.sica.int/cepredenac/); this is particularly important for a cross-border allocation of budgets for disaster management and mitigation measures.

Making Development / Land Use Planning Risk-Sensitive

Another purpose for setting up standard operational risk mapping procedures focuses on making development and land use planning risk-sensitive. Risk-sensitive development planning includes risk assessment into the standard planning processes. This means that land use planning that seeks to the mitigation of risks needs scientifically valid basic information to avoid misinterpretations and undesired outcomes/developments. Therefore, to use planning tools and risk reduction techniques it is imperative to evaluate the parameters that have an effect on risk, i.e. the identification of hazard (s), vulnerability and potential loss estimation. This guidebook identifies a way how to sort this out.

Sustainable development, land use and disaster risk reduction have to be understood as a logical unit. Land use planning that integrates disaster risk can be described as a means to an end in decreasing vulnerability and potential future risk (tangible and no-tangible losses) and therefore to strengthen the resilience of a region or of one or several neighbouring countries. In this context, risk-sensitive land use planning is aiming at, among others:

- Identification and mitigation of possible causes for disaster risk arising from the current land use:
    - *Local/regional level*

      Example: Uncontrolled development of settlement areas outside designated constructible zones, e.g. in landslide prone zones;
    - *National/sub-national level*

      Example: Missing strategic planning as to critical infrastructure measures of national importance, e.g. construction of geothermal power plants in seismic hazard prone zones;
    - *Supra-regional level*

      Example: Missing strategic planning as to critical infrastructure measures of transnational importance, e.g. construction of arterial transit routes in volcanic ash fall prone areas.
- Reduction and adaptation of existing vulnerability of elements at risk:
    - *Local/regional level*

      Example: Allocation of high-density areas and other critical infrastructure (e.g. schools, hospitals) outside inundation prone areas;
    - *National/sub-national level*

      Example: Allotment of areas for the construction of critical infrastructure of national importance (e.g. airports) outside flood prone areas;
    - *Supra-regional level*

      Example: Allotment of areas for the construction of critical infrastructure of transnational importance (e.g. power transmission lines) exclusively outside landslides prone areas.
- Modification of hazard sources:
    - *Local/regional level*

      Example: Prevention (prohibition) of deforestation of slopes to make land ready for building that increases the susceptibility for landslides;
    - *National/sub-national level*

      Example: Avoidance of national-scale river regulation that increases the susceptibility of an area to flooding exclusively within the country's borders;
    - *Supra-regional level*

      Example: Avoidance of supra-regional-scale river regulation that increases the susceptibility of a terrain to inundation across the country's borders.

In view of steadily increasing losses caused by natural hazards, the strategic orientation of land use planning can only be to institutionalize disaster risk reduction into the regular land use planning programs carried out by the national authorities at all administrative levels and last but not least, by supra-regional corporate bodies. Only such an integrative approach guarantees that disaster risk reduction is part of a nation's long-term overall development objectives.

Intended Audience

This guidebook appeals to governmental and intergovernmental authorities in Central America committed to develop national practical guidelines on how to realize the multifaceted task of assessing the risk to natural hazards. It shall give insight into the practical steps necessary to undertake both, national and supra-regional disaster risk mapping. From the national point of view, the applied methodology and the compiled sources of information may easily be projected onto other sub-national administrative entities. For that reason, the guidebook is aiming at providing motivation to also map risks at sub-national levels and to supplement existing risk mapping outcomes by newly arising thematic issues (e.g. population exposed to areas subjected to droughts in the context of climate change adaption).

Furthermore, this document shall be put up for discussion among governmental and non-governmental organizations (NGO's) involved in the context of good governance and/or in integrating the principles of sustainable development into country policies and agendas.

Last but not least, this guidebook is aiming at increasing the awareness of the Central American population to the geological threats and risks they are exposed to.

This document makes frequent references to the usage of digital Geo-Information Systems (GIS). The Chapter *Risk Exposure Mapping Tool: CARA-GIS*, page 17*ff*, will broach this issue focused on the project context, in principle.

Conceptual Background

This guidebook is based on following conceptual assumptions:

- *No data? There are sufficient data available!* The key assumption is that governmental agencies of the involved countries already provide a comprehensive amount of thematic data to educe essential information on the exposure to natural hazards. Even though this information may not always reflect the most recent situation, particularly with regard to specific hazard/susceptibility data, the data are authorized by mandated governmental agencies and thus represent official sources.
- *Simplicity pays!* Simple approaches of risk analysis will facilitate acceptance and implementation of a new regional conceptual standard! Hazard and risk assessments can reach any level of sophistication. Examples from all over the world have shown a varied experience in surveying risks to geohazards. However, since these are often too ambitious and thus difficult to understand, the guidebook's concept does not follow abstract academic examples of risk analysis. The methodology applied for Central America does not claim to be the 'be-all and end-all' one, without any space for discussions. The project's philosophy pursued in mapping risk in all countries involved was the establishment of a pragmatic and traceable workflow based on a stringently organized data model of the risk mapping tool (page 17*ff*).
- *Learning by doing!* Risk mapping in Central America comprises of several intermediate steps with respect to hazard, vulnerability and risk assessment. Although, there is a sound experience in mapping risk it is still a challenge to interpret the outcomes and unanticipated effects therein. Furthermore, learning by doing facilitates to recognize minimum requirements needed to sort out this matter realistically, both in the national and supra-regional context.

How to read this Guidebook?

The manual is structured into sections (chapters), starting with short thematic introductions. Each section comprises of a set of maps representing the individual data sets and steps for the risk assessment process. On the left hand page, the content of the maps and the methodology applied for their compilation is described, following the same set of headings for each map:

- *Map Contents/Character:* gives a brief description about the general aspects the map is showing and characterizes its status as being 'national' or 'supra-regional';
- *Map Purpose with Respect to Disaster Risk Management:* explains why the shown data are relevant in the context of national/supra-regional Disaster Risk Management;
- *Data Source and Availability:* describes where the data can be obtained, what costs, if any, have to be expected, and other aspects regarding the availability of the data. In some cases, alternative data sources may also be listed;
- *Remarks:* contain any additional information for the users. This includes information on the scale of the map, references or any other relevant information;
- *Methodology:* gives an overview about how the data sets have been produced or processed before visualizing them on the map;
- *How to read this map:* gives more detail on how to interpret the map and which conclusions can be drawn from the map. Additional tables may be given as well as more detailed explanations of the legends;
- *Recommendations:* relate to lessons learned during the process of data acquisition, preparation and visualization. Suggestions are made regarding mandates, roles and standards that shall help to enhance the efficiency of disaster risk assessments.

The guidebook does not claim to be exhaustive to illustrate all country-specific and/or supra-regional risk maps theoretically possible! Taking into account the performance of the risk mapping tool to process thematic datasets currently be available, the number of risk mapping outcomes appears almost unmanageable.

For that reason, a selection of national and supra-regional maps representing typical risk scenarios in Central America is presented exemplarily. By using the highly flexible risk mapping tool (see chapter *Risk Exposure Mapping Tool: CARA-GIS*, page 17*ff*) it is up to the authorities in charge of the respective country to create and to compile a set of additional risk maps based on its own requirements, later on.

A principal workflow of the applied risk assessment procedure using CARA-GIS is shown in the appendix on page 102.

In order to avoid any infringements of country-specific map copyrights, the print layout of all maps presented in this guidebook was styled independently from any national map layout and deliberately does not have any authority logo.

Page references for each map and topic covered, facilitates the navigation through the book easily. A glossary on page 110*ff* for the terminology on risk assessment used in this guidebook is attached.

The alphanumeric results of the risk assessments visualized on the maps in the chapter 'Risk Exposure' are fully accessible in the database applications for further reference (see chapter *Risk Exposure Mapping Tool: CARA-GIS*, page 17*ff*). These tables include absolute risk specific figures for all Municipios of a chosen country.

In the context of risk mapping procedures as discussed in this book the phrases *'Central America'* or *'Central American countries'* are restrained to El Salvador, Guatemala, Honduras, and Nicaragua (in alphabetic order), exclusively.

Please note, that there is no consistent English translation of the names of the administrative entities 'Departamento' and 'Municipio' in Central America. To avoid confusion the usage of the Spanish words is favored throughout the guidebook.

Map Notice / Disclaimer

Due to the nature and the scale of national and supra-regional base maps published in this handbook, the information derived from it cannot be regarded as a planning basis for individual sites or buildings/facilities. For that reason, each of the maps of this guidebook carries a notice as below:

> *'This map was compiled from many sources. Use of this map's information is under the user's risk. This map is part of the 'Guidebook for Assessing Risk Exposure to Natural Hazards in Central America' and should not be used without the accompanying explanatory notes. The governmental authorities of the project countries and Bundesanstalt für Geowissenschaften und Rohstoffe give no warranty as to the quality or accuracy of the information supplied nor accept any liability in respect of loss, damage, injury or other occurrences, however caused."*

Geohazards and Georisks in Central America

Overview

Population and Vulnerability

Central America, situated between the Pacific Ocean and the Caribbean Sea, is a sparsely populated (71 inhabitants/km^2) narrow isthmus which connects North and South America. The population of Central America (42 million people) concentrates to a great extent close to the Pacific coast, partly due to climatic conditions and historically easier logistic access from the Pacific coast. Thus, also vulnerability to natural hazards in general is much higher in this part of the region. Vulnerability is generally high in Central America due to underdevelopment of the region where lack of resources and capabilities often prevents the implementation of hazard assessment and disaster risk reduction measures.

Many types of natural hazards are present in the region and they often occur simultaneously. According to the WORLD BANK (2005), the Central American countries rank among those with the highest mortality due to multiple hazards (see table below).

1	Bangladesh	12	Costa Rica
2	Nepal	13	Trinidad and Tobago
3	Dominican Republic	15	Antigua and Barbuda
5	Haiti	16	Dominica
6	Taiwan, China	**17**	**Nicaragua**
8	**El Salvador**	19	Cuba
9	**Honduras**	26	Ecuador
10	**Guatemala**		

Countries with relatively high mortality risk from multiple hazards (top 35 based on population), source: WORLD BANK (2005)

Geology and morphotectonic features

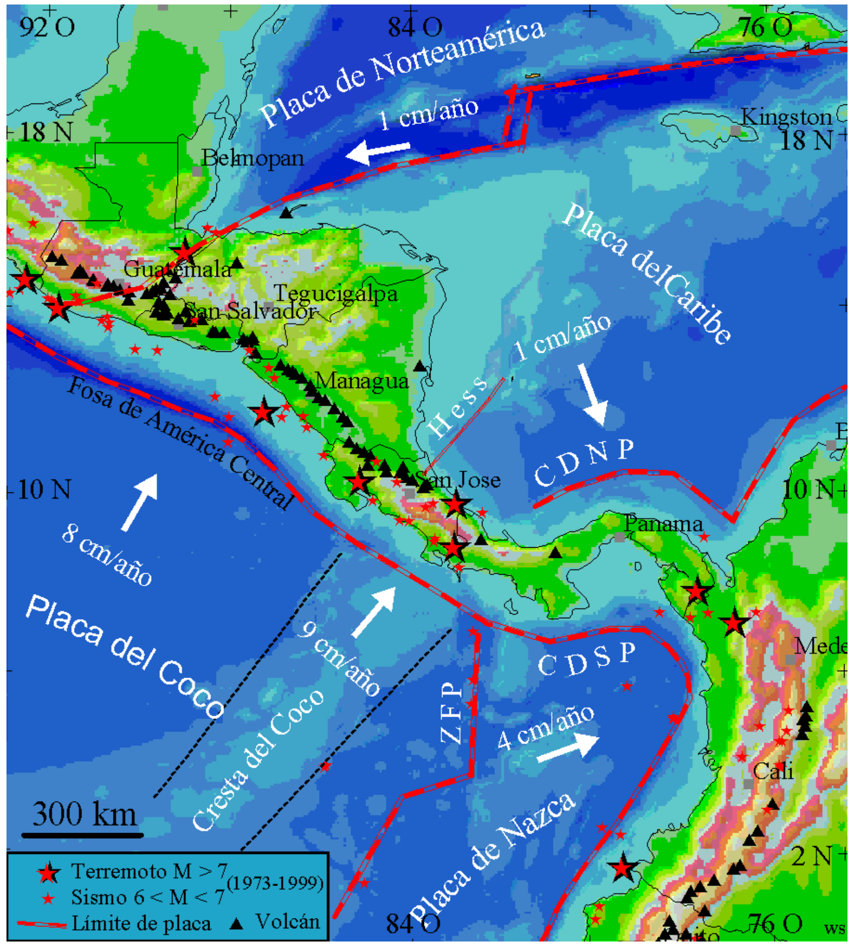
WEYL (1980) distinguished the Central America isthmus into two major units, the northern region comprising Guatemala, Honduras, El Salvador, and northern Nicaragua, and the southern region extending from the southern part of Nicaragua to Panama. The northern region is made up of continental style crust with Paleozoic and even older metamorphic rocks. They are overlain by Upper Paleozoic, Mesozoic and Tertiary sediments, which underwent deformation in Mid-Permian and late Cretaceous times. During the Tertiary, northern Central America experienced violent continental volcanism. The southern region, by contrast, consists of Cretaceous oceanic type crust with thick marine sediments and volcanic rocks that were deposited during the Tertiary.

The highlands (sierras) of northern Central America form an arc from southern Mexico through Guatemala, Honduras and northern Nicaragua to the Caribbean coast. These sierras are formed of a number of sub-parallel ranges, which are composed, from south to north, of Paleozoic to Mesozoic sediments of low-metamorphic grade, high-grade metamorphic and anatexitic rocks with granitoid intrusions and of folded and thrusted Permian and Cretaceous limestones. The ranges are separated from each other by faults and grabens. The volcanic ranges and plateaus of the Tertiary are encountered in large parts of Honduras, Nicaragua and El Salvador as well as in south-west (SW) Guatemala. The sierras of southern Central America start on the Pacific coast of Nicaragua and extend through most of Costa Rica and Panama to the Colombian border. These highlands differ from those in northern Central America, lacking in metamorphic crystalline rock and characterised structurally by gentle folding and faulting. An important feature of the region is the chain of Quaternary volcanoes which is approximately parallel to the Pacific coast and extends from the Guatemala-Mexico border southwards to Costa Rica, terminating in Panama. The volcanoes are located within a major valley, the Nicaraguan depression, and its extension through the Gulf of Fonseca into El Salvador.

Coastal plains dominate both the Pacific and Caribbean seaboards in northern Central America and are also encountered in Costa Rica and Panama, mainly on the Caribbean side (WEYL, 1980; BOMMER & RODRIGUEZ, 2002). In contrast to the narrow Pacific coastal plain with its short rivers draining the volcanic chain, the Caribbean coast is featured by broad extended lowlands drained by a broad extended river system to the Caribbean Sea (MARSHALL, 2007).

Tectonic environment

Central America is part of the circum-Pacific belt of earthquake and volcanic activity known as the 'ring of fire'. The largest earthquakes in the region are caused by the convergence of the Cocos and Caribbean plates in the Middle America Trench situated in the Pacific Ocean (see figure below), which is taking place at about 8 cm/year (DEMETS ET AL., 1994). The driving mechanism of the tectonic plate movements on the earth´s surface is the thermally driven convection in the earth´s mantle generating the main energy source for earthquakes, volcanic processes, tsunamis, and - indirectly - landslides in Central America. In the map, the epicenters of major earthquakes are shown by stars and sites of active volcanoes are indicated as small black triangles.



Tectonic setting of Central America

CDNP/CDSP:
deformed belt north/south of Panama,
ZFP:
Panama Fracture Zone
Hess:
Hess Escarpment
source: STRAUCH (2000)

The Cocos plate collides with the Caribbean plate in north-eastern (NE) direction and descends abruptly in a steep angle of about 80 degrees (Nicaragua) beneath the Pacific margin of the Caribbean plate. Where the Cocos plate bends, a frictional contact interface is formed between the two plates and earthquakes reaching Richter magnitudes of up to M_L = 8 may be triggered.

Oblique subduction at a high rate of convergence along much of the Middle America Trench results in a north-west (NW) directed trench-parallel motion of the forearc, which is accommodated by dextral strike-slip earthquakes and faulting along the Central American volcanic arc (DEMETS ET AL., 1994). As a consequence, bookshelf faulting on north-east (NE) striking left-lateral faults is induced in the volcanic chain, thereby adding a major contribution to the seismic hazard in this zone. Trenchward migration of the volcanic arc since the Miocene and reactivation of north-east (NE) striking Miocene structures may have led to the development of this arc- and trench-normal fault system (LAFEMINA ET AL., 2002).

Exceeding depths of more than 120 km the material of the subducted Cocos plate dehydrates and leads to potential melting of the earth´s mantle driven by high temperatures and pressures. Due to the density contrast with the surrounding mantle the generated magma rises almost vertically and penetrates the Caribbean plate along a thin belt, thus causing volcanic eruptions and forming the volcanic chain at the Pacific margin of Central America. As a consequence, these violent volcanic eruptions pose deadly hazards to large areas.

Oceanographic and climatic conditions

The Central American region is tropical, with the mean temperature at sea level not dropping below 19°C and with small annual temperature variations. The entire region experiences a rainy season with the rainfall maxima in June and September, which usually account for between 15% and 20% of the annual totals. The dry season is much more intense on the Pacific side than on the Caribbean side. Annual rainfall totals generally decrease from south to north, reaching 4000 mm at the Panama-Colombia border and reducing to less than half of this amount in northern Guatemala (BOMMER & RODRIGUEZ, 2002). The Caribbean coast and the eastern slopes of the mountain areas receive twice as much of the annual rainfall than the slopes along the Pacific coast and the western mountains. The Pacific coast is relatively dry, partly due to the presence of cold stable air produced by the cold oceanic currents which inhibit the absorption much water vapor, thereby reducing precipitation. By contrast, prevailing winds from the east transport large amounts of moisture absorbed from the warm water of the Caribbean Sea. Condensation and precipitation occur when the wind driven humid air ascends winds flow up and fall on the high slopes of Central America. Average annual rainfall along the Mosquito coast of Nicaragua reaches up to 6000 mm (BUNDSCHUH ET AL., 2007).

The meteorological conditions in Central America are largely influenced by the thermal energy content of both the Pacific Ocean and Atlantic Ocean/Caribbean Sea. The temperature variations of both oceans control the varying occurrences of phenomena known as 'El Niño' and 'La Niña' and also provoke hurricanes, inundation and droughts. The strong solar radiation of the tropical climate zone provides additional energy for dangerous short term meteorological phenomena when heavy local rains or thunderstorms trigger landslides and flash floods.

The meteorological and hydrological phenomena in combination with steep terrain due to geological land forming processes govern and trigger a variety of hazardous events like landslides, lahars, and inundations. Wind direction and speed also influence the adverse hazardous phenomena as they influence the distribution of volcanic ashes and gases.

Types of hazard

Seismic hazard and risk

Because of its seismotectonic setting and especially because of its proximity to convergent plate boundaries, Central America is characterized by high seismicity. Most Central American earthquakes occur along the offshore subduction zone and within the onshore volcanic chain. Other important areas with significant seismic activity are the left-lateral Motagua-Polochic strike-slip fault system at the north-western (NW) flank of the region that runs through Guatemala from the Swan fracture zone in the Caribbean Sea and marks the boundary between the Caribbean plate and the North American plate. Moreover, a further area of seismic activity is the Panama fracture zone at the south-eastern (SE) margin of the region which acts as the boundary between the Cocos and the Nazca plates (see figure to the left-hand side).

Several studies of earthquake hazard of Central America were conducted in the last decades. The latest study RESIS-II (see section *Seismic Hazard, Supra-regional*, page 42) combines the definition of seismic source areas based on the knowledge of seismotectonics and fault systems, the results of wave attenuation studies and the compilation of regional earthquake catalogues (BENITO ET AL., 2008).

The mere visual comparison of the seismic hazard map (page 42) with the population density map (pages 36 and 60) highlights that in general the areas of high seismic hazard coincide with the existence of a higher population density in the Pacific part of Central America. Thus, hazard and vulnerability combine to a high risk level in this area.

Earthquakes in the subduction zone of Central America may reach magnitudes up to M = 8 on the Richter scale and can affect large areas with relatively high ground accelerations. However, the epicentral areas with the maximum acceleration are of course situated in the Pacific Ocean. The seismic events in the volcanic chain are generally limited to magnitudes of up to 6.5 but due to their shallow focal depths and coincidence with the areas of highest population density, they pose a high seismic threat along the volcanic chain.The capitals of Guatemala, El Salvador, Nicaragua and Costa Rica are all situated along the volcanic chain and have thus a very high earthquake risk (see page 82). A special situation is the Motagua-Polochic fault as it can trigger earthquakes with magnitudes up to M = 8 and is crossing the land mass thereby passing many urbanized areas.

The most destructive earthquake in Central American history occurred 1976 in Guatemala, when the Motagua-Polochic fault caused an earthquake with a magnitude of M_S = 7.5. This earthquake claimed more than 22.700 lives, many due to landslides triggered by the earthquake but most due to the collapse of inadequate constructions (mainly adobe and taquezal constructions) in rural areas. An estimated damage of 1.1 billion US$ was the consequence, representing about 18% of the country's gross national product of that time.

Oblique aerial photograph, taken shortly after the 1972 Managua earthquake

source: Karl V. Steinbrugge Collection, University of California, Berkeley

Managua, the capital of Nicaragua, was destroyed twice by earthquakes. In 1931, an earthquake with a magnitude M = 5.6 devastated the city center and about 2000 people died. Another earthquake struck Managua in 1972, flattened the city centre and killed about 10 000 people. In both cases, the high death toll resulted from the poor and vulnerable building constructions (adobe and taquezal style) which collapsed during the relatively moderate and short shaking. However, in 1972 also some modern buildings built of reinforced concrete could not withstand the shaking and suffered deadly destructions due to improper construction.

San Salvador, the capital of El Salvador, recently suffered from three major seismic events starting in 1986, when a shallow earthquake of magnitude Mw = 5.7 caused extensive destructions and landslides claiming up to 1500 lives. Two further earthquakes on January 13, 2001 (Mw = 7.7) and February 13, 2001 (Mw = 6.7) struck El Salvador, causing a death toll of more than 1000 victims. Whereas the earthquakes caused relatively low structural damages in San Salvador, widespread devastation occurred in rural areas of the country, mainly in areas, where predominating adobe and taquezal constructions coincided with high soil amplification effects. The earthquakes also triggered a large amount of landslides with the most significant landslide of Las Colinas in Santa Tecla, San Salvador, which destroyed several blocks of a residential area and killed about 500 persons. Indeed, the majority of the victims of these earthquakes were caused by seismically driven landslide activity, highlighting the importance of this collateral hazard in regions of susceptible geology and social vulnerability.

In Honduras, by some considered a 'non-seismic country', on May 29, 2009, a magnitude M = 7.3 earthquake was felt all over the country. This event with its epicenter in the Caribbean Sea (approximately 30 km north of Roatan Island) provoked only little damage on the rocky island, whereas large areas around the important towns of San Pedro Sula and El Progreso suffered large destructions (e.g. concrete bridges, newly-constructed buildings) due to local soil amplification and liquefaction phenomena. The harbor of Puerto Cortéz, the most important import and export hub for Honduras, Nicaragua and Guatemala was struck not only by the main shock but also, days and weeks after the main event, by aftershocks which reached magnitudes M = 6 and were located much closer to the damage area than the main event. The same applied for the area of Olanchito, at about 150 km distance from the fault zone of the main shock where adobe style residential houses were heavily damaged days after the main earthquake by secondary local seismic activity with events of magnitudes higher than 5.

The investigation of the influence of soil amplification to the overall seismic hazard was started in Central America at the end of the 1990s with investigations in some larger towns (LINDHOLM ET AL., 2007).

A comprehensive study on the estimation of seismic risk including seismic hazard estimation (peak ground acceleration, pga) and soil amplification based on seismic velocity profiles and seismic noise measurements. Application of vulnerability functions for different construction types was conducted in 2005 for Managua (REINOSO ET AL., 2005) which actually might be the only large city in Central America which disposes of a detailed GIS-based risk map including a vulnerability index for every building in the city. The map and corresponding reports are available on the web (http://www.ineter.gob.ni/geofisica/proyectos/vulsismana/index.html).

Earthquake disaster prevention includes hazard mapping, vulnerability estimation, and preventive land use planning to avoid construction on inadequate soil, legal measures as building codes and their enforcement, education of the population on adequate building practices, among others. In the last decades, programs have been carried out in the Central American countries to create hazard maps, data generated from the seismic monitoring systems were used to produce seismicity maps, seismic microzonation studies were carried out and programs for the information and education of the public were completed.

Good design and construction practices and compliance standards on earthquake resistant design contribute to reducing structural vulnerability to earthquakes. Some important efforts were carried out in Central America for the capitals of the countries. Building codes were elaborated which reflect the knowledge acquired during the last decades. The use of adobe and taquezal architecture declined, ironically to a great extent due to the destructions by recent local earthquakes. Nevertheless, this kind of construction is still used in many smaller towns and rural areas - possibly the next sites of large catastrophes if nothing is done to reduce this vulnerability.

Volcanic hazard and risk

Twenty seven volcanic locations - stratovolcanoes, silicic calderas, cinder cones, complex volcanoes, and several backarc volcanic fields – have shown historic activity in Central America which is one of the most active volcanic regions on earth. Additionally dozens of volcanic centers exist which could be reactivated in the future. Volcanic activity ranges from quiet extrusion of basaltic lavas to large explosive eruptions (ALVARADO ET AL., 2007; VAN WYK DE VRIES ET AL., 2007).

By comparing the volcanic centers presented in the figure above with the population distribution, it is obvious that many population hotspots are located close to active volcanic zones including even settlement on the flanks of active volcanoes. In total, more than 20 million people in Central America live within a distance of only 30 km from active volcanic centers, which is about 50% of the total population (PALMA ET AL., 2009).

Currently, the most frequent volcanic hazards occurring in Central America are lahars, strombolian and vulcanian eruptions, lava flows, and gas emissions. All eruption data below were taken from the Global Volcanism Program (GVP) of Smithsonian Institution.

The strongest eruption in Central American history occurred in 1902 at the Santa Maria volcano, Guatemala. The eruption had a Volcanic Explosivity Index (VEI) = 6 and at least 5000 people were killed. In 1929, a dome collapse with a relatively low VEI = 3 at Santiaguito volcano, in the immediate neighbourhood of Santa María, killed 200-5000 persons. As the second strongest eruption (VEI = 5), the 1831 eruption of Cosigüina volcano in north-western (NW) Nicaragua is listed, about 600 people were killed.

Eruption of Cerro Negro volcano, Nicaragua, 1992
source: W. Strauch

New multidisciplinary investigations have been carried out to improve the record of past volcanic eruptions, including field and maritime mapping and further age determinations of large eruptions. Archeological and geological studies presented evidence for very strong eruptions of some recently not active volcanic centers which are located in the vicinity of large cities. Examples are the following eruptions: Ilopango caldera (401 AD, VEI = 6 +, 20 km distance from San Salvador), Masaya caldera (150 AD, VEI = 5 +, 20 km distance from Managua) and Apoyeque volcano (50 BC, VEI = 6,8 km distance from Managua).

Based on geological and volcanological studies it is stated that high magnitude phreatomagmatic and plinian eruptions, as of cataclysmic eruptions can be expected in the future close to the population centers of Central America. A vivid example is the densely populated region of Managua where approximately two million people (roughly 40% of Nicaragua's population) are concentrated.

During the last decade intensive field studies were performed in the greater area of Managua leading to new compilations of the cumulative thickness distribution of tephra deposits from highly explosive eruptions affecting the region. During the past 10 000 years, seven high-magnitude eruptions covered the city area with a total tephra thickness of 1-4 m, giving an average recurrence period of 1400 years with the highest risk in the north-western sector of the city. In such a scenario vast populated areas in the western and central part of Nicaragua would potentially suffer extensive building collapse during a future plinian eruption.

Eruptions producing pyroclastic surges like those that formed the Masaya tuff and most of the Xiloa tephra would even have much greater destructive potential causing complete devastation of large areas. The Chiltepe volcanic complex seems to be the most likely site of a future, highly explosive eruption considering its past record of high eruption frequency (Freundt et al., 2006a).

But even small eruptions may cause large disasters. In San Salvador and Managua active and dormant volcanic centers exist in the urban areas of these cities. The population density is increasing rapidly on the flanks of the Boqueron volcano of San Salvador (last activity in 1917 with lava flows, VEI = 3). In contrast, densely populated residential areas at the western periphery of Managua surround small 'maar' type volcanic centers created by intense phreatomagmatic explosions. It cannot be ruled out that comparatively small but explosive volcanic events will occur in the future in this area and endanger the lives of many people.

Existing constructions in Central America are generally not expected to withstand the effects of volcanic ash deposits on their roofs with more than five cm thickness. Generally, the best strategy to cope with the impact of intense or long lasting volcanic activity is the evacuation of the population. Large volcanic eruptions often have precursors and can develop within days and weeks. In such cases, monitoring and early warning systems are necessary to warn the population and to organize the timely evacuation.

Evacuation measures have been taken in some occasions by civil defense authorities in several Central American countries incorporating thousands of people (e.g. eruption of Cerro Negro volcano, Nicaragua, 1992; eruption of Santa Ana volcano, El Salvador, 2007).

Examples of successful evacuations on the scale of several ten thousands to hundreds of thousand people are known from other parts of the world (Pinatubo volcano, Philippines, 1991, 60 000 people were evacuated; Rabaul caldera, Papua New Guinea, 1994, the complete city of Rabaul was evacuated) and might be necessary at some point in the future also in Central America (data from Smithsonian Institution, http://www.si.edu/).

Disaster prevention at volcanoes includes hazard mapping, land use planning to prevent construction inside volcanic hazard prone zones, monitoring and early warning. In the last few decades, several projects and programs have been carried out in Central America to generate hazard maps for the most important volcanoes, monitoring systems were installed at the most active volcanic locations and awareness rising and education programs of the population were accomplished .

Tsunami hazard and risk

Central America has a long history of tsunami events. The tsunami catalogue for the whole region lists 50 events which have been recorded since the 16^{th} century on the Pacific and the Caribbean coastline.

In 1992, the most disastrous tsunami occurred at the Pacific coast of Nicaragua. Waves up to 10 m high struck the beaches and created extensive destruction and the death of many people. Tsunamis known from Guatemala, El Salvador, Honduras, and Nicaragua are listed in the table on the next page.

Year	Date (Month/Day)	Region	Magnitude of Triggering Earthquake	Location
2009	05/29	C	7.3	Guatemala, Earthquake north of Roatan
2001	01/13	P	7.6	El Salvador
1992	09/01	P	7.2	Nicaragua
1976	02/04	C	7.5	Cortés, Gulf of Honduras
1968	09/25	P	6	Mexico, Guatemala
1960	05/22	C	8.5	La Unión, Fonseca Bay, El Salvador
1957	03/10	P	8.1	Acajutla, El Salvador
1956	10/24	P	7.2	San Juan del Sur, Nicaragua
1950	10/05	P	7.9	Costa Rica, Nicaragua, El Salvador
1950	10/23	P	7.3	Guatemala, El Salvador
1926	11/05	P	7	Nicaragua, (?)
1920	12/06	P	---	Fonseca Bay
1919	06/29	P	6.7	Corinto, Nicaragua
1919	12/12	P	---	El Ostial, Nicaragua
1906	--/--	P	---	El Salvador
1902	01/18	P	6.3	Ocos, Guatemala
1902	02/26	P	7	Guatemala, El Salvador
1902	04/19	P	7.5	Ocos, Guatemala
1859	08/26	P	6.3	Amapala, Fonseca Bay, Honduras
1859	12/09	P	7.5	Acajutla Bay, El Salvador
1856	08/04	C	7.5	Gulf of Honduras
1855	09/25	C	6.3	Trujillo, Honduras
1844	05/--	P	7.5	Lake Nicaragua (seiche?)
1825	02/--	C	5.5	Roatan Island, Honduras
1539	11/24	C	---	Gulf of Honduras

Tsunamis in northern Central America

P: Pacific
C: Caribbean

source: Molina (1997); Fernandez et Al. (2000)

The main triggers for disastrous tsunamis in Central America are high-magnitude local earthquakes, which occur at shallow depths in the subduction zone of the Pacific Ocean and effect a sudden vertical displacement of huge amounts of water. The generated wave heights off shore are in the range of decimeters or meters, whereas on the affected beaches the waves may reach heights of up to 30 m.

The speed of a tsunami depends on the square root of the water depth. As the shelf areas of Guatemala, El Salvador and Nicaragua are relatively broad and the water depths are shallow, tsunamis propagate with rather slow velocities and there is a considerable time delay between the occurrence of the earthquake and the arrival of the wave at the coastline. In case of the 1992 tsunami-triggering earthquake in Nicaragua, time delays between 30 and 60 minutes were observed. This lag of time is important as it enables an efficient tsunami early warning. For the town of La Unión, an important harbor in the Fonseca Bay, this delay is even more than two hours as the water depth in the bay is less than 30 meters.

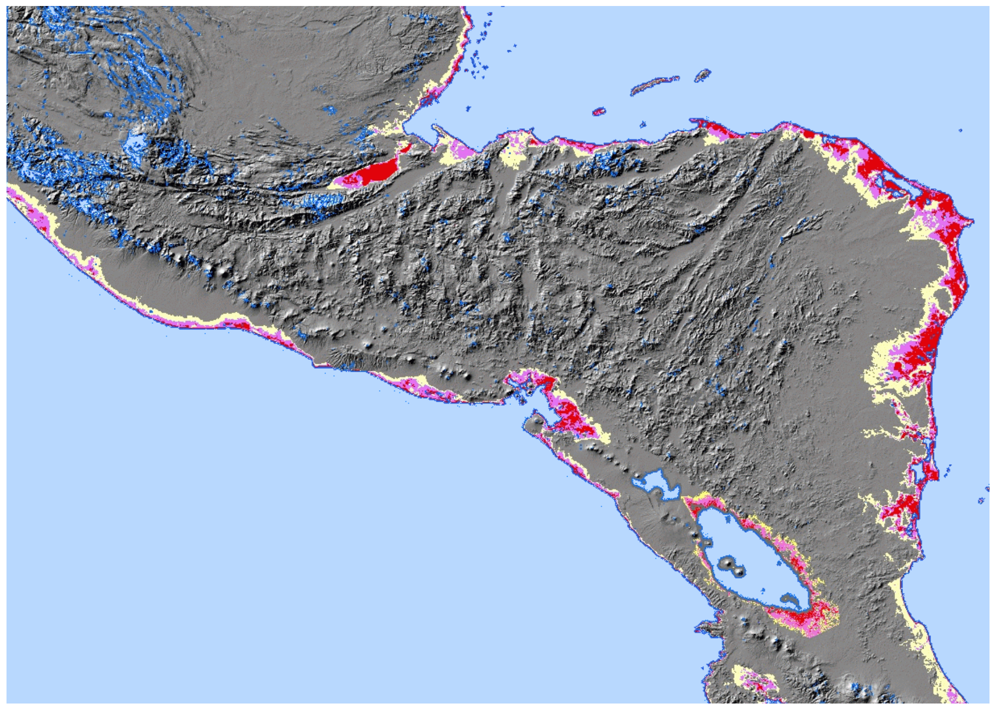
Geological and geophysical studies have been carried out in the last few years along the Pacific coastline of Nicaragua and Costa Rica have shown that tsunamis in Central America are not only triggered by earthquakes along the tectonic plate contacts but possibly by submarine landslides at the steep sea trenches as well (von Huene et al., 2004).

A special situation exists in the Fonseca Bay, which is surrounded by volcanoes (Cosigüina in Nicaragua, Conchagua in El Salvador) and hosts volcanic islands. Volcanic explosions, induced by contact of magma with sea water, bulky landslides as well as flank collapses and pyroclastic flows might also trigger tsunamis.

Location of the 1992 tsunami impact along the Pacific coast,, source: W. Strauch

Geological evidence exists for the occurrence of a tsunami in Lake Managua due to a volcanic explosion at the Chiltepe volcanic complex near Managua (Freundt et al., 2006b). A tsunami provoked by a landslide at Lake Atitlan/Guatemala was observed with 4 m high waves on October, 2005 (Girón & Matías, 2005). The 'Isletas' near Granada, Nicaragua, a peninsula and hundreds of small islands in Lake Nicaragua are the impressive result of a huge flank collapse of Mombacho volcano.

A preliminary tsunami hazard assessment was carried out in 2005, to identify the most endangered sites along the coastlines of Central America using a Digital Elevation Model (DEM) and a global population data base (see map below). Beaches where higher ground (more than 10 m above sea level) can be reached within a few minutes of walking were classified as low hazard areas. High tsunami risk was considered for places where beaches are low and wide, the distances to higher grounds are far-off and the population density is high. Cities like Corinto in Nicaragua or El Triunfo in El Salvador might be future disaster sites because the inhabitants of these cities live in special topographic situations which do not allow for an instant escape to higher ground, even if they have received an immediate tsunami warning.



High Hazard (0 - 5 m)
Medium Hazard (5 - 10 m)
Low Hazard (10 - 20 m)

Preliminary tsunami hazard assessment, northern Central America source: Strauch (2005)

Recently, economic activity and population density boost along the coastlines. Central American beaches attract an increasing number of tourists, causing a growing tsunami risks. Prevention of property loss is only possible by avoiding of constructions in tsunami prone zones. Loss of live can be minimized by implementing early warning systems.

All Central American countries are members of the Pacific Tsunami Warning System. However, this system is not efficient in case of local tsunamis generated off the coast of Central America. Until now, only Nicaragua and El Salvador have implemented a national tsunami warning system. In 1992, an earthquake occurring off shore the Nicaraguan coast generated tsunami waves disproportionally large, taking into account its surface-wave magnitude (M_s). It caused no destruction and was felt only slightly even close to the coast, but was the first tsunami earthquake to be captured by modern broadband seismographs. Subsequent analysis of the data showed that the Nicaragua earthquake had a rupture process slower than in ordinary subduction zone thrust earthquakes. As a consequence, it was concluded, that tsunami warning systems must be able to detect long-period (larger than 100 s) waves (Kanamori & Kikuchi, 1993). Therefore, all Central American countries have recently updated their seismic networks and use broadband seismic stations.

In Nicaragua, tsunami hazard maps were elaborated on a scale of 1:50 000 for the whole Pacific coast using the 5 and 10 meter contour lines of the topographic maps. For the densely populated areas near Corinto, Puerto Sandino, Masachapa and San Juan del Sur, tsunami hazard mapping was carried out based on numerical simulation of tsunami generation, propagation and run-up distance (Yamazaki et al., 2007). In addition, large-scale hazard maps (scale 1:2000) based on high resolution DEM's were elaborated for the areas of Masachapa, Tola, Corinto, including evacuation routes and assembly points (Acosta, 2009).

For the Fonseca bay (El Salvador, Honduras, and Nicaragua), including the main populated islands, tsunami hazard maps on varying scales were elaborated which include evacuation routes and assembly points (Acosta, 2009; Strauch et al., 2010).

Landslide hazard and risk

Landslides are characterised by movements of solid rock, debris or soil that are driven by gravitational forces acting at the surface and in the shallow sub-surface. The triggers are either natural factors, such as extreme rainstorms, prolonged wet periods, and earthquakes, or factors related to human activity like mining, excavations and blasting. There are preparatory factors, which predispose a given area to failures, including natural and induced changes in land cover and land use, presence of soil and physical characteristics, hydrology, and geological conditions, including weathering status (IGOS, http://www.igospartners.org/Docs.htm, 2004). Landslides have caused tens of thousands of deaths and billions of Dollars in losses worldwide and Central America is one of the hotspot areas of gravity driven mass movements, as the geomorphology, geology and climate make the area very susceptible to rainfall- and seismic triggered landslides. Rural poverty, over population and uncontrolled urbanization result in settlements on landslide prone hillsides and on the banks of ravines, creating an ever-increasing exposure of the population to the hazard of earthquake- and rainfall-induced landslides (Rodriguez, 2007).

A large number of studies on landslide hazard and risk were conducted after hurricane 'Mitch' especially in Honduras and Nicaragua which led to the formation of GIS based data bases and the elaboration of numerous landslide susceptibility and hazard maps (e.g. Dévoli et al., 2007; Harp et al., 2002; JICA, 2001).

Nevertheless, landslide inventory databases do not exist in all the countries or are maintained by different organizations and in different database formats.

The countries and morpho-structural regions of Central America are characterized by different types of mass movements and triggering mechanisms, due to the prevailing morphological, geological and climatic differences. Recent investigations, based on a comprehensive landslide database have shown that a high hazard for earthquake induced landslides exists only in Costa Rica, El Salvador, Guatemala and Panama (Bommer & Rodriguez, 2002). In contrast, Nicaragua and Honduras seem to be affected mainly by rainfall induced landslides; however, the lack of landslide surveys for Honduras complicated the analysis (Rodriguez, 2007).

Indeed, recent research activity on landslide activity in Nicaragua seems to support this conclusion. Spatial and temporal information of about 17 000 landslides affecting Nicaragua between 1570 and 2003 were analyzed, though, as 62% of the total number were triggered by strong rainfalls of hurricane 'Mitch' in October 1998, the database obviously is strongly biased for rainfall induced landslides. It was shown, that shallow debris flows have been the most common types of mass movements and represent 66% of the total landslides recorded for Nicaragua, slides represent 24%, rock falls about 6%. Intense and prolonged rainfall, often associated with tropical cyclones, and seismic and volcanic activity, represent the most important landslide triggers, amounting about 62% of the events. In contrast, seismic triggering occurred in 29 %, volcanic activity induced 7 % of the landslides (Devoli et al, 2008).

Also, the influence of topography (elevation, slope angle, slope aspect) and lithologic parameters for run out distance prediction were statistically analyzed for different landslide types (Devoli et Al., 2007). The results showed that debris flows and debris avalanches, affecting the flanks of volcanoes, have the highest mobility and reach longer distances compared to other types of landslides in the region (Dévoli et al., 2007). In general, their height, steep flanks and the inherent weakness of the lithology/soil materials make mass movements on volcanic slopes more deadly than in other geologic environments - even without the presence of volcanic activity. For example, about 1.300 people died when the crater lake of Agua volcano, Guatemala, drained in 1541 (Feldman, 1993). In 1570, a debris avalanche at Mombacho volcano, Nicaragua, killed 400 people (Feldman, 1993). In 2005, a debris flow at Panabaj, Guatemala killed more than 500 people during hurricane 'Stan' (Connor et al., 2006). The most catastrophic event occurred at the Casita volcano, Nicaragua, on 30 October 1998. In this incident, a debris avalanche and debris flow was triggered by heavy rainfall associated with hurricane 'Mitch' and killed more than 2000 inhabitants of two villages (Scott et al., 2005; Dévoli et al., 2009).

Landslide El Suptal/Honduras, 11/2008
source: Kuhn et al. (2009)

Although the probability of hurricanes and intense precipitation is much higher on the Caribbean coast of Central America, the probability of landslides is rather small due to the low topography. In contrast, the rough terrains and steeps flanks of the central highlands and along the volcanic chain on the Pacific side render these regions more prone to rainfall-triggered landslides. Under certain meteorological circumstances, a hurricane located on the eastern coast can induce rather high rainfall on the Pacific side of the region. This happens when the low pressure of the hurricane is able to suck large amounts of humid air from the Pacific Ocean. This scenario took place during the passage of the disastrous hurricane 'Mitch' (Category 4) in October 1998, which caused tremendous precipitations in NW Nicaragua, although the hurricane center was situated over north-eastern (NE) Honduras. Many people were killed in mountainous areas and the volcanic chain of Nicaragua due to landslides and flooding. Similar scenarios may be provoked by smaller hurricanes as showed by hurricane 'Ida' in November 2009. The hurricane (Category 1) on its path heading to the north had affected the Caribbean coast of Nicaragua with minor damages. Though, its centre was situated to the north of Honduras, on November 7, 2010 extremely strong rains occurred suddenly in El Salvador affecting the area between San Salvador, Lago Ilopango and San Vicente volcano. About 120 people died due to lahars, landslides and inundation (STRAUCH ET AL., 2010).

Also smaller meteorological events, such as tropical storms or tropical disturbances can trigger disastrous situations. Examples are the landslides at Cerro Musún in Central Nicaragua (STRAUCH, 2004). Completely unexpected, widespread landslides occurred at the steep flanks of the Musún massif and killed about 30 people. Though precipitation measurements did not exists eye-witness accounts from the local population led to the conclusion that extraordinary rain falls lasting for several hours had deployed the tragedy.

Earthquakes frequently trigger landslides in Central America (e.g. RODRÍGUEZ, 2007). At least 10 000 landslides were caused in 1976 by the magnitude M = 7.5 earthquake at the Motagua fault in Guatemala (HARP ET AL., 1981). Likewise, the two earthquakes affecting El Salvador on January 13, 2001 (Mw = 7.7) and February 13, 2001 (Mw = 6.7) which induced local accelerations up to 0.8 g, triggered extensive mass movements in many parts of the country. The most tragic event was the Las Colinas landslide at Santa Tecla, San Salvador, which killed more than 500 people (EVANS & BENT, 2004).

Disaster prevention for landslides includes susceptibility and hazard mapping, regular inventory updating and proper land use planning to avoid construction in highly susceptible landslide prone areas as well as local and regional early warning. Regional landslide hazard assessments for Central America, considering earthquake and rainfall events, have been elaborated applying the methodology of MORA & VAHRSON (1994). However, evaluations of the modeling results confirm, that the MORA-VAHRSON method tends to underestimate the hazard when applied to regions outside Costa Rica (RODRIGUEZ, 2007). Further approaches were published by NADIM ET AL. (2004), using a simplified version of the MORA-VAHRSON model to elaborate a global hazard map, and by RODRIGUEZ (2007), concentrating on earthquake induced landslides.

Recently, several projects and programs have been carried out in Central America to promote activities for landslide risk reduction. Components for a regional early warning system for landslides, based on precipitation estimation from satellite images are in progress (SCHILLINGER ET AL., 2009; STRAUCH, 2010).

Inundation hazard and risk

Heavy rains and inundations are by far the most frequent hazard events in Central America causing loss of live and property every year.

Inundations in Central America have the following causes:

- *Tropical Cyclones:*
    - The intense and abundant rainfall that comes with tropical cyclones;
    - Storm surges caused by strong winds blowing toward the coast;
    - The air pressure difference between the cyclone and the surrounding area generating large waves that flood the coasts.
- *Convective storms:*
  This type of rain or showers, commonly called waterspouts, cover areas between 5 and 10 km in diameter, are accompanied by lightning, strong winds and hail and may cause flash floods;
- *Hail:*
  Freezing rain is falling in the form of shells and cover sewerage networks, which prevents the removal of water in urban areas;
- *Dam break:*
  Sudden failures of man-made or natural lakes can lead to downstreaming torrents without any warning.

Floods are natural phenomena which have continuously shaped the landscape. Their sedimentary deposits increase agricultural productivity. However, flooding can also induce tremendous damages. Human activities contribute to the risk of flooding by inadequate land use and drainage managements.

Effects of flooding are the overflow of rivers, obstruction and failure of bridges, roads and communication lines, triggering of landslides, sediment deposition, direct damages to buildings and infrastructure and agricultural damage.

Unexpected strong torrential rains in dry rivers or gullies may cause destruction of houses, interruption of life lines and death of people. Frequently, these flash floods transport debris which adds to the destructive forces. Floods in the long river reaches in the plains of the Atlantic part are actually slow rising in hours or days, such as at El Rama, where three rivers, draining the central Nicaraguan mountains flow together. There, the river level may increases by 10 meters or more within a few hours, leading to the flooding of the neighbouring town. Tropical thunderstorms may trigger disastrous flash floods where the river level increases by several meters within 15 minutes, as occurred in November, 2007 in the town of Matagalpa, Nicaragua (STRAUCH ET AL., 2007).

Rescue efforts after flooding destroyed a bridge, close to Siuna, Nicaragua source: Defensa Civil, Nicaragua, 2008

Inundations due to strong precipitations occur not only in riversheds but also on the coast of lakes and inlets of the oceans. For example, the water level of Lake Managua rose more than 4 meters after hurricane 'Mitch'. Afterwards, the lake re-drained through the Tipitapa river to Lake Nicaragua. People living along the lakeshore of Lake Managua had to be evacuated for the first time within the last 50 years. The extreme rainfall during hurricane 'Mitch' led also to widespread inundations on the Honduran coast of Fonseca Bay, e.g. near the village of Cedeño. As a consequence of the 'Mitch' disaster, inundation hazard mapping was intensified in Central America, especially in Honduras (e.g. JICA, 2001; CHIRICO ET AL., 2009)

Each of the Central American countries manages early warning systems on inundations based on meteorological data and river gauges. The CENTRAL AMERICAN FLASH FLOOD GUIDANCE (CAFFG) supports the national hydrological agencies and uses nearly real-time estimations of precipitation intensity using meteorological satellite data.

Monitoring systems, data collection, GIS

Monitoring systems are of prime importance for hazard studies, vulnerability reduction, and disaster prevention. In Central America, monitoring systems of geological and hydro-meteorological phenomena are developed and maintained by governmental institutions and universities.

In Guatemala, the Instituto Sismológico Vulcanológico, Meteorológico y Hidrológico (INSIVUMEH/Guatemala-City; staff about 60 persons) which belongs to the Ministerio de Comunicaciones, Infraestructura y Vivienda is responsible for scientific studies and monitoring of the dangerous natural phenomena. In addition, the Comisión Nacional de Reducción de Desastres (CONRED) participates in monitoring procedures by maintaining a widespread communication system and contributes field observations from all over the country. Until now, only a few data are published on the World Wide Web.

In El Salvador, the Servicio Nacional de Estudios Territoriales (SNET/San Salvador; staff about 80 persons, line authority of the Ministerio de Medio Ambiente y Recursos Naturales) develops and maintains a seismic network, the volcano monitoring system, meteorological and hydrometric station networks, and performs field observations and scientific studies. The institution is also responsible for tsunami warning. Most stations are telemetric and an international data exchange is maintained. The resulting data sets are managed with Geographic Information Systems (GIS) and results are published timely on the institute’s website. In addition, the GI-Systems contain a large amount of project information and data obtained from studies carried out in El Salvador recently.

The Instituto Nicaragüense de Estudios Territoriales (INETER/Managua; staff about 300 persons) is an independent institution subordinated only to the presidency and is by far the largest geo-scientific institution in Central America.

INETER performs seismic, volcanic, meteorological and hydrological monitoring with numerous field stations (most of them telemetric), landslide and tsunami relevant monitoring and is the responsible institution to provide timely information for early warning. International data exchange is maintained. INETER´s cartography department has the function of the cartographic institute in other countries. The institution manages a GIS on georisks and monitoring information is published in nearly real-time on the institutional website. The GIS contains a large amount of data generated or compiled by dozens of projects recently accomplished in Nicaragua on natural hazards, vulnerability, and risk.

In Honduras, a centralized institution responsible for investigation and monitoring of natural phenomena does not exist. The meteorological network is in part managed by the Meteorological Service which belongs to the Secretaría de Recursos Naturales y Ambiente (SERNA). In addition, a telemetric meteorological network for early flood warning is maintained by the Comisión Permanente de Contingencias (COPECO/Tegucigalpa).

Some hydrometric stations are maintained by the National Electrical Power Company (Empresa Nacional de Energía Eléctrica, ENEE), moreover ENEE keeps a short period seismic- and an accelerographic station at its power plant El Cajón.

The Geophysical Department of the University of Honduras (UNAH) owns two seismic stations, one at its headquarters in Tegucigalpa and another at Cerro El Hule, near Tegucigalpa. However, both stations have not been operational for several years. UNAH maintains also a seismic broad band station installed by the US Geological Survey as part of a Caribbean Tsunami Warning System. The station transmits its data by satellite connection to the Incorporated Research Institutions for Seismology (IRIS)/USA, and offers free data access via internet. A minimal seismic network of 5 stations located at the western coast is operated by COPECO but data recording and processing is done at INETER, Nicaragua. SERNA, ENEE, and UNAH have certain GIS capacities data archives. A large amount of data concerning hazard and risk, some down to Municipio level have been compiled and stored in a GIS by the ‘Proyecto Mitigación de Desastres Naturales’ (PMDN) which has been in operation since 2001 with its registered office hosted in the headquarters of COPECO. In addition, a separate regional GIS on georisks is in progress.

In recent years, the region witnessed a huge number of projects were financed and performed by international development banks and aid agencies benefitting dozens of Municipios. Existing information was compiled to create maps and plans usable for land use planning taking into account the disaster prevention aspect.

In Nicaragua a project was conducted by Instituto de la Vivienda Urbana y Rural (INVUR) and INETER to provide natural hazard evaluations for local house building projects in more than 90 sites all over the country, benefitting around 7000 families.

Regional and International Cooperation

The Centro de Coordinación para la Prevención de Desastres Naturales (CEPREDENAC) coordinates the efforts of the Central American countries on the field of disaster prevention and mitigation.

Regional cooperation in the field of hydrology including aspects of disaster prevention is coordinated by the Comité Regional de Recursos Hidráulicos (CRRHH).

El Salvador, Guatemala, Honduras, and Nicaragua are embedded in the Pacific Tsunami Warning System (PTWS) and incorporated in the creation of the emerging Caribbean Tsunami Warning System. These warning systems are supported by an active exchange of seismic data in real-time between El Salvador, Honduras, and Nicaragua, which complement data from other countries of the region and from larger distances. The resulting broadened database is necessary for the proper evaluation of strong earthquakes and is indispensable for a reliable tsunami warning system.

The four countries are also integrated in the World Meteorological Organization (WMO) and exchange meteorological data useful for disaster prevention within this organization, including hurricane warning.

The Central American Seismic Center (CASC) is a regional seismic data center which organizes off-line seismic data exchange between the national seismic data centers. On-line data exchange for fast detection and location of seismic events is organized directly between the national agencies.

Natural Disaster Events (2000 - 2009) using Emergency (EM) - Database (DAT)

Map Contents

The supra-regional map depicts information about disastrous events affecting Central America in the period of 2000 - 2009 and is limited to the disaster main types earthquake, flood, mass movement (wet & dry) and volcanic eruptions as recorded in the Emergency (EM) – Database (DAT) solely. It shows:

- The number of disastrous events per country;
- The number of disastrous events per country specified to EM-DAT compliant disaster main types.

Map Purpose with Respect to Disaster Risk Management

Information about the spatial distribution of natural disastrous events (occurrences), their frequency and resultant tangible/non-tangible loss is an indispensable component of any kind of disaster risk mitigation strategy both national and supra-regional. Disaster information contributes extensively to better understand why regions at risk and what the controlling factors (hazard, vulnerability) are. It is obvious, that disaster event information exerts a strong influence on decision making processes by policy makers.

Data Source and Availability

EM-DAT is provided by the WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED) on http://www.emdat.be/, hosted at the University of Louvain in Belgium.

This database consistently delivers global information about disastrous events in order to support Disaster Risk Management activities both at national and international level. The database reverts to numerous sources from all over the world *'including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies'* (EM-DAT-WEB PAGE, 2010).

EM-DAT is based on a clear disaster event classification schema and applies strict criteria for a 'disaster' to be entered into the database as follows (at least one of the following criteria must be fulfilled):

- Ten (10) or more people reported killed;
- Hundred (100) or more people reported affected;
- Declaration of a state of emergency;
- Call for international assistance.

Remarks

According to the used criteria of the EM-DAT disaster threshold entry schema, less significant loss events have been excluded from this database. It is assumed that a significant portion of total disaster loss caused by local hazardous events is hidden. Due to this scenario, national hazard and/or event databases defining lower thresholds of loss as EM-DAT are of highest importance in terms of mapping more accurate disaster event maps with higher resolution regarding loss.

Furthermore, many hazard and risk mapping concepts rest on statistical approaches of hazard locations. Event inventories, such as for landslides, also provide information about the social and economic impact of hazard events and can thus be used for further detailing risk estimations based on hazard event size as well. As an excellent example for such an inventory, the national landslide database for Nicaragua can be mentioned here (DEVOLI ET AL., 2007).

Methodology

The Project 'Mitigation of Georisks in Central America' queried EM-DAT at March 2010 in order to create a so-called 'disaster list' using following criteria, primarily:

- Location (Region): Central America;
- Timeframe (Period): 2000 – 2009;
- Disaster Group: Natural.

The resulting disaster list contains 219 events comprising ten different EM-DAT disaster main types, spread over eight countries of Central America. By further limitation to the four project countries and five disaster main types of the geophysical and hydrological disaster sub-groups (see table below), the number of disastrous events has been reassessed again. Finally, 52 events have been processed to issue the natural disaster event map at hand.

Disaster Generic Group	Disaster Sub-Group	Disaster Main Type
Natural Disaster	Geophysical	Earthquake
		Volcano
		Mass Movement (dry)
	Hydrological	Flood
		Mass Movement (wet)

How to read this map

The map shows EM-DAT disaster data for the last ten years (period 2000 – 2009) according the constraints just mentioned before. Bar charts represent the number of events by disaster main types per country, whereas the background color indicates the total number of disastrous events per country (classified).

Additionally, the map contains info boxes summarizing EM-DAT based facts about tangible and non-tangible loss caused by disastrous events to be evaluated as follows:

- The number of killed people;
- The number of people affected totally;
- The sum of estimated loss (in Million US$) (not determined for all disastrous events).

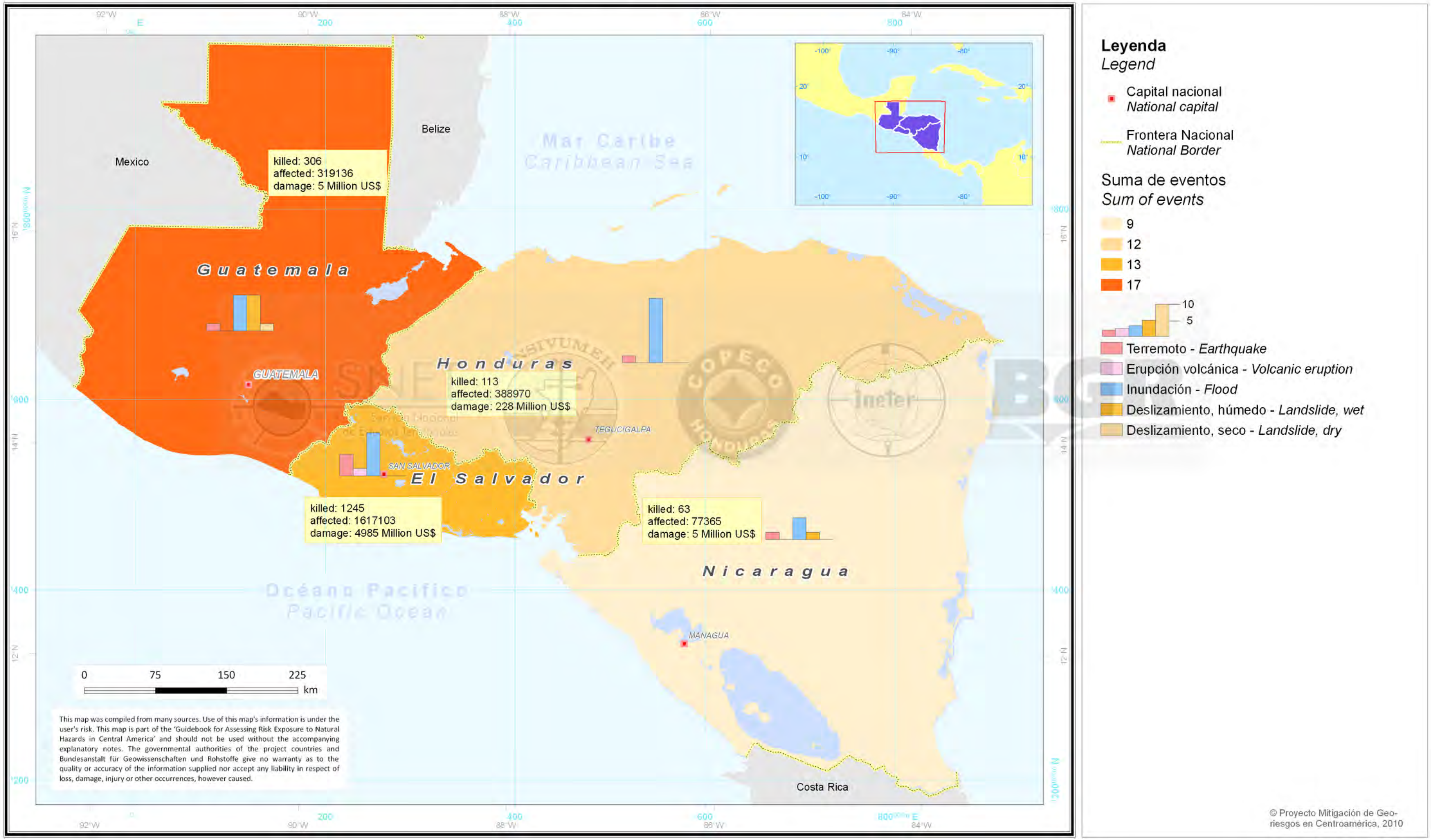
Taking into consideration the number of totally affected people by these disastrous events (threshold: > 100 000), the earthquakes affecting El Salvador in January/February 2001 and the 2008 flooding event in Guatemala and Honduras can be estimated as the most harmful disaster events within the last decade.

Recommendations

At present, numerous national and international institutions are maintaining natural disaster event data globally. From the Central America perspective it is recommended to provide relevant disaster information in a harmonized way to such disaster event database like EM-DAT or to the Munich/Swiss re-insurance databases, continuously. In the long-run, CEPREDENAC should address themselves to this task. On the other hand, national event databases amplify the local perception and can thus underpin local disaster management activities.

Desastres Naturales (2000-2009)

Natural Disaster Events (2000 - 2009)



Risk Exposure Mapping Tool: CARA-GIS

Overall Philosophy

The mapping of risk exposure to geohazards in Central America within the project of technical cooperation 'Mitigation of Georisks in Central America' pursues the following general principles:

- *Holistic approach:* The conceptual design and the development of a national/supra-regional risk mapping tool is an integral part of the risk mapping activities at all points;
- *Flexibility:* The tectonic setting leads Central America being prone to geohazards at different types and magnitudes. For that reason, national and supra-regional risk mapping has to be understood and implemented as an ongoing process by means of different or additional hazard and vulnerability data, should these be available and/or be of better temporal or spatial accuracy. Conceptually, the risk mapping tool has to meet this demand exhaustively;
- *Capacity building and sustainability*: Strengthening of governmental authorities in risk mapping skills is of highest significance as to the incorporation of risk assessment outcomes in Disaster Risk Management strategies and to provide adequate advisory service for policy makers both in the national and supra-regional context. In order to fulfill this requirement sustainably, experts from all involved authorities have been trained comprehensively.

Conceptual Approach

The design of a risk mapping tool for Central America, called '**C**entral **A**merica **R**isk **A**nalysis **G**eo-**I**nformation-**S**ystem (**CARA-GIS**)' to survey risk exposure to geohazards can be theoretically achieved into two different ways:

- *Option 1 - 'Central solution':* Establishing of a transnational CARA-GIS client-server architecture enabling a permanent central data exchange between the involved authorities and hosted by one of the authorities. This approach might be realized conceptually, but requires considerable operational-technical, administrative, and hardware resources;
- *Option 2 - 'Local solution':* Establishing of four country-specific CARA-GIS applications hosted peripherally and administered independently by each authority on its own. This approach facilitates the data management and the maintenance of the risk mapping tool subject to country (authority)-specific resources (e.g. manpower) and priorities, respectively.

Balancing both, the common interests and the capacities of the involved institutions, the partners unanimously agreed to realize the 'local solution' as the *currently* most pragmatic approach in order to remain operational far beyond the end of the project in 2010 (see figure on the next page).

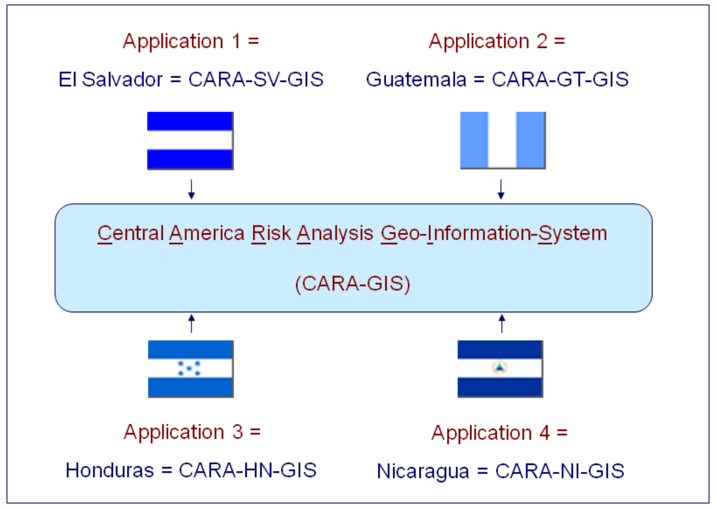
Consequently, four country-specific CARA-GIS applications have been designed almost identically, namely (country codes used according to ISO-STANDARD 3166-1 (status: 2010):

- *El Salvador:* CARA-SV-GIS;
- *Guatemala:* CARA-GT-GIS;
- *Honduras:* CARA-HN-GIS;
- *Nicaragua:* CARA-NI-GIS.

It is suggested, that CARA-GIS can be expanded geographically to all other countries of Central America and moreover.

Although, the country-specific CARA-GIS applications presently exist in parallel, a supra-regional risk assessment and mapping for Central America has already been realized as the following premises are met:

- Use of identical hazard assessment standards/methods;
- Use of identical risk assessment standards/methods;
- Use of a identical GIS architecture/identically structured data;
- Use of identical mapping styles for all resulting maps, in particular.



Conceptual view of CARA-GIS

However, taking into account the latest experiences to establish this guidebook and the growing number of baseline, hazard and vulnerability information in the mind's eye, it will be inevitable to pool the country-specific CARA-GIS applications making the national and supra-regional risk assessment future-proof. In the medium-term, the next logical steps could be:

- Establishing of one CARA-GIS, incorporating all existing country-specific applications, and if desired extended to the countries have not been considered, yet (Costa Rica, Panama);
- Development of a CARA-GIS web application to disseminate the hazard/risk outcomes publicly.

Data Model and GIS / Database Architecture

The technical implementation of the risk exposure mapping concept is based on a logical data model performing a highly efficient and traceable risk mapping workflow, free of any data redundancies. CARA-GIS strictly separates spatial (geometries) from descriptive (attributes) information. This procedure is mainly aimed at the utilization of database querying functionalities, which can properly be executed during the risk assessment procedure by using database software outside the GIS environment.

The CARA-GIS management of risk relevant information and corresponding metadata uses a coding system, hierarchically structured into:

- *Level 1:* Theme group codes;
- *Level 2:* Theme codes;
- *Level 3:* GIS value codes.

Theme Group Codes

Theme groups represent general categories specifying the thematic content of the data. A four digit code for theme groups is restricted to full thousand values (1000, 2000, etc.). In order to ensure an accurate workflow the defined theme groups and their corresponding codes must not be changed.

Theme Group Code	Name of Theme Group
1000	Topographic data
2000	Hydrological data
3000	Geoscientific data
4000	Land use data
5000	Volcanic hazard data
6000	Landslide hazard data
7000	Seismic hazard data
8000	Inundation hazard data
9000	Infrastructure data

Theme codes

Theme codes categorize a theme unambiguously by a four digit code inside a definite theme group. The first digit code is in accordance with the first digit code of the theme group it belongs to. The remaining three digits can be assigned without any restrictions.

Theme Group Code	Theme Code
7000 Seismic hazard (data)	7310 Seismic hazard (map), return period 500 a
	7320 Seismic hazard (map), return period 1000 a
	7330 …

GIS Value Codes

A complete GIS value code is determined by a seven digit composite code encompassing the four digit theme code followed by a unique three digit value for each individual category subordinated to a theme. By indexing the 'GIS value code' being a 'primary key', duplicate or multiple value code entries inside the coding scheme can definitely be ruled out.

Theme Code	GIS Value Code
7310 Seismic hazard (map), return period 500 a	Seismic hazard zoning (map): 'pga' value classes
	7310101: very low
	7310102: low
	7310103: medium
	7310104: high
	7310105: very high

The CARA-GIS coding system facilitates a dynamic incorporation of new thematic information, whenever necessary or desired.

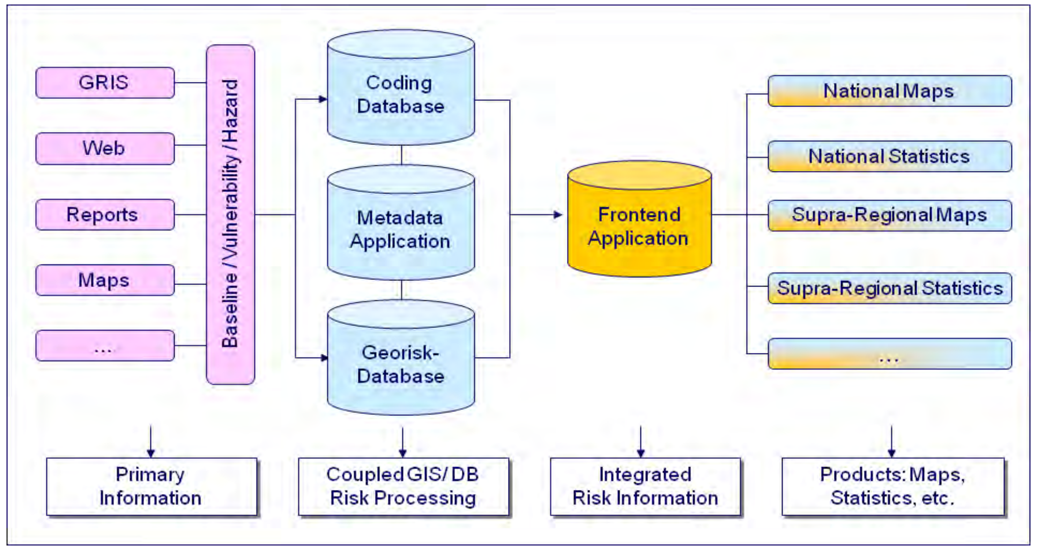
Example:

An existing seismic hazard map ought to be replaced or substituted by a modified one. In such a case, the new theme codes for the seismic hazard zones can be assigned inside the already existing theme group code '7000', e.g. '7410' representing a current issue of a seismic hazard map, return period 500 a. In doing so, the 'original' theme codes will not to be canceled. The new GIS value codes for the theme code '7410' can be added accordingly, e.g. '7410101' could stand for seismic hazard zoning (map) '*pga*'-value class 'low'. This adjustment allows for calculating comparative risk exposure scenarios depending on available seismic hazard maps.

CARA-GIS Applications

CARA-GIS consists of four permanently interrelated database applications managing all relevant risk assessment and mapping information as follows (see figure below):

- *Coding Database:* relational database application enabling the thematic coding procedure;
- *Personal Geodatabase:* a 'georisk database' storing all thematic spatial data in a standardized format; beyond that, all thematic GIS intersection results and relational queries elaborating the final risk exposure are incorporated as well. This format is proprietary of ESRI Inc.;
- *Metadata Database:* a database application to create geo-spatial metadata in compliance with ISO-STANDARD 19115 (2003) describing the spatial information arising from the code annotations of the aforementioned coding database;
- *Frontend Database:* a (optional) relational database application provides a user-optimized access to significant baseline, vulnerability, hazard and risk exposure related codes as well as to statistical and mapping outcomes.

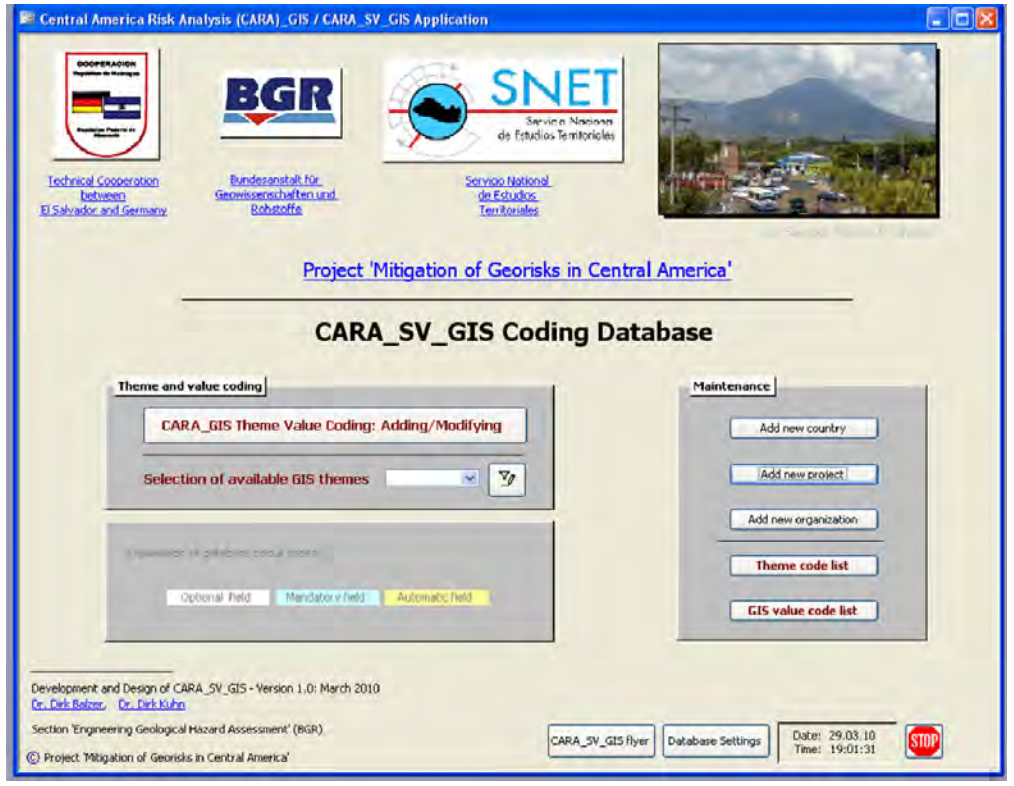


Schema of the CARA-GIS Architecture

Coding Database

In the coding database application the aforementioned coding schema is implemented. Based on a stringent Entity-Relationship (ER)-Model, the coding procedure by itself can effortlessly be accomplished outside the personal geodatabase environment, irrespectively.

All editing steps are controlled by interactive forms and object buttons (see figure on the right-hand site). The newly calculated coding datasets (codes and their annotations) can be applied immediately for generating GIS metadata inside the metadata database application. Hence, the quality of the code annotations exerts influence on the quality of the metadata, extraordinarily.



Coding Database, example El Salvador

Geodatabase

The personal geodatabase concept as the CARA-GIS core entails the following advantages:

- All spatial information of CARA-GIS is kept in a single container that can be shared to different users in a simple way;
- Feature datasets and feature classes facilitate a consistent thematic structuring of risk assessment relevant spatial-related baseline, hazard and vulnerability information;
- Feature classes provide geometric attributes (length, area) which are of utmost importance for risk mapping purposes;
- The geodatabase can be applied to compute the risk exposure by merging spatial information and their corresponding attributive information using standardized database SQL-based querying functionalities.

The designation of a standard CARA_GIS feature dataset combines the name of a single theme group, e.g. infrastructure data and their corresponding theme group code '9000', that is to say the feature dataset is called 'infrastructure _9000'.

Inside a thematic feature datasets all geospatial objects of the CARA-GIS are stored in feature classes. The nomenclature of related thematic feature classes has also been fixed strictly by utilization of the theme group codes, e.g. 'settlement_area_9300' or 'roads_9400'. This approach enables the subsequent creation of metadata automatically.

Feature classes bridge the gap between spatial information and their attributive information by incorporation of an identical item ('value_code') applied in the coding database as well.

All feature classes inside a respective country-specific CARA-GIS geodatabase are characterized by the same coordination system as follows:

Country	Projection & Spheroid	Datum
El Salvador	Lambert Conformal Conic, Clarke 1866, central meridian: 96° W, standard parallels: 20°N, 60°N, latitude of origin: 40°N	NAD 1927
Guatemala	UTM Zone 15 North	WGS 1984
Honduras	UTM Zone 16 North	WGS 1984
Nicaragua	UTM Zone 16 North	WGS 1984

Deviant from this nomenclature, an additional feature dataset has been integrated in order to administer feature classes focusing exclusively on the administrative division of the countries. Given that the administrative units 'Departamentos' (level 2) and 'Municipios' (level 3) have already been coded in accordance to the respective national coding system (see chapter *Administrative Areas, Supra-Regional*, page 24, and *Demography, Supra-Regional*, page 36), the designation of these feature classes is referred to different administrative levels merely, e.g. 'admin_level_2'.

Additionally, several look-up tables have been integrated into the geodatabase delivering essential baseline information about demography arising mostly from external information sources.

Metadata Database

As described above the metadata application is a stand-alone database application that connects the two databases mentioned before. The application has only one form in which users simply select the feature classes from a list. The list itself presents feature classes available in the actual geodatabase just discussed. After selecting an item the related data from the coding database are shown and by pressing the 'Create metadata' button an ISO compatible set of metadata is created inside the geodatabase (see figure below).

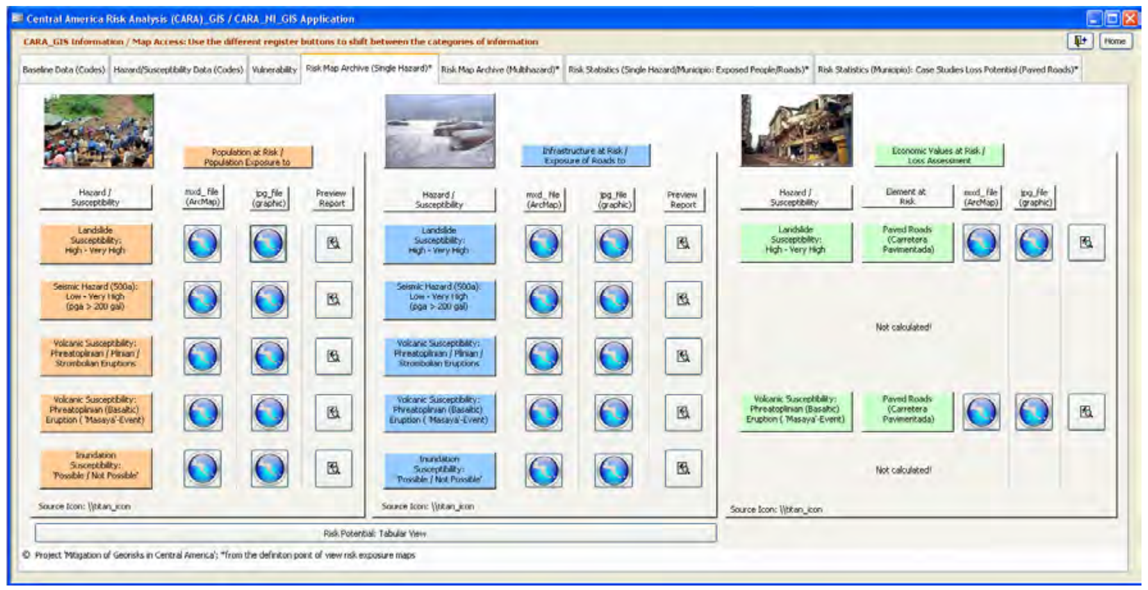
Metadata Database, example Nicaragua

In addition to that, an ArcGIS-compliant layer file will be created and placed in a predefined folder structure. The layer files generated by the application already have the attribute data from the coding tables joined to the geospatial data. Users must consult the ArcGIS manuals in order to understand the concept of layer files. Both, the original feature class and the layer file will have the associated metadata, which will be presented based on a so-called stylesheet (see figure on the right-hand site).

Metadata representation

Frontend Database

The frontend database, called 'CARA-GIS Information Center' (see figure below) is an optional application and therefore not necessarily required for the elaboration of risk outcomes, actually. Otherwise, this application pools and converts the most relevant baseline, vulnerability and hazard information, like codes and their plain language as well as statistics and maps (jpg/pdf/bmp-graphics, mxd-files) of the determined risk exposure scenarios into a user-friendly application. Due to the lack of time and the high expense to design a single CARA frontend application, only the version for Nicaragua has been developed exemplarily and is ready for operation, yet. It is strived to generate further country-specific CARA frontend applications as soon as possible.



Frontend Database, example Nicaragua

Software Requirements

Combined processing of CARA-specific spatial and attributive information requires powerful GIS and database software. While OpenSource software basically seems to be suitable to perform CARA-GIS outcomes as well, all CARA-GIS related IT-solutions have been managed by ESRI ArcGIS 9.3 and Microsoft Access 2003/2007. These software packages and their predecessors have already been utilized since the project's onset.

Problems and Pitfalls

Using Geospatial Data

When using spatial data, geometric accuracy is of utmost importance. Digital geographic data have been produced in Central America for many years. During this time period, the number of organizations creating spatial data has increased constantly and the quality of the data distributed by these organizations varies a lot. Please refer to the individual chapters in this book to find information regarding the accuracy and quality of the data obtained from the different sources.

Geometric Discrepancies

When merging and intersecting thematic data from different organizations, geometric discrepancies are almost inevitable. The problem arises due to the usage of different coordinate systems that often are not explicitly specified.

Mapping Scale Issues

Merging data from different scales in a GIS is a simple task. However, it must be kept in mind, that different scales have different degrees of generalization. This usually affects any result involving geospatial data. Thus, a result produced cannot be more precise than the input data with the largest generalization.

Time Issues

The time a particular data set represents, is an issue to be aware of when combining data from different sources. Many datasets are not updated on a regular basis, forcing us to merge data representing different temporal 'snapshots'. In addition, changing administration coding can make it difficult to merge data, particularly geographical data with statistical data. While on one hand it is of course desirable to have a precise and up-to-date database this is on the other hand a difficult, if not an impossible goal to achieve, in particular in cross-border studies. In the present book, the supra-regional maps are based on data that in most cases have not been compiled from the same data source at the same time. However, we valued the benefits of a supra-regional assessment higher than the draw-backs of asynchronous data.

Future Access to CARA-GIS Outcomes

By the end of the project, country-specific CARA-GIS applications at the authorities in charge mentioned earlier will be deployed. For this reason, each organization has to act on one's own behalf how to organize the access to CARA-GIS and its findings. The project team would highly appreciate to find customer-oriented solutions.

Baseline Data

The chapter 'baseline data' deals with spatial and non-spatial data that are fundamental for any study on risk exposure to natural hazards in Central America. At first glance, these data may appear less relevant to disaster risk assessment activities. Accordingly, the majority of the baseline data presented here often need time-consuming preparation in order to facilitate subsequent risk studies properly. Moreover, a supra-regional risk mapping approach poses a particular challenge as the baseline data of different countries are anything but homogeneous among each other.

Baseline data are an important source of information for development and planning purposes at any administrative level. Therefore, baseline data are commonly collected and provided in the context of entire administrative entities, such as 'Departamentos' and 'Municipios' in the Central American countries. Consequently, hazard and risk assessments should preferably make statements about risk exposure for a complete administrative entity, too. Only this approach enables a supra-regional and comparative risk assessment for Central America!

The quality of baseline information is particularly sensitive in the context of risk assessment as the data strongly influence subsequent decision making processes. For that reason, authorities in charge for data acquisition at all administrative levels are instructed to follow generally accepted guidelines and codes of practice, solely.

The baseline data used in this document represent the status quo at the time of writing. However, in many cases risk exposure can currently not be assessed based on up-to-date information, as mappings, such as for land use, were realized many years ago.

In the long-run, baseline data must be updated and scrutinized at regular intervals. From the supra-regional point of view it is highly recommended to initiate a process of harmonization of risk assessment relevant baseline data throughout Central America, in particular land use/land cover data. As long as this key information diverges from one another substantially, succeeding supra-regional risk assessment procedures are impossible or too abstract in order to be acknowledged as rational.

Baseline data in this document incorporate the following layers:

- Administrative areas and boundaries/supra-regional approach;
- Land use data/country-specific approach;
- Infrastructure (road network)/supra-regional approach;
- Topographic data/supra-regional approach;
- Population figures (demography, population density)/supra-regional approach;
- Economic statistics (spatial representation of economic sectors)/supra-regional approach.

Administrative Areas, Supra-Regional

Map Contents

The supra-regional map shows the outlines of:

- The project countries (yellow boundaries) and their neighbours (Costa Rica, Belize, Mexico);
- All 'Departamentos' (dark gray boundaries);
- All 'Municipios' (pale gray boundaries).

For better orientation the capital cities of the countries and of the 'Departamentos' are plotted additionally. The 'Departamentos' are labeled with their official codes as defined by the respective national statistics authorities. For enhanced legibility these codes have been omitted for the 'Municipio' level. This code uniquely identifies each individual administrative unit within the each country from the 'Departamento' down to 'Municipio' level. However, the comparison among countries shows identical codes. Therefore, this approach can only be pursued as long as several country-specific CARA-GIS applications coexist without any linkage. If a unified, i.e. cross-country application of these codes is envisaged, then the codes must be expanded with a unique country code.

Map Purpose with Respect to Disaster Risk Management

Decision making processes within the disaster management cycle always influence entire administrative entities (Departamentos, Municipios), as do official management, development or planning documents. For that reason, it is obligatory for those carrying out disaster risk assessments as input to decision making authorities to cover the entire administrative area in their responsibility, not only parts of it.

Data Source and Availability

For the project countries there are following data sources for administrative boundaries and codes:

Country	Name of Authority	Reference Scale Adminstrative Data
El Salvador	Centro Nacional de Registros (CNR)/	1:25 000 + Codes
	Instituto Geográfico y del Catastro Nacional (IGCN)	
Guatemala	Instituto Geográfico Nacional (IGN)/	1:250 000 (1:50 000)
	Instituto Nacional de Estadística (INE)	Codes
Honduras	Instituto Geográfico Nacional (IGN)	1:200 000 - 1:350 000 + Codes
Nicaragua	Instituto Nicaragüense de Estudios Territoriales (INETER)/	1:525 000 (1:50 000)
	Instituto Nacional de Información de Desarrollo (INIDE)	Codes

- *El Salvador:* The national mapping authority provides a seamless digital administration boundaries product that is updated permanently and contains the administrative codes of 14 Departamentos and 262 Municipios. This spatial dataset is provided in ESRI GIS file format (shp) or in MicroStation format (dgn) and is available upon request. The access to this information is fee-based, as defined by IGCN.
- *Guatemala:* All administrative information at national and sub-national level was released by IGN (status: 2002) and will be adjusted if necessary. The administrative codes for the sub-national units Departamento (22) and Municipio (331) are in line with the official INE classification. The access to this administrative information is liable to pay costs for the public, defined by IGN; for governmental authorities the data are for free. The data have been provided in ESRI GIS file format (shp).
- *Honduras:* The administrative structure of the Departamentos (18) and its corresponding codes was fixed in 1988, the definition of Municipios (298) and their codes dates from (?)1974. Currently, there is neither any information about pricing policy nor to the accessibility regarding administrative data. The dataset used in CARA-HN-GIS was provided by COPECO in ESRI GIS file format (shp).
- *Nicaragua:* There is a countrywide set of analogous topographic maps at a scale of 1:50 000 (Original status: 1986) that have been used for the outline definition of 15 Departamentos/2 autonomous regions and 153 Municipios at scale 1:525 000 (status: 2006; originally published at the official register 'La Gaceta' in the year 2002). The georeferenced digital dataset has been established by INETER in ESRI GIS file format (shp) and MicroStation (dng). Boundary lines of sub-national units will be updated if necessary. The administrative data are accessible upon request at INETER. The costs for one shape file amounts 20 US$. The administrative codes have originally been fixed in the range of the foundation of the Asociación de Municipios de Nicaragua (AMUNIC) in 1993. The official codes are available at the INIDE web page.

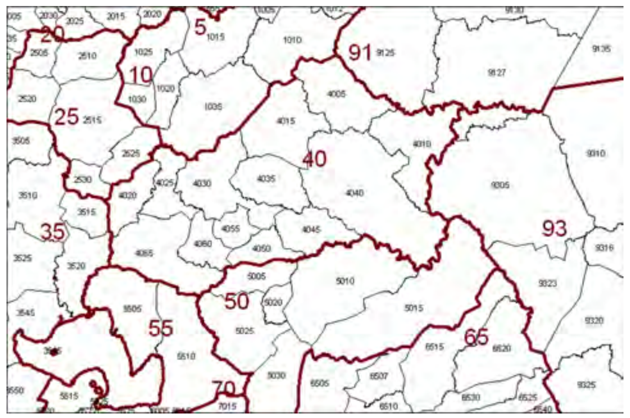
Remarks

The administrative division of the Central American countries is subject to continuous changes. For example, according to the ISO-3166-2 NEWSLETTER No I-2 from May 21, 2002 (http://en.wikipedia.org/wiki/ISO_3166-2:NI#Changes), two new autonomous regions in Nicaragua (Atlantico Norte; Atlantico Sur) were added and one Departamento (Zelaya) was dissolved concurrently. Hence, it is vitally important for risk mapping purposes to keep the attributes of the spatial data in line with the statistical data. In case of failing, this can lead to inaccuracies in results, affecting those areas, where there is a discrepancy between the spatial data and other data that they will be related to (e.g. demographic data).

Methodology

The supra-regional administrative area map compiles all single area maps of the project countries. Statistical data collected by the national statistical authorities, e.g. census data that contain valuable information for the risk analysis, are categorized according to the respective administrative codes. Therefore, the usage of the administrative codes in a GIS allows for trouble-free linkage of statistical data to spatial entities in the succeeding risk analysis. A coupling by names would lead to mismatches because Municipios can have identical names. There are, for example, three Municipios named 'El Rosario' within three different Departamentos in El Salvador!

How to read this map



The map represents the hierarchical coding system for all relevant countries in a graphical way (see also *Demography, Supra-Regional*, page 36*f*). The GIS also provides the area (in km²) of each administrative unit, which is of significance for many steps in the risk analysis, later on.

For example, the Nicaraguan Municipio 'San Dionisio' inside Departamento 'Matagalpa' (two-digit INEC code 40) has the four-digit INEC composite code 4055 and an area of 169 km² (see figure).

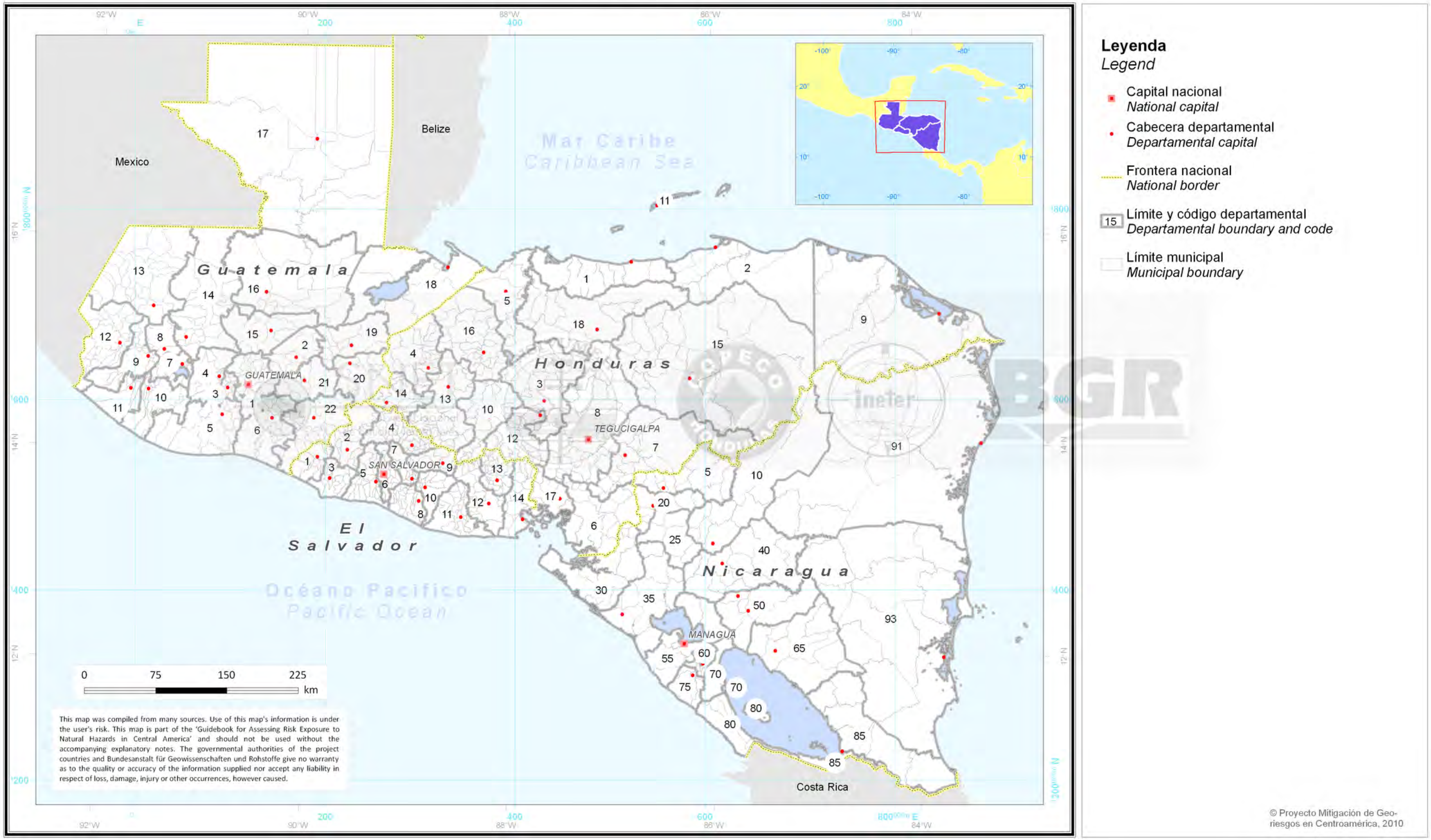
Complete tabular listings of names and codes for all Departamentos and Municipios can be accessed in the individual CARA-GIS applications.

Recommendations

- A well structured administrative dataset is the most critical precondition as all succeeding GIS steps build on it. It contributes to a reliable workflow throughout the risk analysis procedure considerably.
- Using the numerical codes to address administrative entities in GIS avoids ongoing problems arising from spelling of administrative entities as well as from duplicate names.
- It is recommended to obligatory use the country-specific administrative codes for all digital risk mapping purposes by governmental and intergovernmental authorities in Central America.

Áreas Administrativas (Límites y Códigos)

Administrative Areas (Boundaries and Codes)



Baseline Data

Land Use: Example El Salvador

Map Contents

The national map shows the land use classes of El Salvador.

Map Purpose with Respect to Disaster Risk Management

'Land use is based on the functional dimension of land for different human purposes or economic activities' (OECD, 2005; 'http://stats.oecd.org/glossary/). In other words, categories of land use reflect the variety of activities that takes place at a specific site or region. Land use and/or land cover data are fundamental for any risk assessment mapping. In subsequent steps of the risk assessment it is then possible to conclude whether a specific activity is exposed to a hazard or not. Land use data, when intersected with administrative data, facilitates the spatial analysis of statistical data, such as demographic or economic key data. There again, the accuracy of risk mapping outcomes is mainly governed by the resolution of land use information!

A theoretical example: a nationwide land use survey is based on satellite images with a lower resolution. Especially in rural areas, sparsely populated areas are often too small to be surveyed as land use category 'settlement area' at a scale of 1:250 000 or lower. Consequently, these sparsely populated areas will often be formally (methodically) excluded from the risk assessment, as they cannot be exposed to any hazard.

Vice versa, hazard but also risk mapping outcomes can mainly influence ongoing land management practices. It is known, for example, from many regions, that man-made deforestation results in an increased susceptibility of slopes to mass movements (landslides) which cause material and/or non-material loss in the run-out areas. A response of an adopted land management strategy can either be the reallocation of these areas into forestation areas or the technical reinforcement of preventive measures at the slope.

Data Source and Availability

Land use data surveyed by Ministerio de Medio Ambiente y Recursos Naturales (MARN) and IGCN in 2003 are mainly directed towards usage in the ecological or agricultural sector, but accurate enough for the risk assessment. The identified land cover classes are in compliance with the CORINE land cover project (2000). According to the data sources the resolution of the used LANDSAT images is 15 m, whereas the scale of the aerial photography is 1:5000. The findings of remote sensing based land use survey have been validated at the field, additionally. There is no information by MARN/IGCN about the update frequency, currently. The data cover the entire country and are prepared in ESRI GIS file format (shp) ready to use. The land use data are accessible upon request and free of charge.

Remarks

In order to deliver reliable risk information for decision makers, risk assessments should draw upon up-to-date information. As land use data are crucial for the risk analysis, this information ideally should be as prevailing as possible. The provided land use data incorporated into CARA-SV-GIS are seven years old by now and can thus not reflect changes that have occurred in the last few years, caused, for example, by the flooding event in November, 2009.

Methodology

Remote sensing is the most fitting tool for establishing land use or land cover maps for larger areas. Countrywide approaches are based on the visual interpretation of Landsat-TM and/or SPOT hard copies or the digital classification of the same kind of images. Subsequently, the imagery raster data are converted into vector-based formats.

Though, the MARN/IGCN original land use file provides aggregated categories as well, the risk analysis rests upon the detailed land use classification. According to the number of land use classes (58) the table below shows only an excerpt of the original land use classification by MARN/IGCN (2003), added by the seven-digit CARA-SV-GIS value codes (theme group code: 4000/land use; theme code: 4100/land use; status: 2003). These codes allow for the unanimously addressing of land use classes during CARA-SV procedures. The whole land use classification is delineated at the map legend.

Land Use Class (MARN/IGCN, 2003) *English Version*	Land Use Class (MARN/IGCN, 2003) *Spanish Version*	CARA-SV-GIS Value Code
…	…	…
Bananas (Trees and Shrubs)	Platanales y Bananeras	4100135
Playas, Dunes and Sand	Playas, Dunas y Arenales	4100136
Swampy Grassland	Praderas Pantanosas	4100137
Rivers	Ríos	4100138
Rocks, Lava	Roqueda, Lavas	4100139
Saline	Salinas	4100140
Agriculture and Forestry Systems	Sistemas Agroforestales	4100141
Contiguous Urban Area	Tejido Urbano Continuo	4100142
Discontiguous Urban Area	Tejido Urbano Discontinuo	4100143
Sparsely Populated Area	Tejido Urbano Precario	4100144
…	…	…

How to read this map

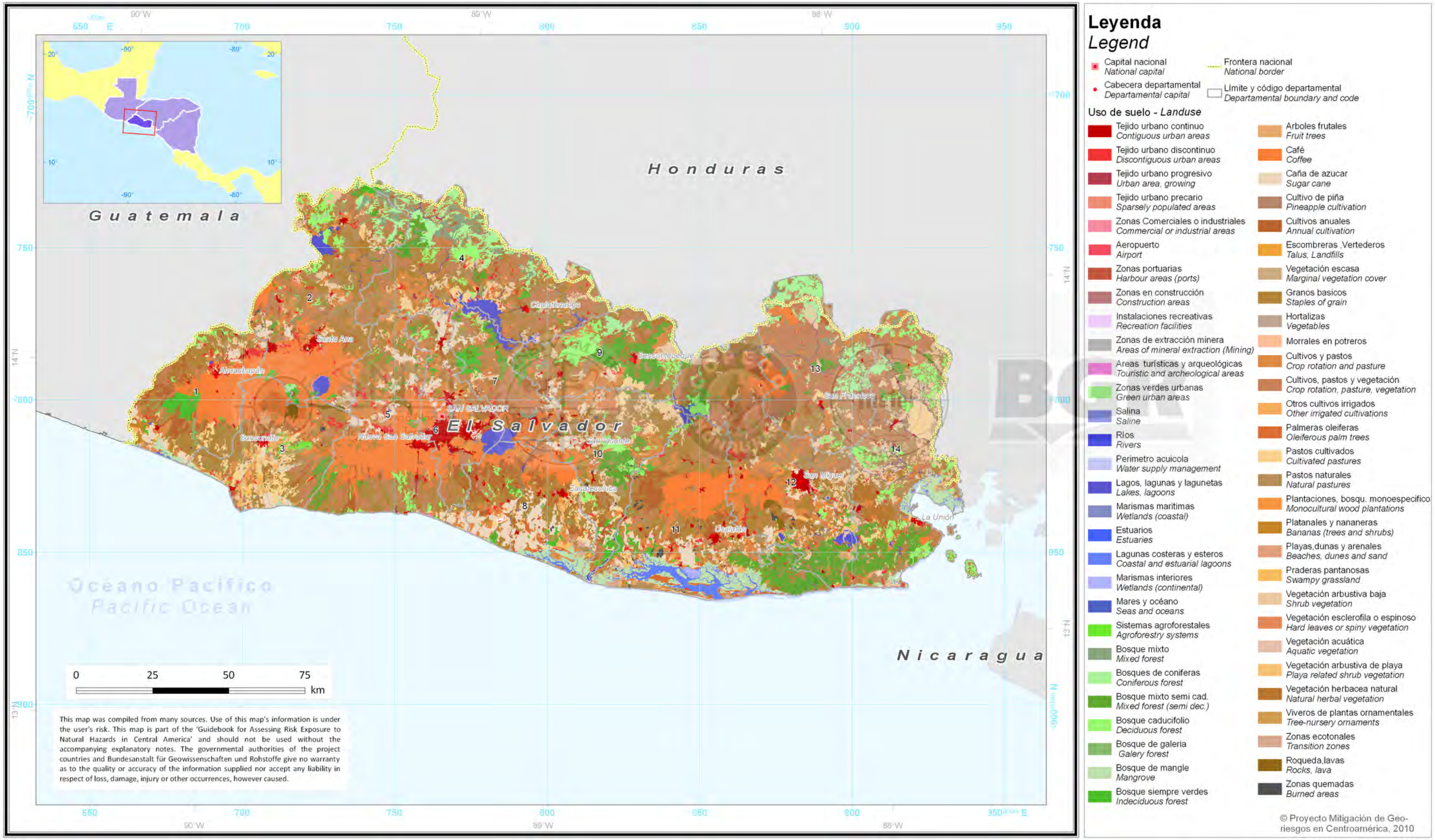
Colors represent areas of specific land use representing functional dimensions of land for different human purposes or economic activities in El Salvador.

Recommendations

Though, the refreshment of land use information is expensive and time-consuming it is highly recommended to sort out this activity regularly in order to guarantee realistic and reliable risk mapping outcomes in the long term.

Uso de Suelo / Cobertura Terrestre

Land Use / Land Cover



Baseline Data

Land Use: Example Guatemala

Map Contents

The national map shows the land use classes of Guatemala.

Map Purpose with Respect to Disaster Risk Management

It is pointed to the explanation on page 26.

Data Source and Availability

The nationwide land use data of Guatemala have been collected by Unidad des Planificacion y Gestion del Riesgo on behalf of the Ministerio de Agricultura y Alimentacion (MAGA), published in the year 2005 (scale 1:50 000). The land use classification is exclusively directed towards usage in the ecological or agricultural sector, i.e., if any, only the largest urban settlement areas have been mapped so that the majority of Municipios seem spuriously unpopulated (see figure on the right-hand page). This has in turn a stake in risk mapping using CARA as to determine the exposition of population to a certain hazard. To tackle that problem an external dataset delivered by INSIVUMEH containing spatial settlement information with higher resolution (original source is still unknown) has been embedded into the existing land use information. The geospatial quality of the merged dataset is accurate enough for the risk assessment activities.

This combined land use data set can also be estimated as an adequate starting point for deriving an economic classification (see page 38) as a preliminary stage to analyze the nationwide and/or the supra-regional economic risk (loss) potential to hazards finally (see page 62).

The land use classification of Guatemala rests upon remote sensing information (SPOT, LANDSAT, IRS) and aerial photographs (images taken: 2003). The primary findings of that survey have been additionally checked at the field. The update frequency depends on the need. The data cover the entire country and are prepared in ESRI GIS file format (shp) ready to use. The land use data are accessible upon request and free of charge for public institutions.

Remarks

In order to deliver reliable risk information for decision makers, risk assessments should draw upon up to date information. As land use data are crucial for the risk analysis, this information ideally should be as prevailing as possible. The provided land use data incorporated into CARA-GT-GIS are five years old by now and can thus not reflect possible changes having been occurred in the last few years.

Methodology

For more general information about technical items to establish land use or land cover maps for larger areas it is referred to page 26.

How to read this map

Colors represent areas of specific land use representing functional dimensions of land for different human purposes or economic activities in Guatemala.

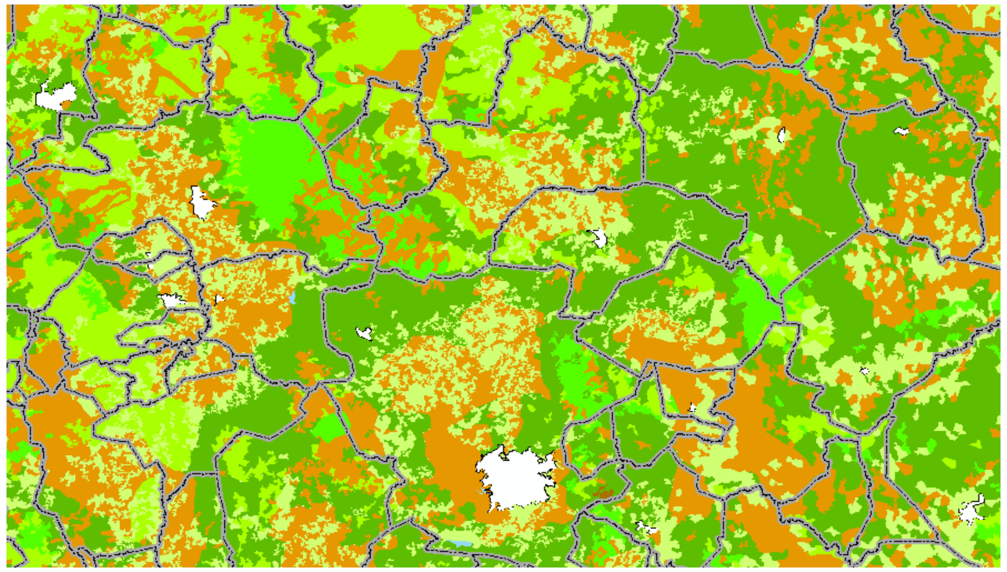
Recommendations

Though, the refreshment of land use information is expensive and time-consuming it is highly recommended to sort out this activity regularly in order to assure realistic and resilient risk mapping outcomes in the long term.

A special note to the land use data of Honduras and its impact for the guidebook

Unlike the countries of El Salvador, Guatemala, and Nicaragua there is currently no suitable land use data set available for Honduras that allows for carrying out specific CARA compliant risk mapping procedures, unfortunately. The reasons are:

- Obviously, the spatial resolution of the available land use datasets appears too low to capture settlement areas in rural areas as well. Either only the largest urban settlement areas have been mapped (see example below) or settlement areas have not been taken into account hardly ever;
- Regrettably, in contrast to the country of Guatemala there is presently no way out to supplement the ‘missing’ settlement information in the available land use dataset by a discrete settlement data set (see explanation for Guatemala on the left-hand page).



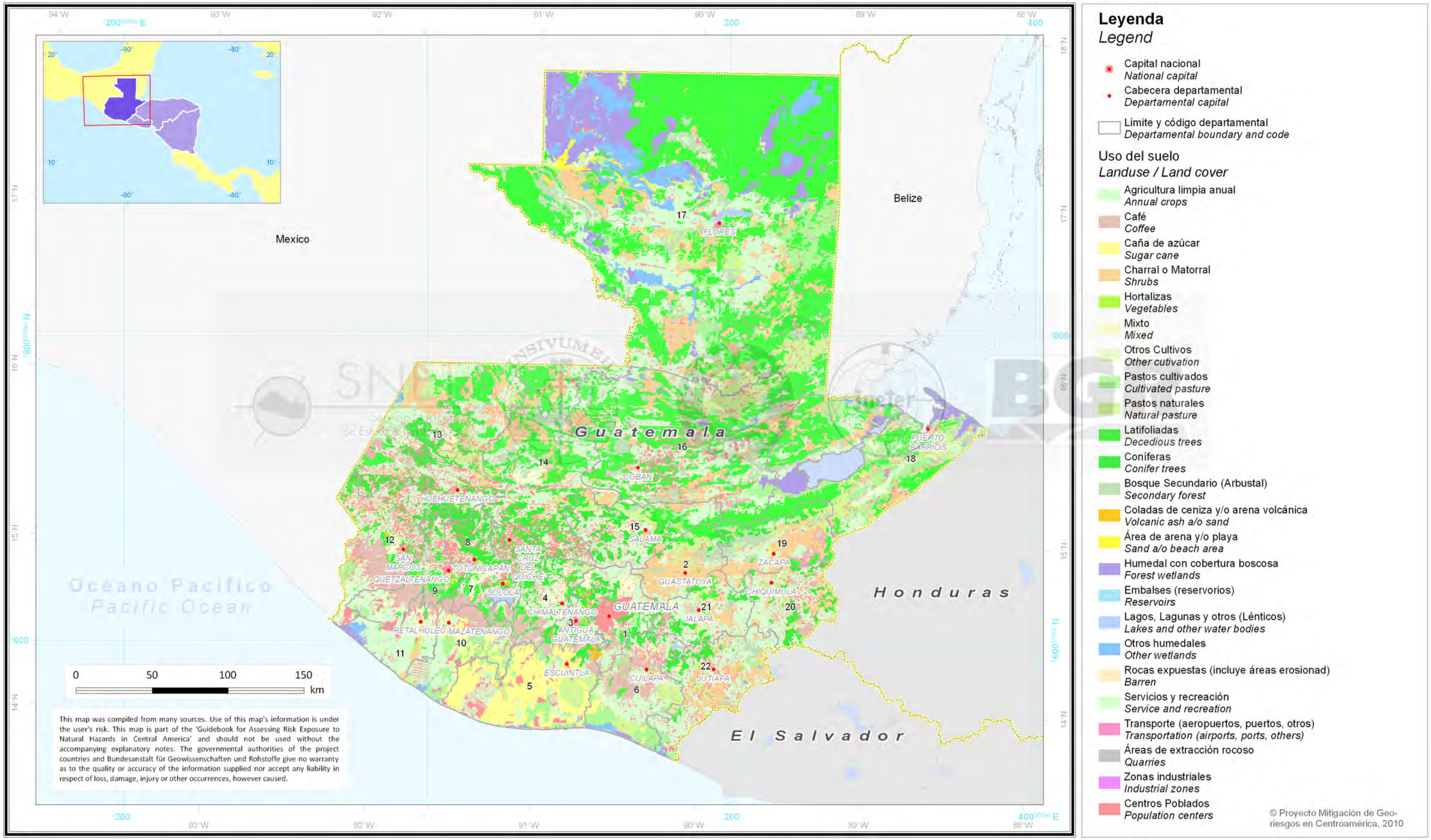
Excerpt of a digital land use map for Honduras (status: 2002) based on LANDSAT TM, divided into nine land use classes (white areas: mapped settlement areas)

For ongoing risk mapping procedures using CARA-GIS this instance has far-reaching consequences in the following way:

- The assessment of the ‘population at risk’ to any geohazard is impossible for Honduras, actually. Hence, in the supra-regional context all maps focusing on the vulnerability indicator ‘population’ could only be depicted without Honduras;
- Also, the assessment of the ‘economic potential at risk’ to any geohazard is impossible for Honduras (see page 88) as the required grouping of land use classes into economic sector categories (see page 62*ff*) cannot be accomplished. Therefore, in the supra-regional context the map example focusing on the vulnerability indicator ‘economic potential’ could only be illustrated without Honduras;
- By providing qualified spatial information about settlement areas/land use for the country of Honduras the relevant supra-regional risk maps could be extended.

Uso de Suelo / Cobertura Terrestre

Land Use / Land Cover



Land Use: Example Nicaragua

Map Contents

The national map shows the land use classes of Nicaragua.

Map Purpose with Respect to Disaster Risk Management

It is referred to the explanation on page 26.

Data Source and Availability

Land use data are provided by Ministerio Agropecuario y Forestal (MAGFOR) and INETER (status: 2000; scale 1:50 000). According to the data sources the resolution of used LANDSAT images is 30 m. The geospatial quality of the data is accurate enough for risk assessment at the present scale. The data cover the entire country and were prepared in ESRI GIS file format (shp) ready to use. Land use information and information about the corresponding pricing policy is provided by MAGFOR on request.

Remarks

In order to deliver reliable risk information for decision makers, risk assessments should draw upon up-to-date information. As land use data are crucial for the risk analysis, these information ideally should be as current as possible. The provided land use data incorporated into CARA-NI-GIS are ten years old by now and can thus not reflect changes that have occurred during the last few years. Currently, an inter-institutional working group is under way to finalize a new issue of a land use map for Nicaragua (scale 1:50 000), based on SPOT images (taken 2006; 20 m resolution). According to the CARA-GIS data management the new land use map could easily be incorporated into the risk mapping workflow to establish adjusted risk maps for Nicaragua, later on.

Methodology

For more general information about technical items to establish land use or land cover maps for large areas it is referred to page 26.
According to the number of land use classes (32) the table below shows only an excerpt of the original land use classification by MAGFOR (status: 2000), added by the seven-digit CARA-NI-GIS value codes (theme group code: 4000/land use; theme code: 4100/land use). These codes allow for the unanimously addressing of land use classes during CARA-NI procedures. The whole land use classification is delineated at the map legend.

Land Use Class (MAGFOR, 2000) *English Version*	Land Use Class (MAGFOR, 2000) *Spanish Version*	CARA-NI-GIS Value Code
...	...	...
Settlement Areas	Centros Poblados/Areas Humanizada	4100103
Volcanic Area	Area Volcanica	4100104
Coniferous Forest, Sparse	Bosque de Pino, Abierto	4100105
Coniferous Forest, Dense	Bosque de Pino, Cerrado	4100106
Deciduous Forest, Sparse	Bosque Latifoliado, Abierto	4100107
Deciduous Forest, Dense	Bosque Latifoliado, Cerrado	4100108
Mixed Forest	Bosque Mixto	4100109
Cafe Plantation, Shaded	Café, con Sombra	4100110
Cafe Plantation, not Shaded	Café, sin Sombra	4100111
Shrimps	Camaroneras	4100112
Sugar Cane	Caña de Azucar	4100113
...	...	...

How to read this map

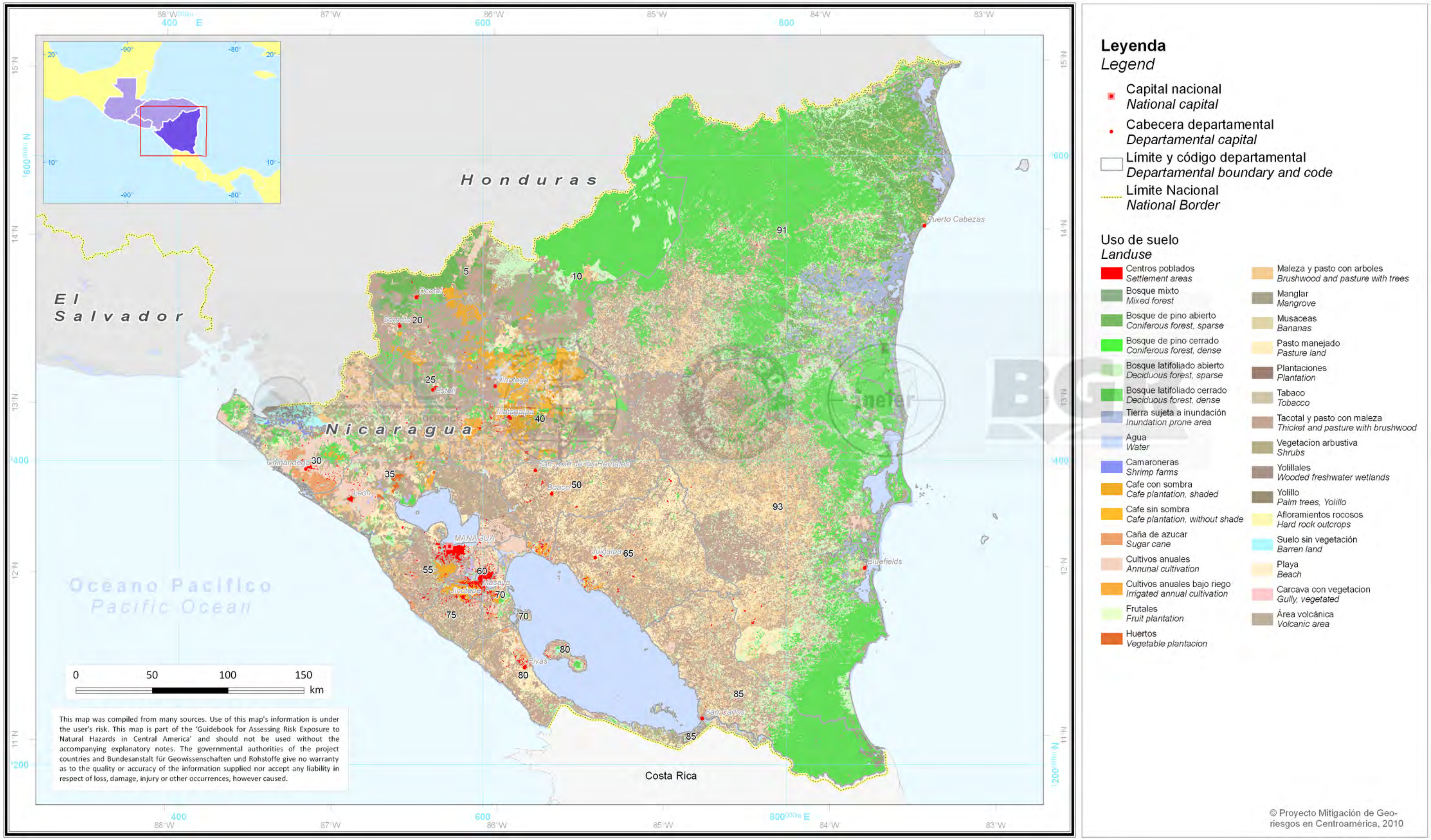
Colors symbolize areas of specific land use representing functional dimensions of land for different human purposes or economic activities in Nicaragua.

Recommendations

After releasing the new land use map for Nicaragua expected in 2010 it is recommended to reassess the risk exposure potential for Nicaragua focusing on the vulnerability indicator ‘population’ as fast as possible. This reevaluation can be used to study the sensitiveness of one of the most significant baseline parameter with respect to the risk assessment outcomes.

Uso de Suelo / Cobertura Terrestre

Land Use / Land Cover



Baseline Data

Infrastructure (Road Network), Supra-Regional

Map Contents

The supra-regional map shows the road network of the first and second order as the most important infra-structure feature of the Central American countries.

Due to scale reasons, additional infrastructure items (e.g. minor roads, bridges, airports, hospitals, and utility/life lines) are not illustrated on the map. Additionally, there are significant distinctions with respect to the digital availability of this information between the project countries. The compromise that has been found is to map 'roads' as a common denominator existing in all countries, exclusively.

Map Purpose with Respect to Disaster Risk Management

Infrastructure data serve as a central input variable in assessing risks, among other information (e.g. land use data). Infrastructure elements are on the one hand highly vulnerable to almost all hazardous events. On the other hand, they play an important role in the implementation of preparedness measures within the risk management cycle (e.g. healthcare capacity) as well as with regard to the coping capacity (e.g. escape routes).

In the supra-regional context, infrastructural elements at risk are of utmost importance as, for instance, the damage of a arterial transit route in one country caused by landslides and/or flooding can seriously impair the functionality of that road in an adjacent country, too. This is mainly taken into account in frontier areas. Therefore, in order to avoid far-reaching negative consequences in regions highly prone to harmful events, possible prevention measures should not only be designed but also implemented in a common supra-regional approach.

Data Source and Availability

The following governmental authorities of the project countries are accountable for collecting countrywide infrastructure information used in CARA-GIS:

Country	Name of Authority	Type of Infrastructure
El Salvador	Ministerio de Educación (MNED)	(Schools*)
	Ministerio de Salud Pública y Asistencia Social (MSPAS)	Healthcare facilities
	Ministerio de Obras Públicas (MOP)	Roads
Guatemala	Ministerio de Comunicaciones, Infraestructura y Vivienda (CIV)	Roads, bridges, (airports*, power plants*)
	Instituto Geográfico Nacional (IGN)	
	Instituto Nacional de Estadística (INE)	Schools (not yet in CARA-GIS)
Honduras	Ministerio de Comunicaciones, Obras Públicas y Transporte	Roads
	Instituto Nacional Geográfico (ING)	
Nicaragua	Ministerio de Transporte e Infraestructura (MTI)	Roads
	Instituto Nicaragüense de Estudios Territoriales (INETER)	Roads (Pacific part of the country; not yet CARA-GIS)
	Ministerio de Educación y Deportes (MINED)	Schools (not yet in CARA-GIS)
	Ministerio de Salud (MINSA)	Healthcare facilities (not yet in CARA-GIS)

** = available in CARA-GIS, but not evaluated regarding risk*

- *El Salvador:* Infrastructure information collected by MNED and MSPAS originates from 2006; the status of the MOP data is unknown). MNED (schools) and MSPAS (healthcare facilities: hospitals, out-patient facilities) datasets were provided as MS Excel files. The georeferencing of the point information was carried out by SNET (outcome: ESRI GIS file format [shp]). For CARA mapping purposes the two spatial datasets of health care facilities have been merged into one common feature class. There is no information by MNED and MSPAS about the update frequency. The aforementioned data are accessible upon request and free of charge. The digital road dataset prepared by MOP is based on a topographic map scale of 1:25 000 and is ready to use (ESRI GIS file format [shp]); the geospatial quality of the data is accurate enough for risk mapping purposes. The road information is updated continuously.
- *Guatemala:* Commissioned by the Ministerio de Comunicaciones, Infraestructura y Vivienda (CIV) two national authorities are in charge for publishing nationwide infrastructure information: Instituto Geográfico Nacional (IGN) and Unidad Ejecutora de Conservación Vial (COVIAL). The used dataset is originally based on topographic maps at scale 1:250 000 and was updated in the year 2009 by IGN. The digital road dataset is ready to use (ESRI GIS file format [shp]); the geospatial quality of the data has sufficient accuracy for risk mapping purposes. The data are accessible upon request and visible at the COVIAL web page.
- *Honduras:* Currently, CARA-GIS does not possess resilient meta-information about infrastructure data of Honduras. The used feature class dataset provided by COPECO was extracted as feature class from a national geodatabase that has been established within the scope of the 'Proyecto Mitigación de Desastres Naturales (PMDN)'. There is neither any information about the status nor to any other relevant topics (responsibilities, accessibilities, pricing policy, etc.).
- *Nicaragua:* There are different digital road dataset available at following scales:
    - Scale 1:525 000 (status: 2004): nationwide, mainly based on topographic maps at scale 1:50 000 (used in CARA-NI-GIS), provided by MTI;
    - Scale 1:50 000 (status: unknown): based on topographic maps at scale 1:50 000, provided by MTI
    - Scale 1:10 000; based on aerial photography's (only Pacific part of the country), provided by INETER.

  In general, the geospatial road information is delivered in ESRI GIS file format (shp) or MicroStation format (dgn). Road information can be purchased at the authorities just mentioned, respectively. A digital road file (shp) at national level costs 20 US$. The quality of the used dataset is precise enough for CARA purposes and is ready to use.

Methodology

The supra-regional infrastructure map focusing on the road network in Central America was easily created by seamless compiling of the country-related digital road datasets using the consistent CARA-GIS codes. Exemplarily, the country-specific classification of 'roads' for El Salvador is shown in the table below, added by the seven-digit CARA-SV-GIS value codes (theme group code: 9000/infrastructure; theme code: 9400/infrastructure: roads). These codes allow for the unanimously addressing of road type classes during CARA-procedures.

Country	Road Types (MOP Classification; Status: Unknown) *English Version*	Road Types (MOP Classification; Status: Unknown) *Spanish Version*	CARA-SV-GIS Value Code
El Salvador	Main Road	Camino Principal (Carreteras)	9400101
	Improved Road	Camino Mejorado	9400102
	Seasonal Road (Summer)	Camino Solo Transitables en Verano	9400103
	Main Street (Urban Area)	Calle Urbana	9400104
	Main Street (Subdistrict Level)	Calle Cantonal	9400105

How to read this map

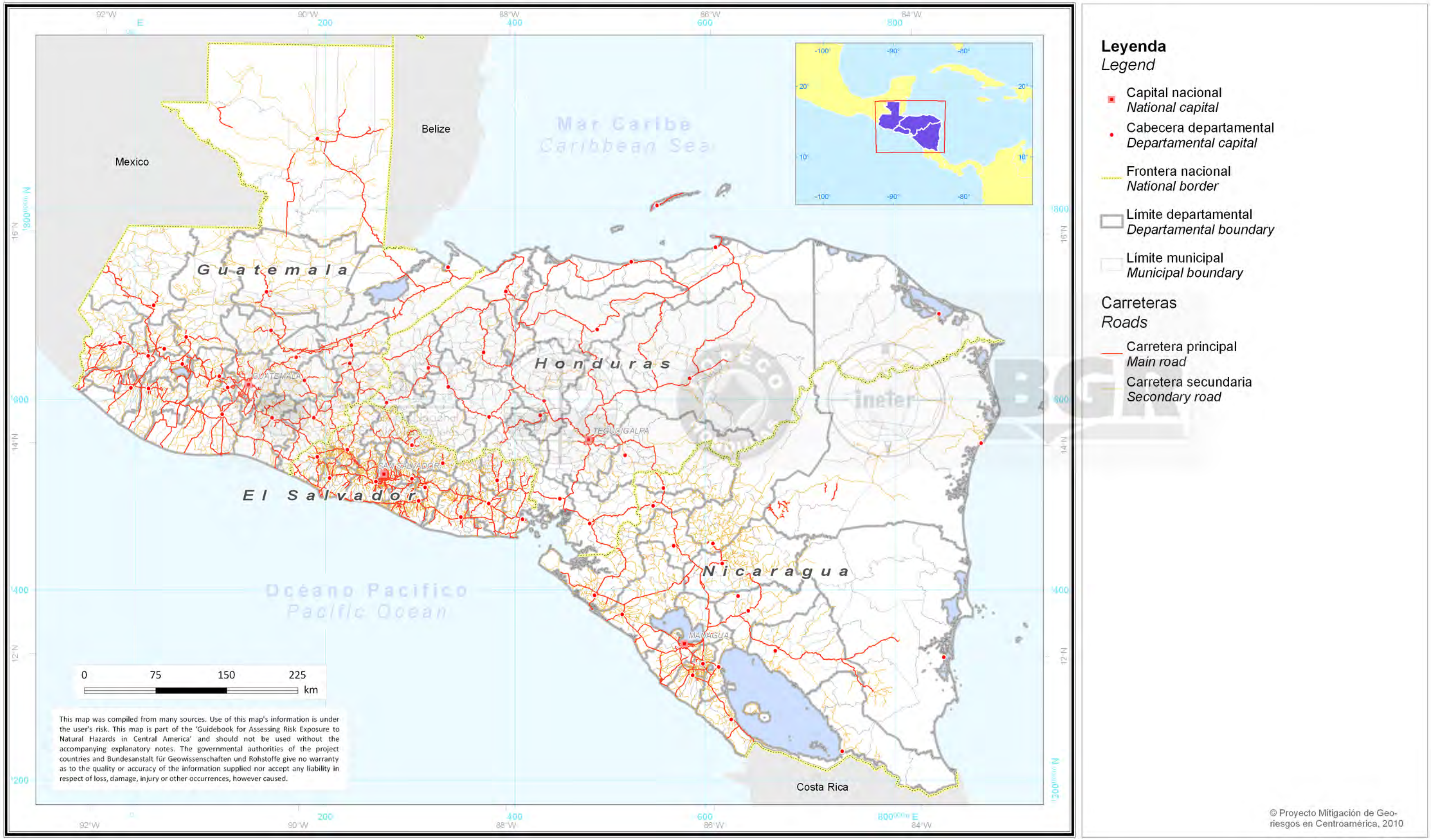
The map only depicts the linear infrastructure feature class 'roads'.

Recommendations

It is recommended to improve the quality of digital infrastructure information by assigning more properties to the individual objects (e.g. the capacity of a bridge, etc.). For detailed studies even a field survey may be appropriate, possibly in the framework of surveying vulnerability and capacity at Municipio/Departamento level.

Infraestructura (Red Vial)

Infrastructure (Road Network)



Baseline Data

Topography / Elevation, Supra-Regional

Map Content

The supra-regional map displays a shaded relief depiction of the ground surface topography (terrain) of the Central America countries. Terrain information has only been applied indirectly for the assessment of risks in Central America, but terrain information has of course been an indispensable precondition for precursory hazard mapping activities (e.g. for assessing landslide susceptibility). For better orientation the capital cities of the countries and of the 'Departamentos' are plotted additionally.

Map Purpose with Respect to Disaster Risk Management

Terrain information is of importance in the disaster risk assessment context in many ways. For a number of hazards (e.g. floods, landslides, lahars), the morphology of a terrain determines the path along which the hazard propagates. Digital Elevation Models (DEM) are essential, either for modeling of these processes, such as flooding, or for deriving factors leading to their onset (e.g. slope angle for landslide susceptibility assessment).

From the supra-regional Disaster Risk Management point of view, the computer based modeling of potential hazard events using DEM's becomes increasingly important. For example, a flooding event in the catchment area of the Rio Lempa river caused by torrential rains may not only impact the upper reaches in (Guatemala) Honduras, but also the lower reaches of the river in El Salvador (~320 km length). In the preparedness context, hydrodynamic modeling would not only help in calculating thetim e-depending propagation of a flood wave at a given site but also in computing the necessary retention area capacity in order to avoid regional-scale flooding of elements at risk (settlement areas, roads, industrial facilities, etc.) downstream. By incorporating such modeling-based results, intergovernmental planning authorities would strengthen the transnational coping capacity sustainably.

Data Source and Availability

For mapping purposes using CARA-GIS a Digital Elevation Model (SRTM-3) comprising all project countries has been downloaded from the USGS web page (see table below). For the sake of completeness the table below focuses on governmental authorities in charge of providing general topographic information.

Country	Name of Authority	Digital Elevation Model
El Salvador	Centro Nacional de Registros (CNR)/Instituto Geográfico y del Catastro Nacional (IGCN)	SRTM-3 (90 m)
	Servicio Nacional de Estudios Territoriales (SNET)	DEM derived from contour lines (distance: 10 m), structured according to map sheet index 1:25 000
Guatemala	Instituto Geográfico Nacional (IGN)	SRTM-3 (90 m)
		DEM derived from contour lines (distance: 100, 50 m)
Honduras	Instituto Nacional Geográfico (ING)?	No country-specific information available
Nicaragua	Instituto Nicaragüense de Estudios Territoriales (INETER)	SRTM-1 (30 m)
		SRTM-3 (90 m)
	INETER/Japan International Cooperation Agency (JICA)	Regional DEM (Pacific part of Nicaragua; based on photogrammetric data, resolution 20 m)

- *El Salvador:* Topographic information is provided by CNR/IGCN (status SRTM-3: 2000; see below) and SNET (status: unknown). The data are accessible upon request and free of charge.
- *Guatemala:* Topographic information provided by IGN can be purchased upon request (no further specification obtainable).
- *Honduras:* At present, additional information about the availability of digital topographic data (e.g. local DEM's derived from contour lines, etc.) does not exist, regrettably;
- *Nicaragua:* INETER maintains both types of DEM, the SRTM-1 as well as to the SRTM-3 covering the whole territory of Nicaragua. SRTM-3 is for free and can be downloaded (see below). SRTM-1 data are accessible upon request. For the Pacific part of Nicaragua a regional DEM based on photogrammetric data (resolution: 20 m) has been elaborated by INETER in cooperation with JICA (status: 2004). The charge for this DEM is 350 C$ per 'quadrant' according to the map index 1:50 000;
- *SRTM-Data (general statement):* For small- and medium-scale analyses with lower demands on spatial accuracy the NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEM's) for almost all areas of the globe. The data were taken in the year 2000 (re-assessed in 2005) and are in the public domain by USGS (edc.usgs.gov/srtm/data/obtainingdata.html). SRTM data are available with following spatial resolution:
  - SRTM-1: 1 arc second is equivalent to 30 m (available for US territory and other selected areas);
  - SRTM-3: 3 arc second is equivalent to 90 m resolution near the equator (globally available);
  - Vertical accuracy of the DEM's is described to be less than 16 m.

Remarks

Previous methods of creating DEMs often involved interpolating digital contour maps that may have been produced by direct survey of the land surface; this method is still used in mountainous areas, where alternative remote sensing techniques are not always satisfactory. The contour line data or any other sampled elevation datasets (e.g. GPS) are not DEMs, but may be considered as Digital Terrain Models (DTM). A DEM implies that elevation information is continuously available at each location in the study area.

Methodology

The data used for this composite map was derived from the aforementioned SRTM-3 (90 m resolution) dataset. The shaded relief representation can be built by using a GIS raster data processing tool.

How to read this map

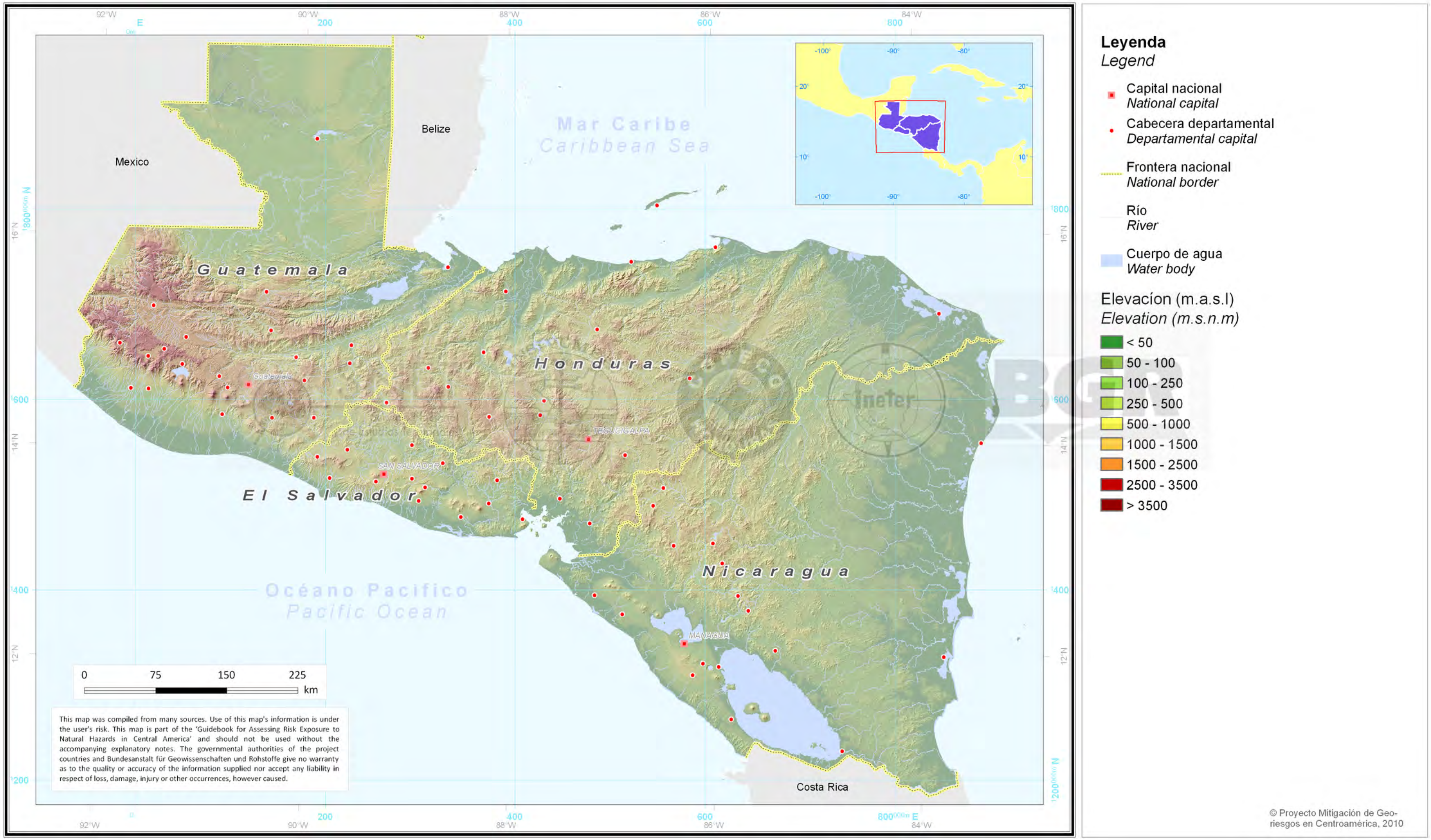
The shaded relief representation of terrain provides a quick impression of the general geomorphologic situation of the Central American project countries.

Recommendations

It is recommended to use improved Digital Elevation Model data compared to the SRTM-data whenever possible. Such an additional investment is mainly aimed at enhancing hazard assessment methods, including modeling.

Topografía / Elevación

Topography / Elevation



Baseline Data

Demography, Supra-Regional

Map Contents

The supra-regional map shows a geographic representation of population density figures at Municipio level. Data shown are based upon the countries' latest census, respectively (see table below). For better orientation the capital cities of the countries and of the 'Departamentos' are plotted additionally.

Map Purpose with Respect to Disaster Risk Management

Assessing the risk exposure of the population (also expressed as 'people exposed to … hazard') is a key challenge of any risk assessment inside the Disaster Risk Management cycle. Therefore, there is a substantial need in having reliable demographic data at hand. Furthermore, such information usually contains significant details on the demographic characteristics of a country (e.g. gender-specific information) and thus delivers also indirect information on the coping capacity of a society.

Data Source and Availability

Following governmental authorities of the project countries are responsible for collecting demographic data used in CARA-GIS :

Country	Name of Authority	Census: Year/Number, Type
El Salvador	Ministerio de Economía (MINEC) (carried out by Dirección General de Estadística y Censos)	2007/ VI. Census of Population V. Census of Dwellings
Guatemala	Instituto Nacional de Estadística (INE)	2002/ XI. Census of Population VI. Census of Dwellings
Honduras	Instituto Nacional de Estadística (INE)	2001/ XVI. Census of Population V. Census of Dwellings
Nicaragua	Instituto Nacional de Estadística y Censos de Nicaragua (INEC)/ Instituto Nacional de Información de Desarrollo (INIDE)	2005/ VIII. Census of Population IV. Census of Dwellings

Assessing nationwide risk exposure of the population to geohazards at Municipio level requires corresponding demographic data. This information are available in the following manner:

- *El Salvador:* Demographic information is provided by MINEC. It is recommended to download this information from the web page of Dirección General de Estadísticas y Censos directly;
- *Guatemala:* Demographic information is provided by Instituto Nacional de Estadísticas (INE) (GT). It is suggested to download this information from the web page;
- *Honduras:* Demographic information is provided by Instituto Nacional de Estadísticas (INE) (HN). It is recommended to download this information from the web page;
- *Nicaragua:* Demographic information is provided by Instituto Nacional de Información de Desarrollo (INIDE). It is suggested to download this information from the institution's web site.

Remarks

The map illustrated is confined to the population/population density. Moreover, demographic information makes far more social and economic specifications available than merely population figures.

In the subsequent process of risk assessment the population density figures for the administrative entities need to be spatially combined with the surveyed settlement areas. This step has been done in chapter 'Modified Population Density' on page 60.

Methodology

As already mentioned in chapter ‚Administrative Areas (Boundaries and Codes)', page 24*f,* the administrative units of the project countries are unambiguously addressed by a hierarchical numerical system. These coding systems were primarily introduced by the national statistic authorities in order to structure census data. For nationwide or supra-regional risk mapping purposes using CARA-GIS, the administrative entities 'Municipio' and 'Departamentos' are of interest, only. The coding system is briefly explained in the table given below:

Country	Number of Departamentos	Code Departamento	Number of Municipios	Code Municipio	Example of Composite Code Departamento/Municipio
El Salvador	14	(1)2-digit * (numbered serially)	262	(1)2-digit (numbered serially inside Departamento)	1002: San Vicente: 10/Alegria: 02
Guatemala	22	(1)2-digit * (numbered serially)	331	(1)2-digit (numbered serially inside Departamento)	1218: San Marcos: 12/Ocos: 18
Honduras	18	(1)2-digit * (numbered serially)	298	(1)2-digit (numbered serially inside Departamento)	1320: Lempira: 13/San Rafael: 20
Nicaragua	15 + 2 autonomous regions	(1)2-digit * (numbered serially)	153	(1)2-digit (numbered serially inside Departamento)	4055: Matagalpa: 40/San Dionisio: 55

** in case of numerical processing a 1-digit Departamento code (e.g. '5' instead of '05') entails a final 3-digit composite code*

How to read this map

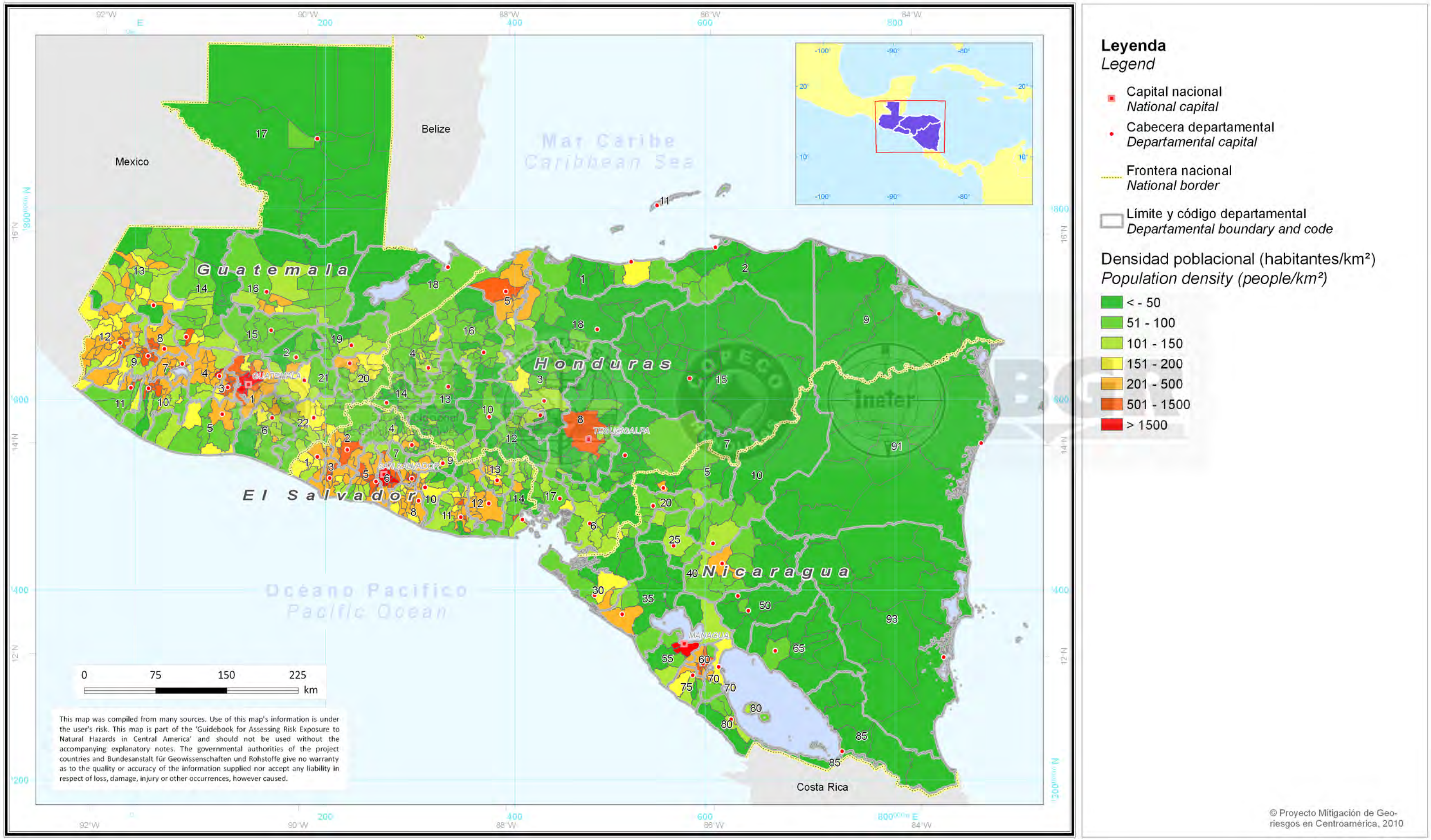
Population densities have been calculated from the number of inhabitants per Municipio as given in country-specific statistics and from the area size of each Municipio provided in the appropriate GIS data. Major urban centers become evident and clearly stick out in all countries. The chosen legend classification takes into account the population density of all countries to be considered.

Recommendations

In case of linking administrative area information and statistical information it is highly recommended to use national administrative codes in order to be in line with official sources during the entire risk analysis procedure.

Demografía

Demography



Economic Classification, Supra-Regional

Map Contents

The supra-regional map shows where certain kinds of economic activity take place in the Central American countries. For that purpose, land use classes presented with the maps discussed earlier (see pages 26 to 30) were regrouped to better reflect economic sectors such as industry, services, forestry or agriculture.

Map Purpose with Respect to Disaster Risk Management

The exposure of economic values to natural hazards is of utter importance and thus a strategic focal point in the Disaster Risk Management on a national and on the supra-regional level, too. The impacts on properties, assets and businesses have frequently negative effects on the development and the recovery of a region or a society long after a disaster has occurred. Therefore, knowledge about the spatial typology of economic activity of the Central American countries therefore provides important information about potential threats to the performance of the economic environment.

Data Source and Availability

Economic data used for this study were taken from official data sources available from the Economic Commission for Latin America and the Caribbean (ECLAC). These figures are provided annually and can be obtained in printed form or directly downloaded from the ECLAC-website (for more details see page 62).

The land use/land cover data were compiled from the maps described on pages 26 to 30. The economic data used in this book are Gross Domestic Product (GDP) figures of the year 2008 given for specific economic sectors for the entire country (the actual figures can be found in the appendix on page 102). These figures reflect current market prices. The data can be found on the website of ECLAC (http://websie.eclac.cl/anuario_estadistico/anuario_2009/-eng/default.asp).

Remarks

The classification is certainly somewhat arbitrary and relies on the availability of data in each country. If the same study were to be carried out on one singly country, the grouping may look different.

For a better understanding of integration of the data in the methodology presented here, please see also the maps described on pages 62 and 88).

As mentioned previously (see page 28) due to the lack of resilient land use data Honduras had to be excluded from the mapping.

Methodology

This map is based on the methodological assumption that economic activities take place on one or more types of land use. Therefore, economic activity can be translated into spatial patterns by using the land use or land cover data presented earlier. The indicator to express the economic activity used here is the Gross Domestic Product (GDP) that ECLAC summarizes for economic sectors over the entire region of Latin America (see table in the appendix on page 106 and the map on 62).

To achieve a spatial representation of economic sectors one has to group economic sectors and/or subsectors as they are given by ECLAC figures into so-called economic vulnerability groups. A vulnerability group contains economic activities of a similar kind i.e. that will likely take place on identical land use classes. The grouping was accomplished on a supra-regional basis, that means the heterogeneous land use/land cover data of the participating countries had to be grouped in common categories. All in all, six different vulnerability groups have been distinguished (see tables on the right-hand page).

Country	Land Use *English Version*	Land Use *Spanish Version*	CARA-GIS Value Code	Code Vulnerability Group
...	...	...	...	...
Nicaragua	Settlement Areas	Centros Poblados/Areas Humanizadas	4100103	1
Nicaragua	Deciduous Forest, dense	Bosque Latifoliado Cerrado	4100108	3
Nicaragua	Mixed Forest	Bosque Mixto	4100109	3
Nicaragua	Hard Rock Outcrops	Afloramientos Rocosos	4100101	0
Nicaragua	Water	Agua	4100102	0
...	...	...	...	...
El Salvador	Airports	Aeropuertos	4100101	1
El Salvador	Fruit Trees	Arboles Frutales	4100102	2
El Salvador	Touristical and Archeological Areas	Areas Turisticas y Arqueologicas	4100103	1
...	...	...	...	...
Guatemala	Transportation/Airports	Transporte (Aeropuertos, Puertos, Otros)	4100130	1
Guatemala	Vegetables	Hortalizas	4100212	2
Guatemala	Coffee	Café	4100221	5
...	...	...	...	...

How to read this map

The map depicts in colors the six vulnerability groups into which the various economic activities were grouped. The vulnerability groups reflect economic activities that can be linked to land use categories. The map per se simply reflects a reclassified or, in other words an economically indexed land use map. However, as it was the intention to have a supra-regional homogeneous classification in order to be able to compare subsequent analysis.

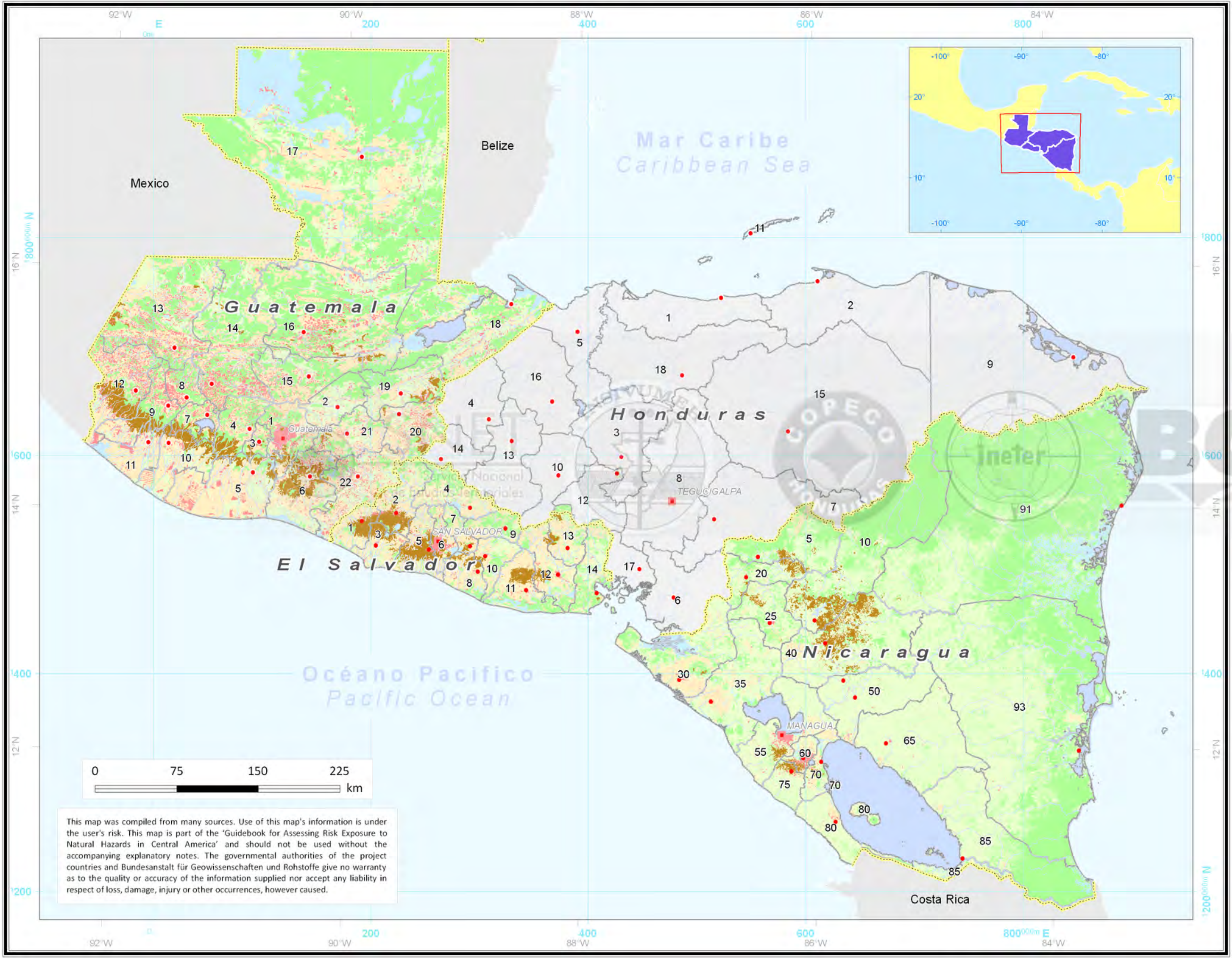
Code Vulnerability Group	Description
0	Water
1	Industry/Service
2	Agriculture
3	Forestry
4	Pasture
5	Coffee

Recommendations

As can be seen from the process described above, there is no general rule or correct solution for assigning economic sectors to land use – apart from the common sense rules. The assignment gets better the more detailed economic sectors and land use classes are differentiated. Therefore, the quality of this method also strongly depends on the scale of the data available, and the scale of the intended outcome. However, we cannot omit some subjectivity, as long as land use and economic data are not collected in a synchronized way, having in mind that they need to be combined and used together.

Clasificación Económica

Economic Classification



This map was compiled from many sources. Use of this map's information is under the user's risk. This map is part of the 'Guidebook for Assessing Risk Exposure to Natural Hazards in Central America' and should not be used without the accompanying explanatory notes. The governmental authorities of the project countries and Bundesanstalt für Geowissenschaften und Rohstoffe give no warranty as to the quality or accuracy of the information supplied nor accept any liability in respect of loss, damage, injury or other occurrences, however caused.

Leyenda
Legend

- Capital nacional / *National capital*
- Cabecera departamental / *Departamental capital*
- Frontera nacional / *National border*
- Límite departamental / *Departamental boundary*
- Río / *River*
- Industria y servicio / *Industry and service*
- Agricultura / *Agriculture*
- Selvicultura / *Forestry*
- Pradera / *Pasture*
- Cultivo café / *Coffee cultivation*
- Agua / *Water areas*
- Sin datos / *No data*

Hazard / Susceptibility

No hazard, no risk! This apparently simple statement emphasizes the fundamental role of hazard information in the risk assessment process. In the Central American project countries a number of governmental agencies are authorized to assess hazards and to publish these results, such as in the form of maps, guidelines, reports, etc. as official documents.

The objective of hazard maps is to make the information on the range of possible threats in their surrounding environment available to the public in a plausible way. Mostly, such summary maps delineate different intensities or probabilities of a specific hazard as color-coded zones according to the well-known traffic-light principle.

In other words, a geological hazard map bridges the gap between a geological phenomenon with a potential to do harm and social activities in a professional way. Undoubtedly, a geological hazard map is one of the most suitable instruments to increase the awareness of people to geological threats they are potentially exposed to.

Beyond that, hazard maps are a crucial factor to strengthen the coping capacity of a society within the scope of Disaster Risk Management activities, especially in the context of preparedness and mitigation. Hazard maps are invaluable as they can be applied in a versatile way, among others:

- As a resource for land use and development planning;
- As a primary resource for planned business activities, e.g. construction projects (public/private sector);
- As a resource to establish evacuation systems and/or escape routes;
- As a resource to enhance existing early warning systems;
- As a resource for the insurance industry to continuously adapt their premium schema to the latest spatial hazard information.

In the following chapter a set of national and supra-regional hazard maps will be shown and discussed concisely. Because it is additionally be distinguished between 'susceptibility maps' and 'hazard maps', a brief explanation should be given at this point:

A *susceptibility map* provides spatial information on whether a definite area is prone to the occurrence of a hazardous event. Or in other words, it is asked, *where* a hazardous event could occur. This type of map is widely-used for assessing the potential of a region of being susceptible to mass movements by incorporating landslide inventories and/or geomorphologic, geological, and soil-mechanical parameters.

A *hazard map* additionally focuses on the temporal component. It is asked, *when* a hazardous event could occur or what is the frequency or the probability of occurrence.

It is pointed out, that the terms ‘susceptibility (map)’ and ‘hazard (map)’ are often used synonymously, accepted by the scientific community.

All subsequent risk exposure assessment activities are based upon freely accessible hazard and susceptibility maps. The majority of those maps have been established by the national governmental authorities during the last few years, partially by cooperating with external partners, such as the project of ‘Mitigation of Georisks in Central America’, among others.

Seismic Hazard, Supra-Regional

Map Contents

The supra-regional map shows the seismic hazard, return period of 500 years, for Central American countries.

Additionally, the map contains information about earthquake epicenters recorded for that region. For better legibility, the epicenters have been classified taking into account:

- Their magnitude (M_w), limited to $M_w > 5.5$ (the bigger the circle the higher the magnitude);
- Their depth (km), subdivided into three classes: < 25 km/superficial seismicity, 25-60 km/intermediate seismicity; > 60 km/deep seismicity (color-coded, see map legend).

Map Purpose with Respect to Disaster Risk Management

This map represents the major source of information with respect to the earthquake hazard within the supra-regional risk assessment process. Such seismic hazard maps are relevant for earthquake engineering. They need to have spatially (geographically) related information about the ground shaking potential expressed as peak ground acceleration (pga) that engineered structures (e.g. critical infrastructure) have to withstand. Thus, in contrast to the Richter scale, ground shaking is not a measure of the total size of an earthquake. Earthquake engineering in proper compliance with building codes relies on such basic information for the design, construction, and maintenance of engineered structures, in order to reduce seismic exposure.

Data Source and Availability

The map displays an exemplary excerpt of the final results of a probabilistic seismic hazard analysis (PSHA) for Central America, carried out within the RESIS-II-Project. This project was jointly funded by the Norwegian Development Agency (NORAD) and CEPREDENAC and conducted by several seismologists from Central American governmental authorities, from Norway and Spain. RESIS-II represents the latest study on seismic hazard assessment for the countries of Central America. The project was finalized in 2008. All information is published in BENITO ET AL. (2008).

Remarks

In addition to the seismic hazard map with a return period of 500 years exemplarily used in CARA-GIS, further seismic hazard maps were calculated for the return periods of 1 000 and 2 500 years, respectively.

Methodology

The RESIS-II findings are based on earthquake catalogues of the Central American countries reflecting the historical seismicity (first entries from the 16th century), completed by instrumental data from regional and global seismic networks (record keeping since 1900). Information, specifying a region as being tectonically active (faults) has also been incorporated into the calculation of the seismic hazard. Furthermore, the results of previous studies on the attenuation of seismic waves subject to the distance have been taken into account. The results shown rests upon the assumption of inhomogeneous underlying lithologic conditions (hard rock/soil).

Under reflection of the probabilistic definition of the seismic hazard expressed as the probability to exceed a certain level of seismic ground shaking within a certain period of time, it must be specified what level of ground motion is considered to be dangerous and what period of time is expected that such a ground motion might occur.

Generally, to characterize this movement the maximum values of the corresponding time history of parameters are considered such as acceleration, velocity or displacement within certain ranges of frequencies or periods or spectral values. In RESIS-II, the maximum earthquake acceleration or peak ground acceleration (pga) is used (expressed in *g* as the acceleration due to gravity or in m s^{-2}; 1 g = 9.81 m s^{-2} or in gal).

In order to judge the seismic hazard for any site in Central America, the probability of the occurrence of earthquakes of different magnitudes that may affect the region has been calculated.

How to read this map

The color-coded zones of the map show ground shaking values (*pga*) that have a 10% probability of being exceeded within a 500 year time period. This means, there is a chance of 90% that these ground motions will not be exceeded following an earthquake within a 500 year time period.

For better understanding the interaction between 'probability' and 'return period' an explaining example from Switzerland/PLANAT should be given (assumption: expected life span of structures is 50 years):

Probability (in %)		Return Period (in Years)
High	100-82	1 - 30
Medium	82 - 40	30 - 100
Low	40 - 15	100 - 300

The ground motion values resulting from this assumption are typical earthquake engineering parameters. Engineered structures have to be dimensioned in a way that they are capable to withstand ground shaking as indicated on a seismic hazard map. The majority of countries having implemented a building code currently pursue two different assumptions (compare also Eurocode 8):

- *Verification of the bearing capacity of a structure exposed to ground shaking:* a structure has to withstand a total failure caused by an earthquake with a return period of 475 years corresponding to a 10% probability of exceedance in 50 years (expected life span of building). This approach is mainly aimed to safeguard life;
- *Verification of the general usability of a structure exposed to ground shaking:* a structure has to withstand a smaller earthquake with a return period of 95 years corresponding to a 10% probability of exceedance in 10 years causing no or minor damages and thus less tangible loss.

The table below opposes seismic hazard zones with corresponding *pga*-values as mapped, added by some real pga-values (500a) calculated for the capitals of the project countries according to RESIS-II and *Modified Mercalli Intensities (MMI)*

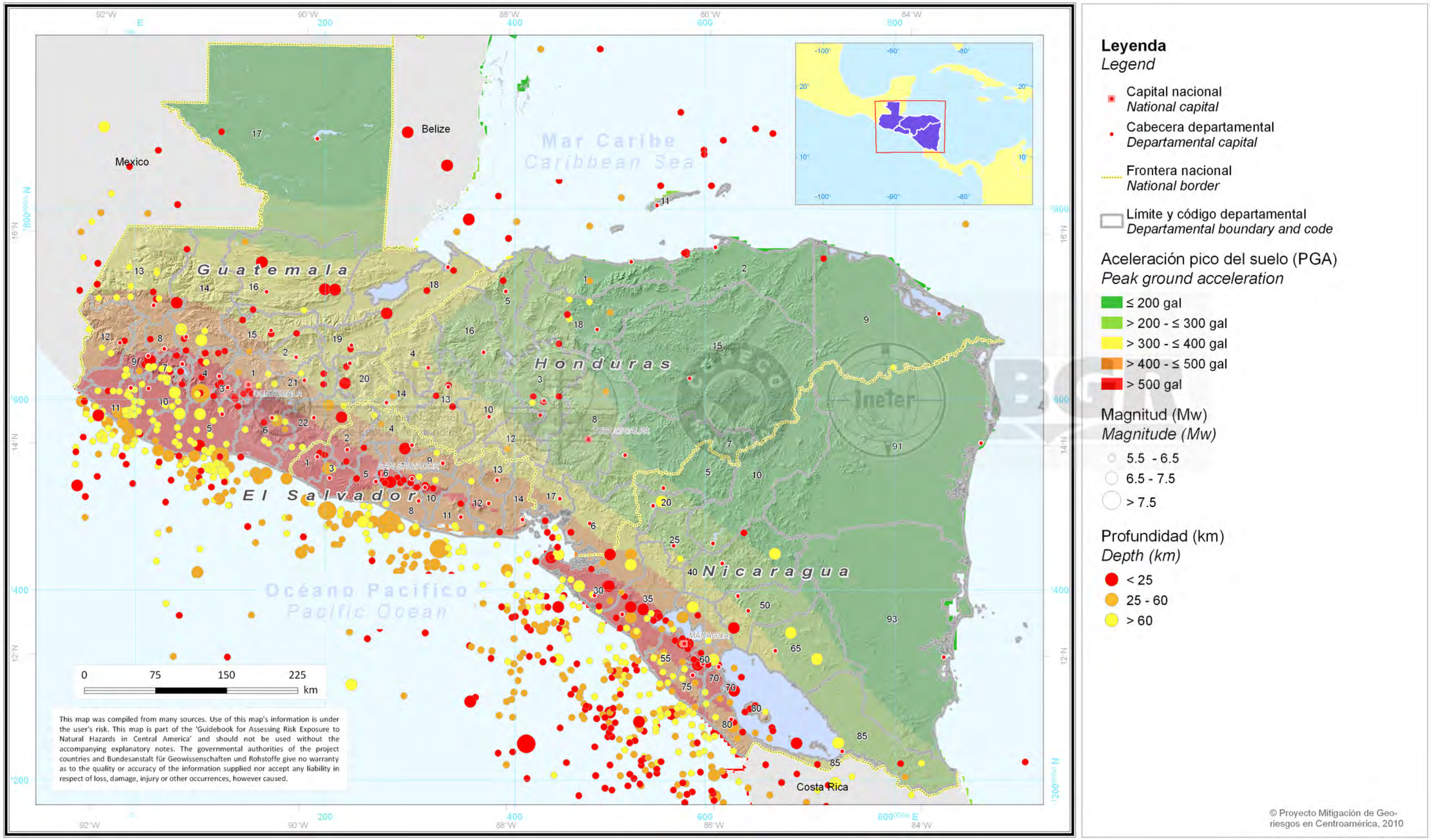
Seismic Hazard Zone	Peak Ground Acceleration (gal)	Corresponding Modified Mercalli Intensity (MMI)	
Examples: Capitals of Project Countries	*Calculated PGA-Values According to RESIS-II (500 a)*		
Very high	> 500	VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse; damage great in poorly built structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturned (VIII).
Guatemala-City	*524*		
Managua	*507*		
San Salvador	*510*		
High	400 - 500	VII - VIII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken (VII).
Medium	300 - 400	VII	
Low	*200 - 300*	VI	Felt by all, many frightened; some heavy furniture moved; a few instances of fallen plaster; damage slight.
Tegucigalpa	*231*		
Very low	< 200	V - VI	Felt by nearly everyone; many awakened; some dishes, windows broken; unstable objects overturned; pendulum clocks may stop (V).

Recommendations

The application of building codes tailored to the needs of the Central American countries is a fundamental step to reduce seismic risk.

Amenaza Sísmica, Periodo de Retorno 500 Años

Seismic Hazard, Return Period 500 years



Volcanic Hazard (Ash Fall): Example El Salvador

Map Contents

The national map illustrates a simplified excerpt of the official volcanic hazard maps of the volcanoes of Santa Ana (in the west) and San Miguel (in the east) containing spatial information about the most probable volcanic hazard ash fall scenario (scenario 1, see page on the right-hand side).

Map Purpose with Respect to Disaster Risk Management

Ash fall can be expected as the volcanic threat having the largest geographic extent and is thus of highest relevance for national- and supra-regional-scale risk assessment (bear in mind the ash cloud impact of Eyjafjallajökull volcano/Iceland to the air traffic in Europe in 2010).

The official large-scale volcanic hazard maps of El Salvador provide valuable information for spatial planners to efficiently develop evacuation, rescue, and shelter scenarios to be prepared for potential volcanic eruptions.

The simplified volcanic hazard map at hand represents a main input for assessing the exposure of different vulnerability indicators to volcanic ash fall deposits in the surroundings of two active volcanoes at national level, exemplarily. In other words, the existing volcanic hazard information can be amended by information about resulting risk potentials suitable to be incorporated into Disaster Risk Management activities.

Data Source and Availability

The governmental authority Servicio Nacional de Estudios Territoriales (SNET) is mandated both with monitoring of the volcanoes and assessing/mapping of volcanic hazards in El Salvador.

Due to ongoing volcanic activity (gas emission, exceptional ash fall), four of eight active volcanoes in El Salvador (Santa Ana, San Salvador, San Miguel, Izalco) are currently under particular observation. Thus, the majority of these volcanoes have recently been surveyed and mapped in detail and judged to its hazardous potential. SNET currently provides site specific volcanic hazard maps at its website as follows (status: April, 2010):

Name of Volcano	Hazard Map/Status	URL
Santa Ana	'Volcanic Hazard Scenario Map'/2004	http://www.snet.gob.sv/Geologia/Vulcanologia/amenazas /MAPAVSA.pdf
San Salvador	'Volcanic Hazards in the San Salvador Region, El Salvador'/2001	http://www.snet.gob.sv/Geologia/Vulcanologia/amenazas /laharmVSS2.pdf
San Miguel	'Volcanic Hazard Scenario Map'/2004	http://www.snet.gob.sv/Geologia/Vulcanologia/amenazas /MAPAVSM.pdf
San Vicente	'Volcano-Hazard Zonation for San Vicente Volcano, El Salvador'/2001	http://www.snet.gob.sv/Geologia/Vulcanologia/amenazas /laharmVSV.pdf

All spatial information about volcanic hazards of the two case studies used in CARA-GIS was digitally provided by SNET in ESRI GIS file format (shp) ready to use (status: see table above).

Remarks

The two poster images shown in the appendix (see page 102*ff*) encompass the whole spectrum of possible volcanic hazards (e.g. lava flows, pyroclastic flows, lahars, etc.) and reflect the complexity of their assessment. Focusing on a local level, the majority of these surveyed volcanic hazards can easily be analyzed by using CARA-GIS as to their risk potential.

Methodology

Volcanic hazard mapping results for the volcanoes Santa Ana and San Miguel present a synopsis of historical information about volcanic eruptions, field work and results of modeling activities. The latter have been comprehensively performed by SNET in cooperation with the Universidad Autonoma de Mexico (UNAM) and the United States Geological Survey (USGS).

Generally, site specific hazard assessment of volcanic ash fall in El Salvador rests upon information about:

- The volume of material emitted;
- The height of the eruption column;
- The predominant wind direction.

For the Santa Ana volcano three different ash fall scenarios have been defined, whereas the first scenario is the most probable one (see appendix page 102f):

- Scenario 1: Potentially ash fall affected area based on verified spatial information about ash fall deposits from historic events, in particular from the last 1904 Santa Ana eruption. This scenario provides the input parameter to map risk exposure using CARA-GIS (see page 70);
- Scenario 2: Potentially ash fall affected area assuming an eruption column height of 5 km;
- Scenario 3: Potentially ash fall affected area assuming an eruption column height of 14 km and different wind conditions (dry season/rainy season approach).

For the volcano San Miguel three different as fall scenarios have been defined, the first of which is the most probable one (see appendix page 102*f*):

- Scenario 1: Potentially ash fall affected area assuming a low magnitude volcanic eruption with ash fall deposits up to 5 cm. This scenario provides the input parameter to map risk exposure using CARA-GIS (see page 70);
- Scenario 2: Potentially ash fall affected area assuming a moderate, but less probable volcanic eruption in comparison to scenario 1; such an eruption might cause ash fall deposits between 5m (proximal) and 5 cm (distal);
- Scenario 3: Potentially ash fall affected area assuming a strong, but less probable volcanic eruption in comparison to scenario 2; such an eruption might cause ash fall deposits between 4 cm and 3 mm.

How to read this map

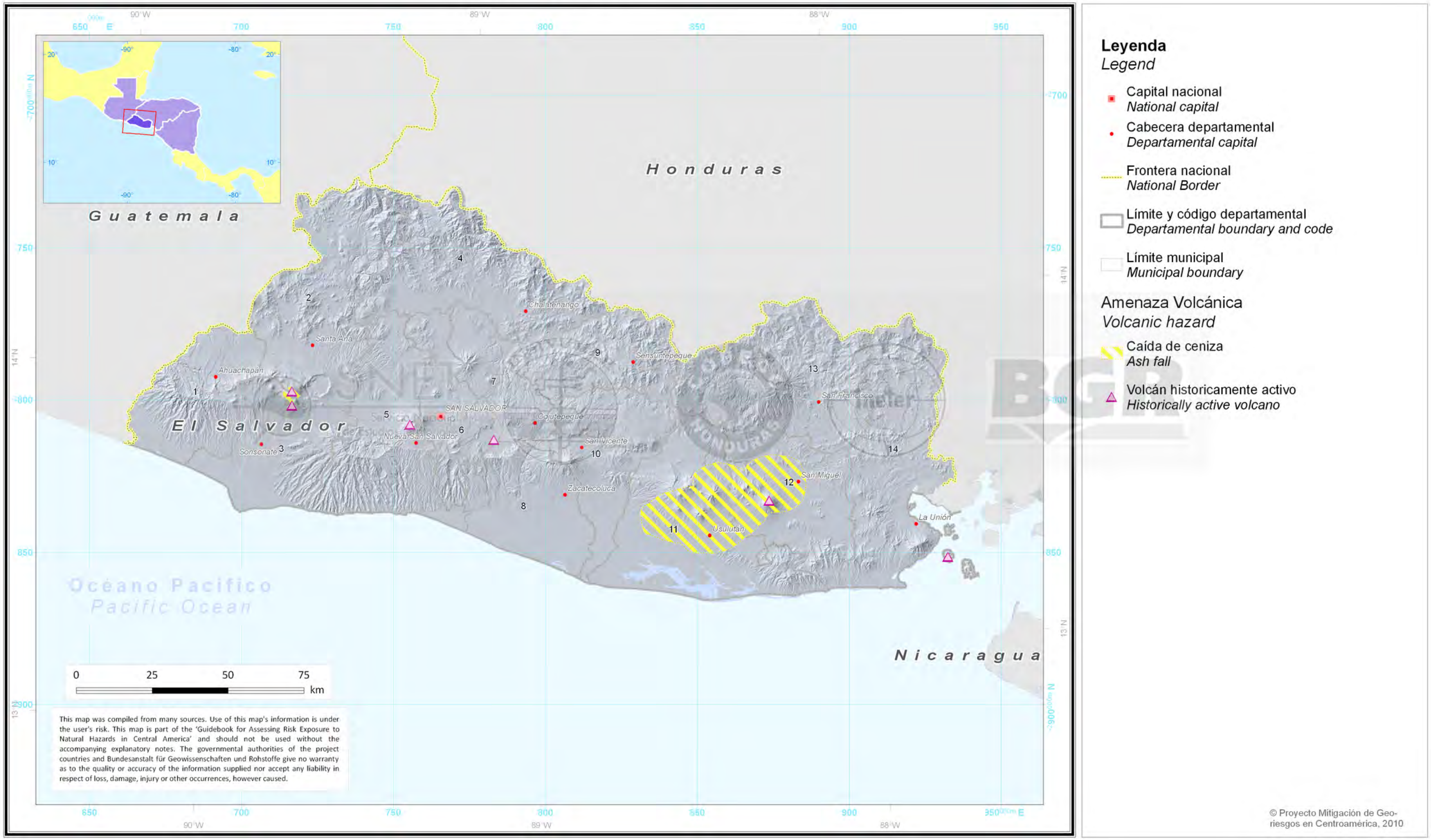
The map indicates the geographical extent of the most probable ash fall scenario of the active volcanoes Santa Ana and San Miguel. According to the chosen scenarios the areas surveyed as potentially affected by ash fall are hachured in yellow colors. Beyond that, all further six active volcanoes of El Salvador are plotted as small triangles. Due to scale reasons other volcanic hazards (e.g. lava flows) have not been mapped here.

Recommendations

It is recommended to establish mandatory regulations (standards) for mapping volcanic hazards in Central America at different scales by applying of impartial criteria (e.g. defined diameters of ash fall buffers) facilitating the comparison of different volcanoes among themselves both at national and supra-regional level.

Amenaza Volcánica (Caída de Ceniza)

Volcanic Hazard (Ash Fall)



Volcanic Hazard (Lahars): Example Guatemala

Map Contents

The national map illustrates a simplified excerpt of the official volcanic hazard maps of some volcanoes of Guatemala. Displayed are the lahar runout zones for the volcanoes Tacaná, Cerro Quemado (Almolonga), Santiaguito, Fuego, and Pacaya. Additionally, volcano locations as listed by the Global Volcanism Program (GVP) of the Smithsonian Institution are shown. Their type of activity is categorized to the Smithsonian's classification.

Map Purpose with Respect to Disaster Risk Management

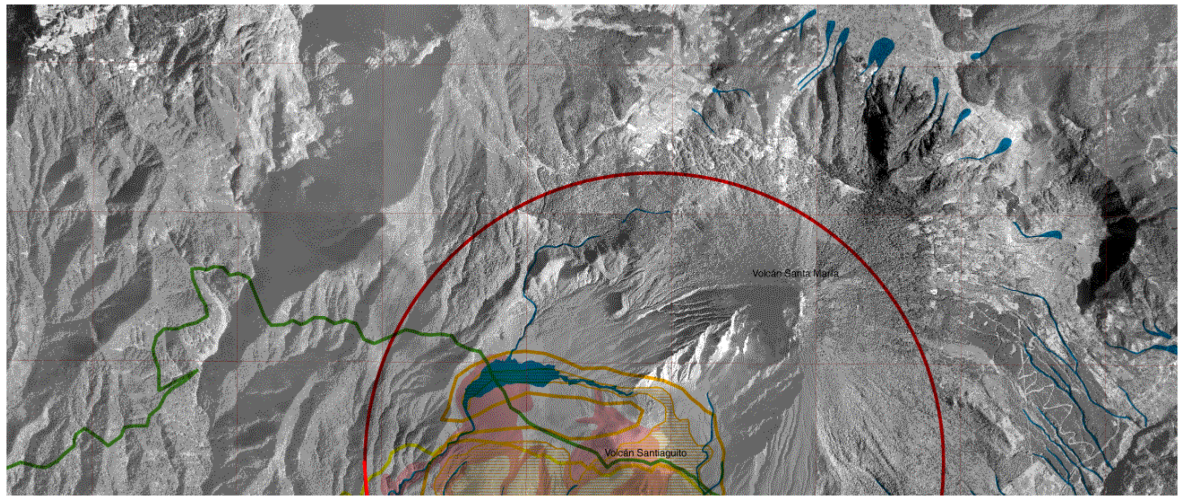
Lahars are among of the most dangerous phenomena associated with volcanoes. Knowledge about their potential extents and paths is of extreme importance when site-specific planning is carried out.

Data Source and Availability

The data presented in this map were extracted from the maps listed in the table below. With exception of Fuego, these maps were produced with the assistance of a cooperation project of the Japan International Cooperation Agency (JICA), between 2000 and 2003 jointly carried out with several Guatemalan governmental agencies (IGN, INSIVUMEH, SEGEPLAN). Partially, these maps are based on mapping carried out in the 1970s by Michigan Technological University. Some of the maps can be downloaded from INSIVUMEH's web-site.

All digital information used in CARA-GIS has been provided by INSIVUMEH in ESRI GIS file format (shp).

Name of Volcano	Source	Scale
Tacaná	INSIVUMEH, with JICA	1:25 000, 1 sheet
Cerro Quemado/Almolonga	INSIVUMEH, with JICA	1:25 000, 4 sheets
Fuego/Acatenango	INSIVUMEH, with USGS	No printed version
Pacaya	INSIVUMEH, with JICA	1:25 000, 4 sheets
Santiaguito/Santa Maria	INSIVUMEH, with JICA	1:25 000, 5 sheets



Reduced part of the Volcanic Hazard Map of the Santiaguito volcano

(source: INSIVUMEH, website)

For further details consult the following resources:

INSIVUMEH, Departamento de Investigación y Servicios Geológicos

http://www.insivumeh.gob.gt/geofisica.html

http://www.insivumeh.gob.gt/mapas/Mapas_de_Amenaza_Volcanica.htm

Remarks

The Global Volcanism Program (GVP) of the Smithsonian Institution (http://www.volcano.si.edu/) lists a total of 22 volcanoes for Guatemala, 6 of them are categorized as historically active. In the case of the Fuego volcano, even two hazard maps were produced in the past. The data used her was taken from VALLANCE ET AL., (2001).

Methodology

As mentioned on the left, the data presented here are taken from a series of comprehensive volcanic hazard maps officially published by INSIVUMEH. Only data that were available in digital, GIS-ready formats could be utilized. The extent of the lahars as well as other features is the results of modeling procedures performed by the mentioned projects. It is referred to these projects for details of the modeling process.

How to read this map

The purple areas represent the largest extent of the lahar modeling of each individual volcano. For better legibility and cartographic purposes the outline has been highlighted (thickened). Additionally, the locations of volcanoes as listed by the GVP are shown, categorized by their state of activity. These activity categories are explained in detail on the web-site of the GVP (see above).

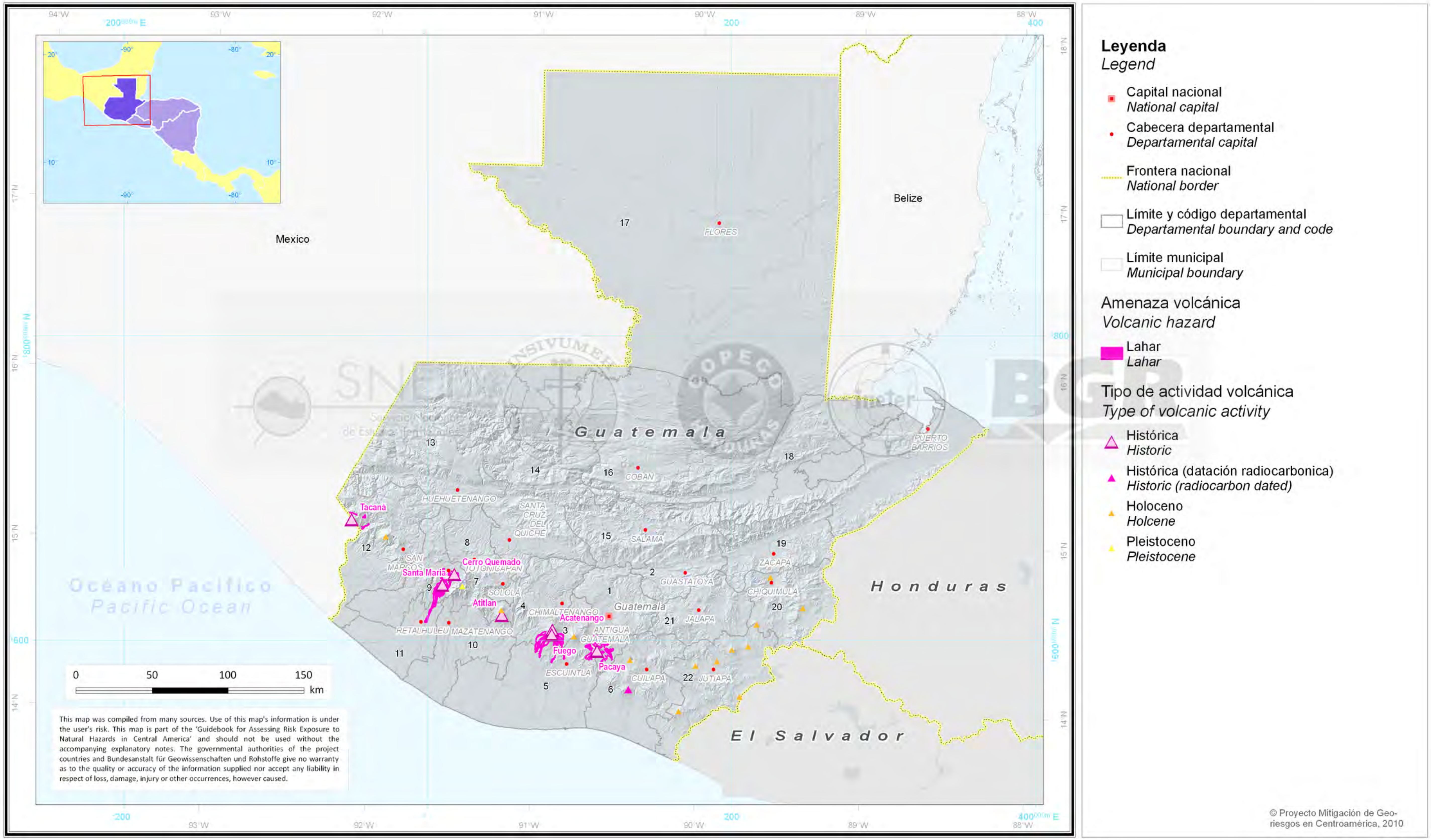
Recommendations

For detailed local studies and planning purposes it is recommended to consult and obtain the detailed maps mentioned before. It is also referred to consult INSIVUMEH's website for up-to-date information on the alert level of the volcanoes in Guatemala.

Obviously, volcanic hazard maps have not been produced for all active volcanoes in Guatemala, it is thus recommended to develop the hazard maps for the remaining volcanoes, too.

Amenaza Volcánica (Lahares)

Volcanic Hazard (Lahars)



Volcanic Hazard (Ash Fall): Example Nicaragua

Map Contents

The national map shows a simplified excerpt of the official volcanic hazard map of Nicaragua (INETER, 1995) and depicts the maximum possible spatial extent affected by ash fall deposits during volcanic eruptions. Beyond that, all historically active volcanoes of Nicaragua alongside the volcanic chain are plotted as small triangles. Due to scale reasons other volcanic hazards (e.g. lava flows) have not been included.

Map Purpose with Respect to Disaster Risk Management

The official volcanic hazard map of Nicaragua (INETER, 1995) provides valuable information for spatial planners at national-scale. Such a map is less important to develop detailed evacuation, rescue and shelter scenarios to be prepared for potential volcanic eruptions. Based on this official volcanic hazard map, the simplified excerpt at hand represents a main input for assessing the exposure of different vulnerability indicators to potential volcanic ash fall deposits in the surroundings of volcanoes at national level. In other words, the existing nationwide volcanic hazard information can be supplemented by information about resulting risk of historically active volcanoes, suitable to be integrated into the national Disaster Risk Management activities.

Data Source and Availability

The governmental authority Instituto Nicaragüense de Estudios Territoriales (INETER) is mandated with both, the monitoring of volcanoes and the assessment/mapping of volcanic hazards in Nicaragua. Beside the national volcanic hazard map at scale: 1:400 000 (INETER, 1995) a number of several detailed site-specific volcanic hazard maps have been established in the last few years. For more information it is pointed to HUETE (2001). Presently, two of these maps are accessible at the INETER web page:

Name of Volcano	Hazard Map/Status	URL
San Cristóbal	Amenazas asociadas al volcán San Cristobal/ no information	http://mapserver.ineter.gob.ni/website/Mapas/cristobal/viewer.htm
Concepción	Mapa de Amenazas del volcán Concepción/ no information	http://mapserver.ineter.gob.ni/website/Mapas/conce/viewer.htm

All information about the national volcanic hazard map incorporated in CARA-GIS was digitally provided by INETER in ESRI GIS file format (shp) (status: 1995, prepared for CARA-NI-GIS in 6/2009). The national volcanic hazard map of Nicaragua at scale 1:400 000 (INETER, 1995) can be purchased both as a printed version and as digital file at the INETER map store at the price of 50 US$, respectively.

Remarks

The national volcanic hazard map contains not only information about possible ash fall scenarios, but also information on a range of other relevant volcanic hazards (e.g. lava flow, lahars).

Methodology

Focusing solely on the ash fall scenario, the national volcanic hazard map has been developed stepwise as follows (Step 3: CARA specific adjustment):

1. Large-scale site specific volcanic hazard assessment that incorporates field mapping survey outcomes and published scientific investigations about historical volcanic events in Nicaragua. Accordingly, the contour lines representing the maximum reach of tephra deposits caused by different types of eruption (phreatoplinian, plinian, strombolian) have been mapped in a first step for each volcano individually. Although a distance dependent decrease of grain size and thickness of the deposit is characteristic for volcanic eruptions, a further classification has not been applied;
2. Superimposition of spatial ash fall information for all types of eruptions nationwide; this results in a partial overlap of ash fall contour lines between neighbouring volcanoes;
3. (CARA-GIS: creation of a 'dissolved' digital set of contour lines that define the maximum reach of tephra deposits for all volcanoes to be considered).

How to read this map

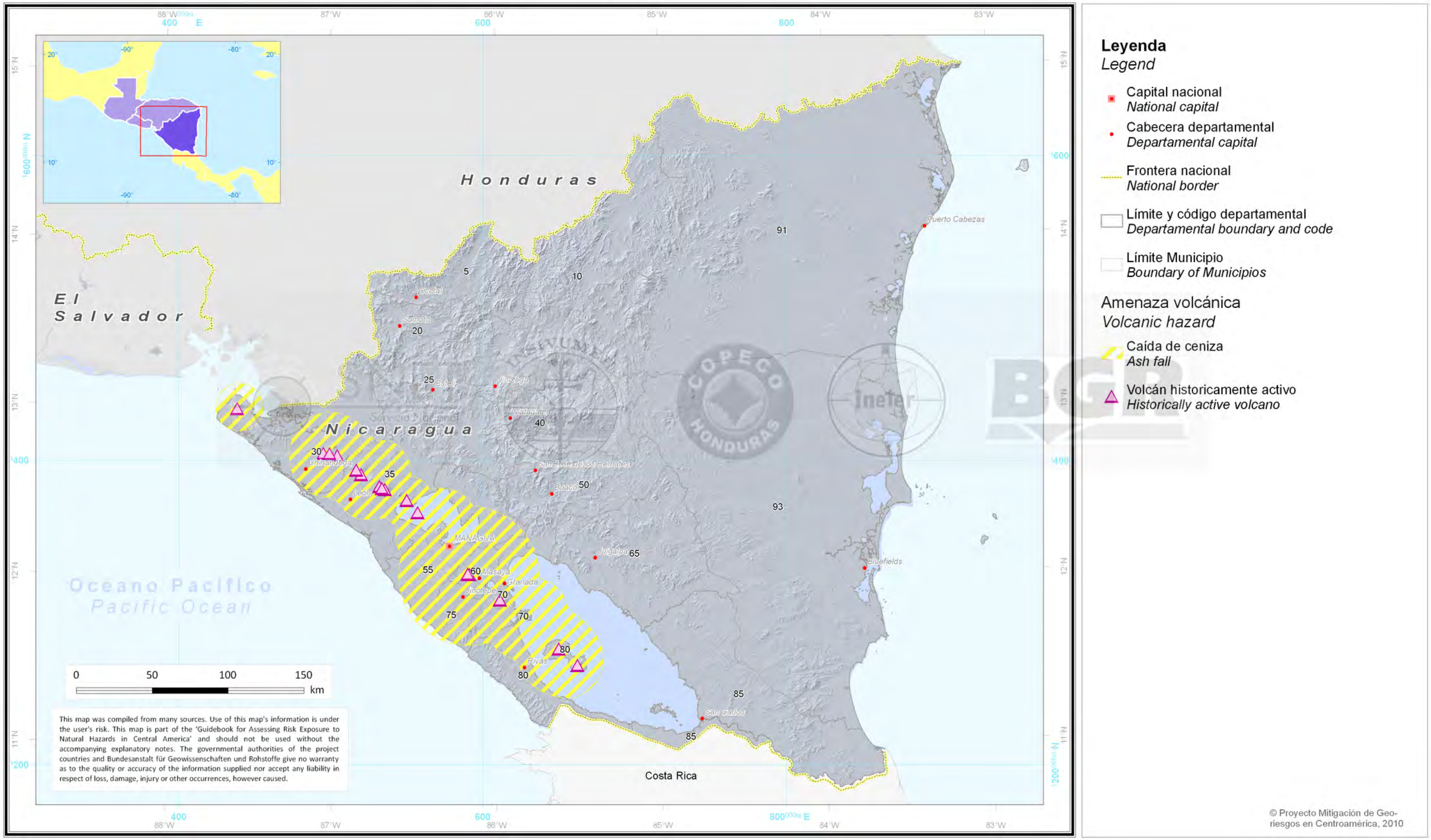
The map synthesizes information about the probable maximum geographical extent of ash fall deposits caused by volcanic eruptions in Nicaragua. These areas are hachured in yellow colors. However, the mapped scenario does not imply the assumption of simultaneous eruptions of all volcanoes. This approach has only been chosen to assess the *nationwide* risk to volcanic ash fall in order to draw attention of stakeholder to this significant threat (see page 48).

Recommendations

It is referred to the recommendations on page 44 .

Amenaza Volcánica (Caída de Ceniza)

Volcanic Hazard (Ash Fall)



Landslide Susceptibility, Supra-Regional

Map Contents

The supra-regional map depicts the landslide susceptibility zones for the Central American countries. Based on the methodology of MORA & VAHRSON (1994) the presented map synthesizes four single national maps that have been issued in the last few years independently from each other.

Map Purpose with Respect to Disaster Risk Management

This map delivers the technical input with reference to landslide hazard (susceptibility) within the CARA process. It shows the spatial distribution of landslide susceptibility zones that can be combined with vulnerability data in subsequent risk exposure mapping steps. Hence, it serves as a contribution to raise the awareness of national governmental and intergovernmental authorities for landslide prone areas beyond the well-investigated landslide hotspots. As landslides are often triggered by torrential rains, this map is exceptionally important for future supra-regional assessments in the context of climate change adaption as well.

Data Source and Availability

In the Central American project countries governmental authorities are mandated to evaluate and map landslide hazards at the national level. In Honduras and Nicaragua the project 'Mitigation of Georisks in Central America' gave substantial assistance to finalize this specific hazard assessment activity (see table below).

Country	Authority/Official Name of National Map	Type of Data/Accessibility	Date of Publishing
El Salvador	Servicio Nacional de Estudios Territoriales (SNET)/'Mapa de Susceptibilidad a Deslizamientos en El Salvador'	Digital version/at SNET web page	2002
Guatemala	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH)/'Mapa de Susceptibilidad de Deslizamientos de Tierra en Guatemala'	Digital version/not available at INSIVUMEH web page	2008
Honduras	Comisión Permanente de Contingencias (COPECO) in cooperation with the Project 'Mitigation of Georisks in Central America'/'Mapa de Susceptibilidad a Deslizamientos en Honduras'	Digital version/not available at COPECO web page	2008
Nicaragua	Instituto Nicaragüense de Estudios Territoriales (INETER) in cooperation with the Project 'Mitigation of Georisks in Central America'/'Mapa de Susceptibilidad a Deslizamientos en Nicaragua'	Digital version/at INETER web page	2004

The following table gives an insight into the data used to elaborate the national landslide susceptibility maps according to the methodical approach of MORA & VAHRSON (1994).

Country	Used Topographic Data (DEM)	Used Geological Data	Used Seismological Data	Used Climate Data
El Salvador	DEM 25 m (based on digitized contour lines of topographic maps 1:25 000)	Geological Map, Scale 1:100 000	Seismic acceleration map for El Salvador, return period: 100 years (1993)	Precipitation data taken from the Study: ABEL CENTELLA ET AL. (1998): 'Escenarios Climáticos de Referencia para El Salvador"
Guatemala	DEM 20 m	Geological Map, Scale 1:250 000	Project GSHAP (1992-1999), no further information	Precipitation data taken from registers (1926-recent) of INSIVUMEH
Honduras	DEM 50 m	Geological Map, Scale 1:500 000	Project GSHAP (1992-1999): pga [m/s²], return period: 475 years	Discontinuous precipitation data from 8 meteorological stations (1943-2000), source SINIT.
Nicaragua	DEM 90 m (SRTM-3)	Geological Map, Scale 1:500 000	Project GSHAP (1992-1999): pga [m/s²], return period: 50 years	Climatic/Meteorologic Atlas: Average monthly precipitation [mm/month], Maximum precipitation in 24 h [mm/d] (1971 – 2000)

For ongoing CARA activities, all landslide susceptibility modeling results have been digitally provided by the aforementioned authorities as raster GRID files.

Remarks

The supra-regional landslide susceptibility map results from the compilation of individual national maps. While all national maps rest upon an identical methodological approach, the available sources of information characterizing the input parameters (see *Methodology*, below) are anything but homogenous among the countries. However, to facilitate a supra-regional risk exposure mapping there is currently no alternative to this approach.

Methodology

The landslide susceptibility map was elaborated using the methodology of MORA & VAHRSON (1994), a simple grid-unit based expert system allowing a fast classification of landslide hazard in seismically active tropical areas with scarce quantitative field data. The methodology is based on the evaluation of five factors, three intrinsic, called susceptibility factors (SUSC):

- Relative relief (Sr);
- Lithology (Sl);
- Soil saturation (Sh).

and two external, called triggering factors (DISP):

- Seismic activity (Ts);
- Precipitation (Tp).

For each of these factors an index of influence is determined by a reference value through a specific weight, and by calculating with the following equations:

$$H = SUSC * DISP$$

$$H = (Sr * Sl * Sh) * (Ts+Tp)$$

a 'relative Hazard' (H) may be determined. The map shows the calculated hazard classes given in the publication of the methodology.

How to read this map

The map shows in graded colours the four classes of landslide susceptibility (low, moderate, high, very high) describing the general tendency for slope failure in the considered area. Unfortunately, the susceptibility classes have not been validated with landslide inventory data yet. Therefore, a transfer of the calculated values into a more comprehensible explanation of the classes is still missing. For that purpose, a practical but provisional interpretation of the susceptibility classes is given below:

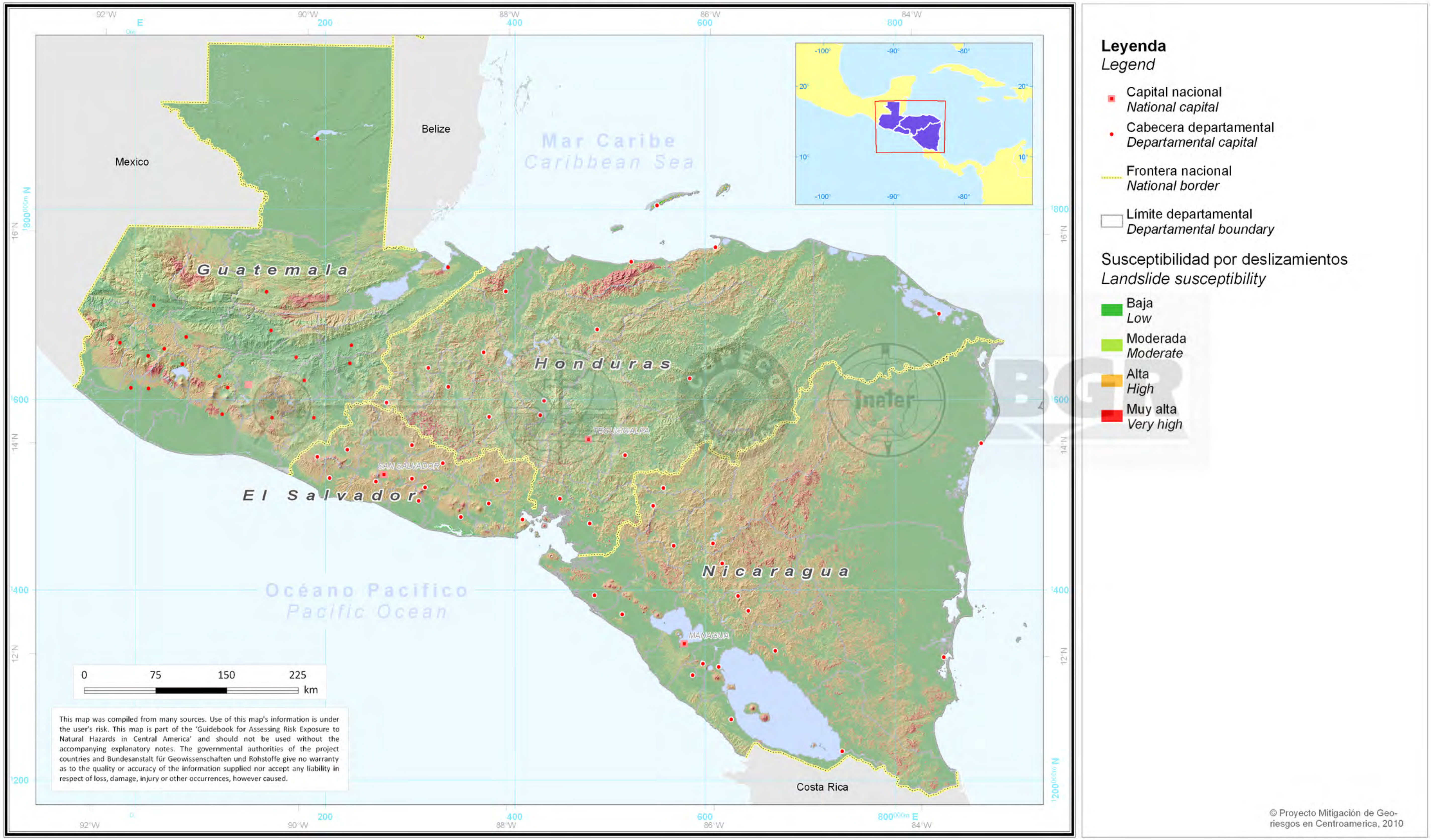
- *Low Susceptibility:* There exists a very low probability for the occurrence of landslides;
- *Moderate Susceptibility:* Landslides rarely occur, often triggered by human activities (e.g. deforestation, steep road cuts);
- *High Susceptibility:* The area was affected by landslides in the past and new landslides could occur, also due to reactivation processes affecting dormant landslides;
- *Very High Susceptibility:* Landslides occur frequently with different magnitudes.

Recommendations

It is highly recommended to standardize the input parameter for a nationwide/supra-regional landslide susceptibility assessment in Central America and to validate the modeling results with inventory data.

Susceptibilidad por Deslizamientos

Landslide Susceptibility



Inundation Hazard: Examples El Salvador, Guatemala, Nicaragua

Map Contents

The national maps for El Salvador (see map on the right-hand side), Guatemala (page 54), and Nicaragua (page 55) show areas (zones) prone to inundation (flooding). Due to the divergent methodical approaches to survey flood-prone areas at national level these maps have not yet been merged to a supra-regional one.

Map Purpose with Respect to Disaster Risk Management

The maps provide the technical input with reference to inundation hazard (susceptibility) within the CARA process. Information about the spatial distribution of inundation susceptible areas is valuable as flooding may lead to massive tangible and non-tangible losses (infrastructure). Inside Disaster Risk Management activities, this hazard information is indispensable for analyzing nationwide risks to inundation in consideration of different vulnerability indicators (e.g. infrastructure exposed, people exposed).

In addition, inundation events are often associated with landslides. Therefore, to direct policy and decision makers' attention to this fatal combination this map serves also as input to assess this specific risk exposure jointly (multi-hazard approach), too.

Data Source and Availability

In the Central American project countries governmental authorities are mandated with evaluating and mapping inundations hazards at national level (see table below).

Country	Authority/Official Name of National Map	Type of Data/Accessibility	Status
El Salvador	Servicio Nacional de Estudios Territoriales (SNET)/'Mapa de Susceptibilidad a Inundaciones en El Salvador'	Digital version (vectorized)/ not officially available	2002
Guatemala	Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) in cooperation with Ministerio de Agricultura, Ganadería y Alimentación (MAGA)/'Mapa de Amenaza por Inundación Republica de Guatemala'	Digital version (pdf)/ at MAGA web page	2001
Honduras	Comisión Permanente de Contingencias (COPECO)/no information about nationwide inundation map provided	-	-
Nicaragua	Instituto Nicaragüense de Estudios Territoriales (INETER)'/'Mapa de Amenaza de Inundaciones', also issued as 'Mapa de Inundaciones Históricas en Nicaragua'	1) Digital version (jpg)/ at INETER web page; 2) Digital version (vectorized)/ not officially available	1999

The table below summarizes the most relevant information has been used to generate the national inundation susceptibility/hazard maps, respectively.

Country	Used Topographic Data	Further Input Parameter (Referring to the Geographical Extent)	Update Frequency of Map
El Salvador	1:25 000 + DEM (SRTM-3)	- Historical flooding events - Extrem events (e.g. hurricane 'Mitch')	annual
Guatemala	1:250 000	- Historical flooding events - Extrem events (e.g. hurricane 'Mitch')	continuous
Nicaragua	1:750 000	- Historical flooding events - Extrem events (e.g. hurricane 'Mitch')	continuous

For ongoing CARA activities, all available country-specific flood hazard mapping results have been digitally provided by the aforementioned authorities as ESRI GIS file format (shp) ready to use.

Remarks

It is pointed out, that a number of inundation maps at different scales have been elaborated for Guatemala (INSIVUMEH in cooperation with JICA, status: 2001) and Nicaragua (INETER in cooperation with COSUDE, status: 2004; at Municipio level). However, these maps do not exist all over the country. For El Salvador, SNET offers a web-based querying tool that provides alphanumeric information about historical flood events at Departamento level.

Methodology

The survey of nationwide flood-prone areas in the three considered countries is mainly based on an empiric approach using information about the geographical extent of historical flooding events and of extreme meteorological events (e.g. hurricane 'Mitch') subject to the topographical (terrain) conditions, respectively. Partially, the nationwide maps result from the aggregation of available local information with a higher degree of resolution (see *Remarks*).

How to read this map (s)

Irrespective of the country-specific zoning scheme, the areas surveyed as potentially affected by inundation are hachured in blue or graded blue colors.

For El Salvador, the map shows three zones of susceptibility to inundations that have been defined as follows:

- Very high;
- High;
- Medium.

For Guatemala, a two-stage zoning for the nationwide inundation susceptibility is given on the map:

- Areas susceptible to flooding;
- Areas susceptible to extreme flooding.

For Nicaragua, there is only the information, whether an area is prone (yes: hachured) to inundation or not.

In all cases, an explanation of the hazard zones is still missing. For that purpose, a schema is provisionally given below, seeking to harmonize inundation susceptibility zones in a supra-regional way (in style of JICA, 2001):

A) Flood as large as or larger than the one that occurred due to hurricane 'Mitch';
B) Flood that occurs due to an extreme meteorological event, e. g. a hurricane smaller in scale than hurricane 'Mitch'. Flood that mainly inundates lowland areas along rivers and coastlines;
C) Flood that frequently occurs due to torrential rain events and inundates lowland areas along rivers.

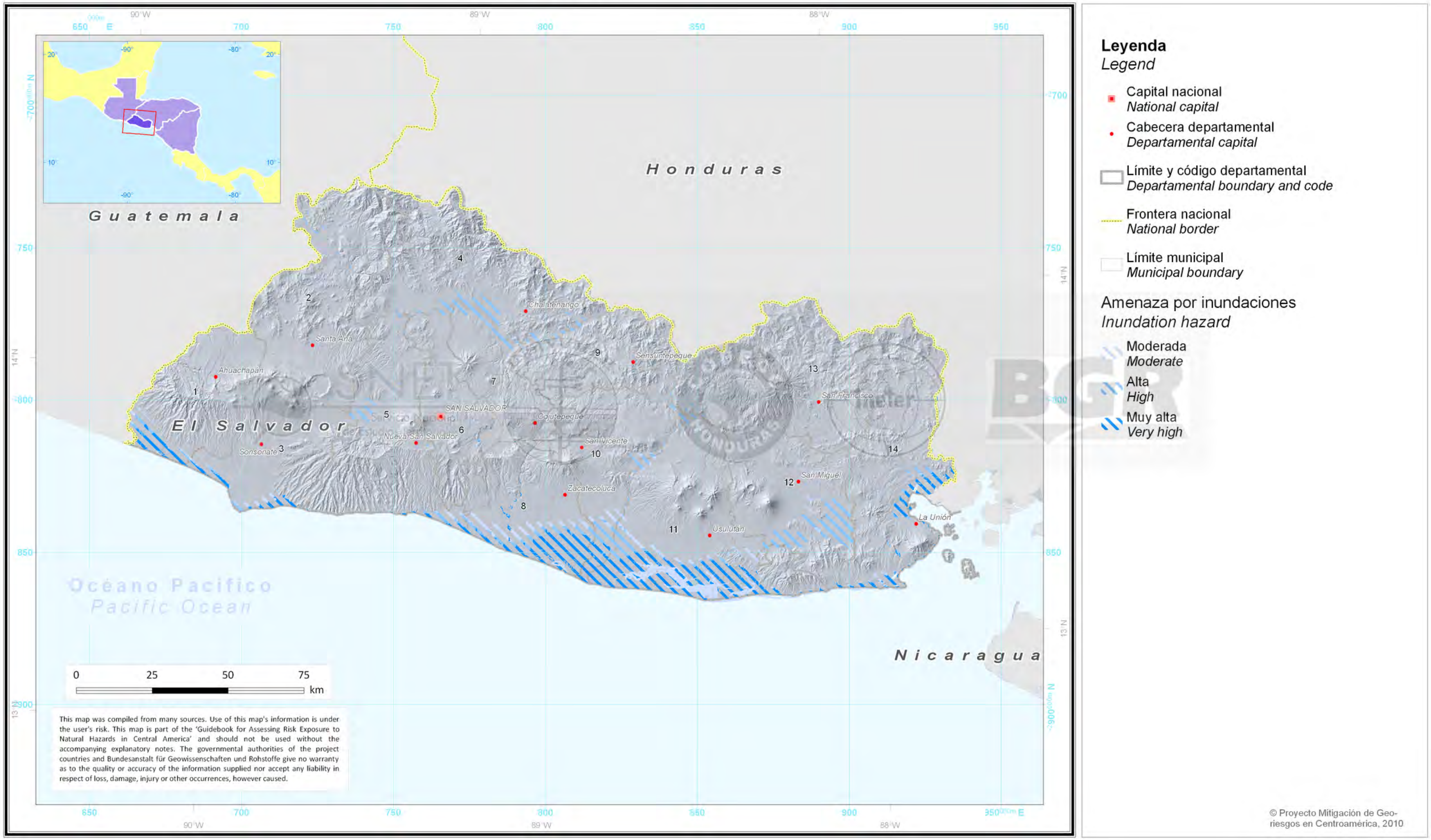
Hazard/Susceptibility Zone (Supra-Regional, *not official*)	El Salvador	Guatemala	Nicaragua
A	Very high	Areas prone to extreme flooding	Areas prone to flooding
B	High		
C	Medium	Areas prone to flooding	

Recommendations

It is suggested to implement a common inundation hazard/susceptibility zoning scheme for the countries of Central America in order to facilitate an impartial supra-regional comparison of the flooding event magnitudes and their recurrence period.

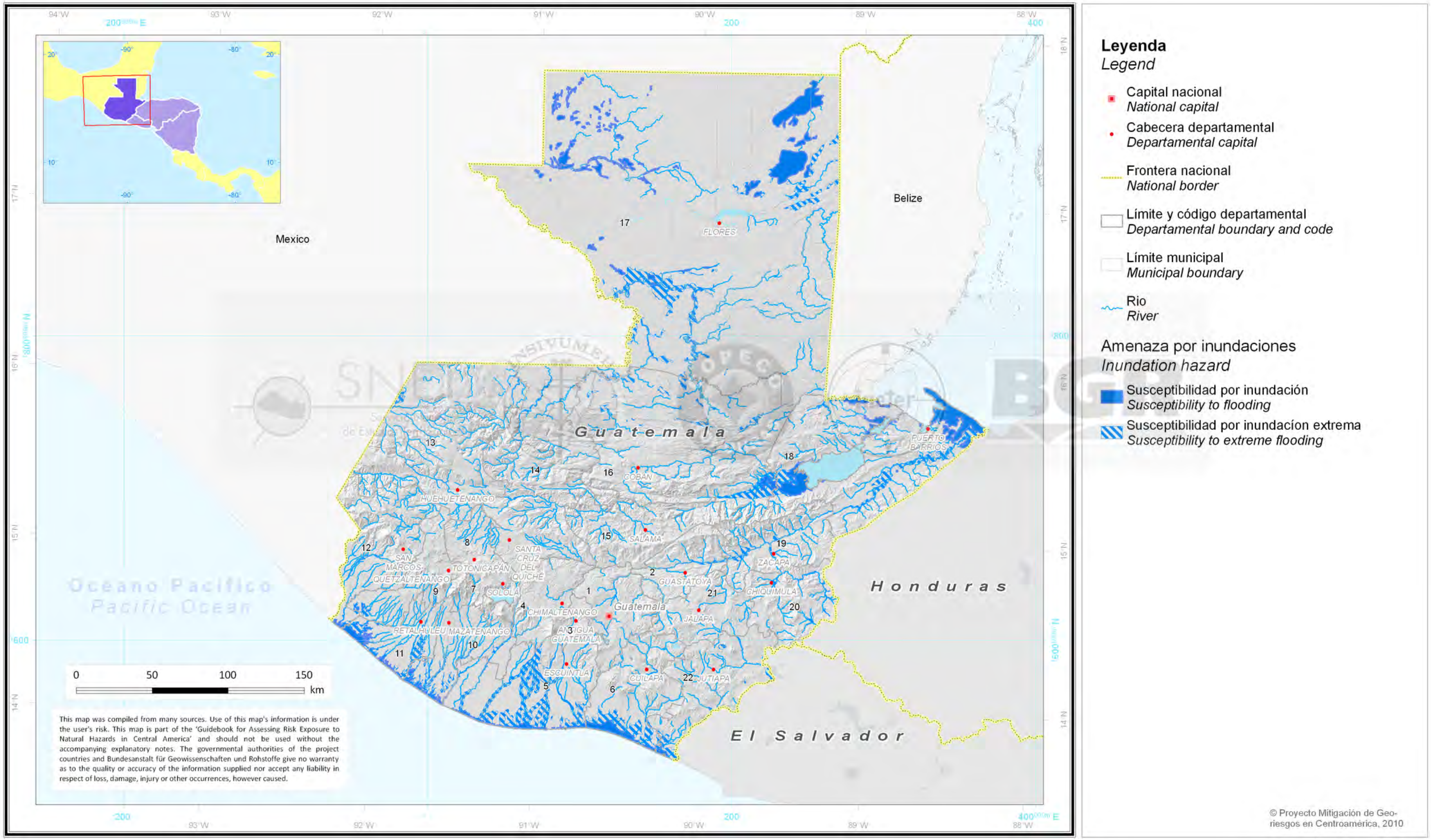
Amenaza por Inundaciones

Inundation Hazard



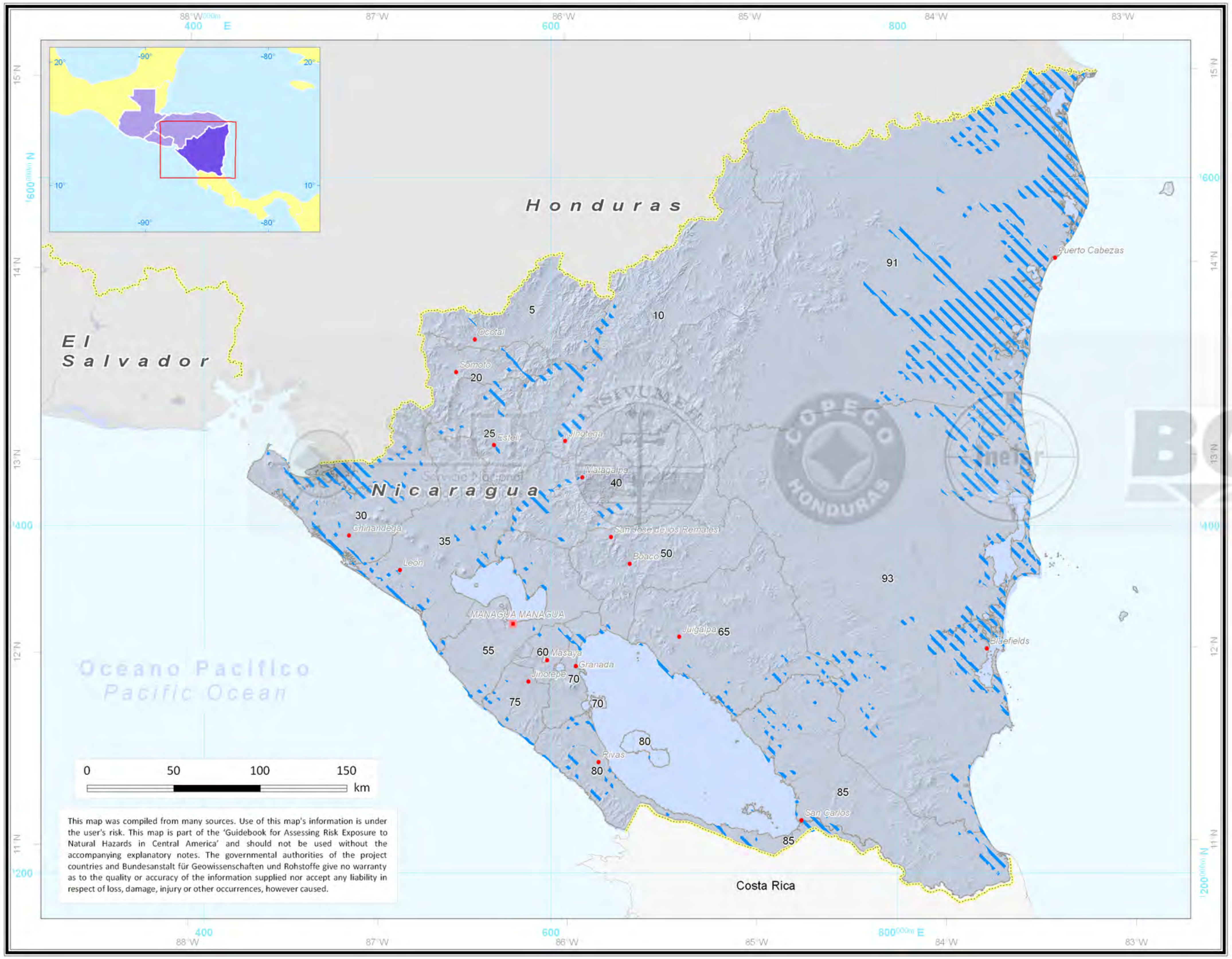
Amenaza por Inundaciones

Inundation Hazard



Amenaza por Inundaciones

Inundation Hazard



Leyenda
Legend

- Capital nacional / *National capital*
- Cabecera departamento / *Departamento capital*
- Límite y código Departamento / *Boundary and code of Departamentos*
- Límite Municipio / *Boundary of Municipio*

Amenaza por inundaciones
Inundation hazard

- Área susceptible por inundaciones / *Inundation prone area*

Hazard / Susceptibility

Spatial Hazard, Supra-Regional

Map Contents

The supra-regional map shows a synopsis of the hazard maps presented and discussed on pages 42 to 55.

Map Purpose with Respect to Disaster Risk Management

Mapping the spatial hazard at a supra-regional scale is a suitable step to make Disaster Risk managers acting on cross-border level aware of the spatial complexity of the hazards the Central American countries are exposed to. Accordingly, this map emphasizes again both the outstanding importance of a common hazard and risk exposure mapping and the necessity to tackle this challenge in a supra-regional Disaster Risk Management context.

Data Source and Availability

The spatial hazard map is a compilation of the following individual supra-regional hazard maps:

- Seismic hazard (page 42);
- Volcanic hazard (ash fall: in El Salvador two volcano case studies only; lahars: in Guatemala for five volcanoes) (pages 44, 46, and 48);
- Landslide susceptibility (page 50);
- Inundation hazard (page 52ff).

All relevant information on the single hazard maps is explained comprehensively in these respective chapters.

Remarks

The data presented here are the basis for the multi-hazard risk exposure map presented in the section *Risk Exposure*.

Methodology

This map results from a geographical overlay of the input maps previously mentioned using GIS. Usually, in such blue sheets not all hazard zones are depicted. The focal point lies on the zones of high and moderate hazard in order to achieve a distinguishable representation and to draw the attention to gist of matters. It is obvious, that the regions of high hazard are the ones that deserve most attention for mitigation efforts.

How to read this map

For better readability, hazard information has been merged or omitted occasionally. The different hazards and their spatial distribution are symbolized by color-coded hachures or areas and other typical cartographic elements.

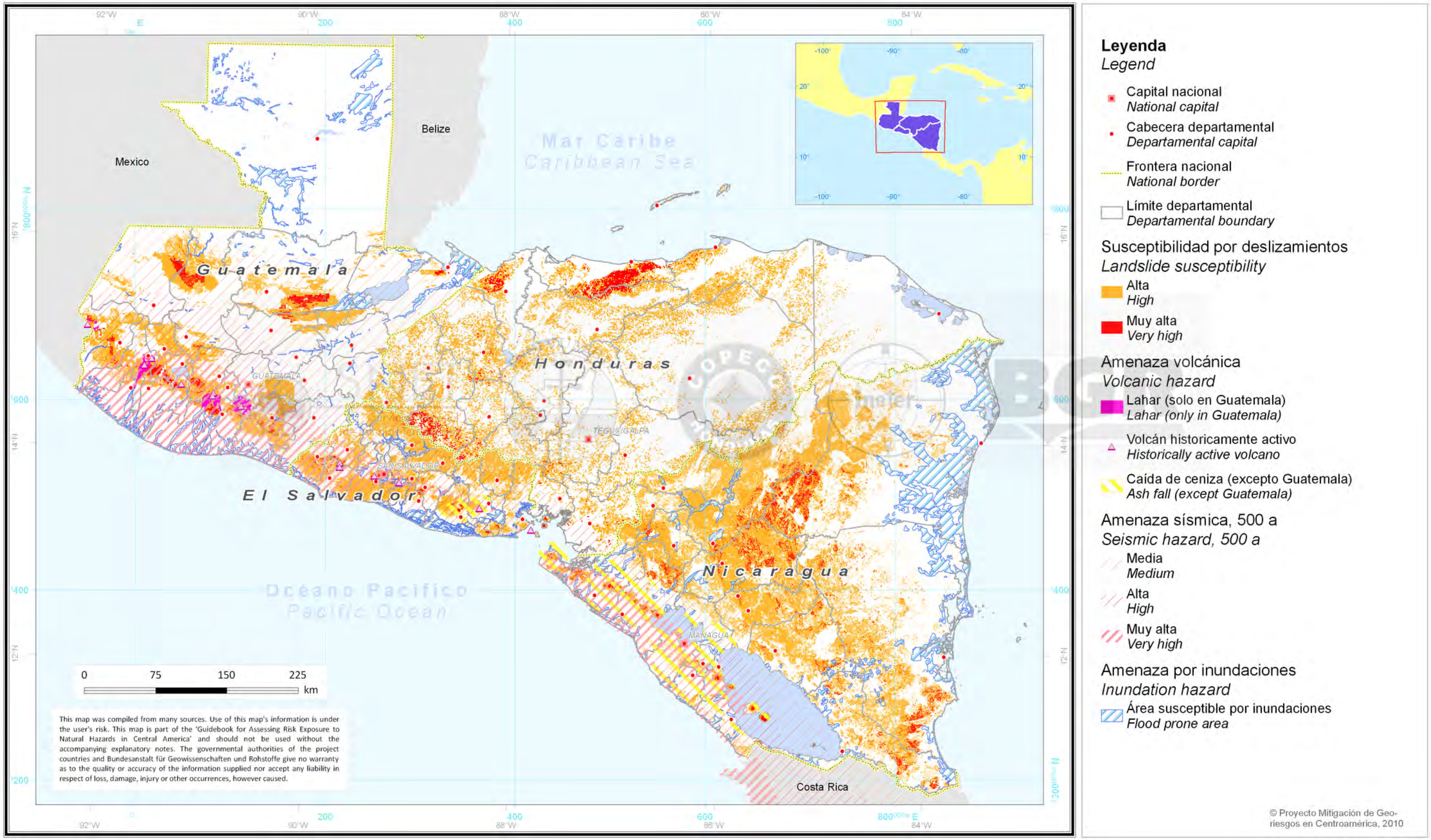
At this point, the mapped hazard items have not been intersected with any spatial information characterizing elements at risk. Consequently, this map does not say anything about the risk potential as to the social or infrastructural vulnerability, neither at Municipio nor at Departamento or country level.

Recommendations

Spatial hazard maps contain essential information for professionals to judge, which threats a country or region is facing and what countermeasures could be the most appropriate to mitigate risks, in particular on the regional level. Therefore, hazard maps should not be interpreted independent from risk exposure maps as shown on the maps in the section on Risk Exposure, page 67ff.

Distribución Espacial de las Amenazas

Spatial Hazard



Vulnerability / Capacity

No vulnerability, no risk! Vulnerability describes the conditions determined by physical, social, economic, and environmental factors or processes to be strained by the impact of natural hazards. Hazard in combination with vulnerability itself defines the risk or in general parlance, no vulnerability, no risk or the higher the vulnerability the higher the risk (potential).

The capacity, also denoted as capability, specifies all strengths and resources of an individual, of an organization, or of a community (society) that can increase the ability of people concerned to cope with and to withstand natural hazards they are faced to and thus reduce the level of risk or the consequences of a natural disaster.

Assuming a given hazard, vulnerability and capacity are in a strong correlation to one another. For example, due to the pitched roof design a building may be not or only little vulnerable to ash fall deposits during a volcanic eruption, but it may be highly vulnerable to structural damages caused by earthquake-triggered ground motion. Enhancing the capacity of a building through structural retrofitting may reduce its vulnerability to earthquake-induced shaking. However, structural changes that include the replacement of the pitched roof by a flat roof may impair the capacity to withstand volcanic ash fall deposits seriously. In other words, the vulnerability is increasing.

The subject of vulnerability and capacity is sophisticated and there is no final solution as to how an assessment should ideally be performed. Determining vulnerability and capacity strongly depends on the scale at which an assessment is made. Means and methods appropriate for assessing the vulnerability and capacity of a single building are certainly not suitable for the assessment of an entire Municipio or Departamento. On a national or supra-regional scale, the focus lies on the provision of information describing the overall vulnerability or capacity – information that needs to be comparable and reproducible throughout the considered administrative level.

The CARA vulnerability and capacity maps presented subsequently were created with the Central American, i.e., the supra-regional perspective in mind. Following the philosophy of keeping the assessments simple and of using available or easily accessible data, the focus is set on analyzing the overall or general vulnerability of the population, the infrastructure and the economic potential. It is illustrated how settlement areas, roads and economic areas are distributed throughout Central America. No attempt was made to do a vulnerability assessment on a more detailed scale. Such studies would require far more detailed data, for example data on education and gender issues or data on building parameters. There are, however, some individual studies available which elaborate on these topics (see for example the earthquake risk study for Managua referred to on page 6f). Bear in mind, that the vulnerability map of infrastructure (roads) has actually already been discussed (see page 32).

Capacity is exemplified using a simple approach that depicts the availability of public health facilities at Municipio level for the country of El Salvador.

Modified Population Density, Supra-Regional

Map Contents

The supra-regional map shows the *modified population density* that is defined as the population of a given Municipio divided by its settlement area. The *modified population density* can also be called *net population density.*

Map Purpose with Respect to Disaster Risk Management

The purpose of calculating a modified value for the population density is to better estimate the number of people potentially affected by hazards in their settlement areas (see the population exposure maps later in the section *Risk Exposure* for more details). Modified population density is a direct measure for a community's vulnerability.

Data Source and Availability

The data sources used here are:

- Settlement areas of the land use maps (see section on land use, pages 26*ff*), not available for Honduras, therefore a calculation of the *modified population density* is not possible (see special note on page 28)*;*
- The population statistics on Municipio level (page 36);
- The administrative boundaries (areas) of Municipios (see page 24).

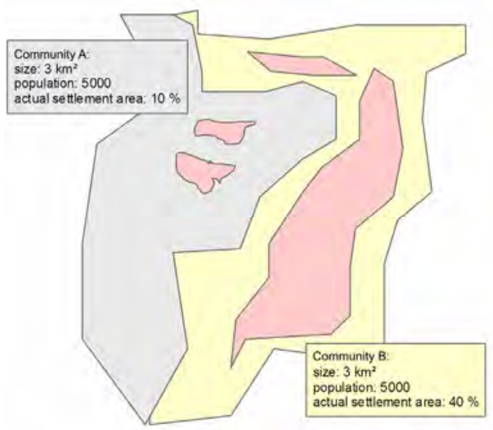
Remarks

The methodology described below is sensitive to precise area size estimates for the settlement areas. If the settlement areas outlined in the land use or land cover map are too small compared to the real situation, the resulting modified density figures will be overestimated. This problem may particularly arise if land use data are used that are a lot older than the population statistics. For detailed studies (Municipio level), the time lag between land use data based on satellite imagery of the 1990s and recent population statistics may result in imprecise population densities given the growth of the population. Furthermore, the probability of introducing errors is higher in rural areas, where analytical underestimation of settlement areas is more likely.

Please refer to the maps on pages 68*ff* for a better understanding of how these data can be utilized to determine exposure and risk.

Methodology

The aim is to recalculate the population density of a given Municipio to a population density of this Municipio based on its settlement area only. The figure below illustrates the calculation process in more detail.



Sketch illustrating the concept of 'modified population density'. The grey area represents the area size of Community A, the yellow area the extent of Community B. Actual settlement areas of these communities are shown in red.

From the numbers given it can be calculated that Community A and B have the same 'regular' population density:

5000 people/3 km² = 1667 people/km².

The area where people actually live is bigger for Community B compared to Community A. Therefore, B has a smaller modified (net) population density of

5000 people/0.4 x 3 km² = 4167 people/km²

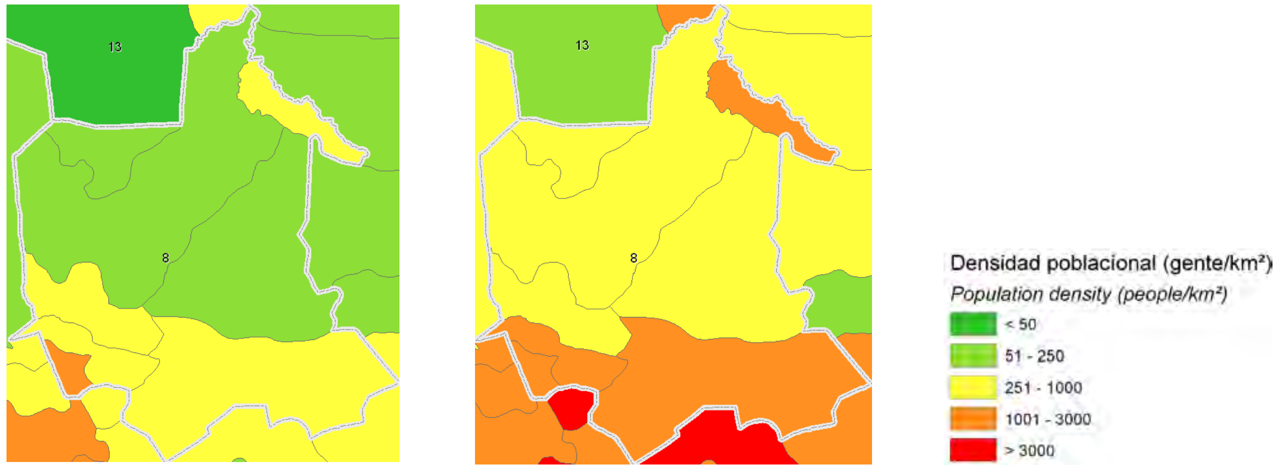
compared to Community A with

5000 people/0.1 x 3 km² = 16 667 people/km².

All these numbers can easily be derived by intersecting aforementioned input data using a GIS and a database system. Through this intersecting process a combined geospatial dataset is being created that holds all the attributes of all input data and can easily be processed in further risk assessment steps.

How to read this map

The colored regions on the map denote settlement areas as derived from the land use map. The colors by oneself represent the modified population density obtained for each Municipio. The figure below illustrates the difference between the population density as an average over the entire area of a Community (left, see also page 36) and the modified population density (right) for the Municipios of Departamento 8 (Totonicapan) in Guatemala.



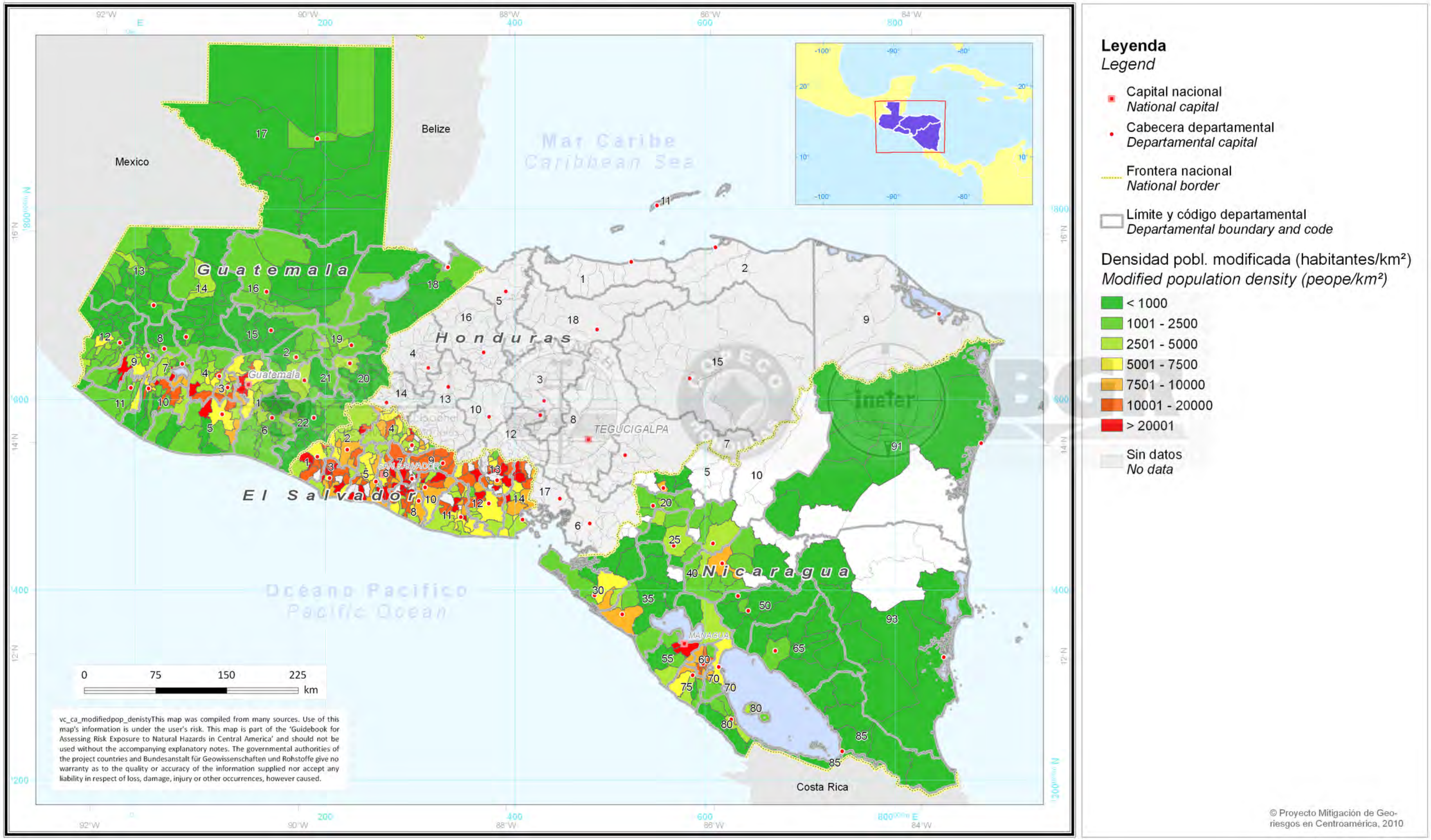
Due to the more rural nature of this Departamento the population density values are much higher when estimated for settlement areas only. These modified population density figures give a more accurate representation of how many people actually live on a certain area of land. In the process of calculating modified population density, the figures resulting for urban areas remain high (e.g. compare densities in the vicinity of the Guatemala-City to those of the map on page 36) but high population density figures can also result for rural areas. White Municipios (e.g. in Nicaragua) implies that no settlement areas have been surveyed for such Municipios in the context of land use mapping. The modified population density will later be used for estimating the number of people living in particular hazard zones (population exposure map in the section *Risk Exposure*, page 68*ff*).

Recommendations

- A good base map that realistically reflects settlement land cover is essential. The smaller a study area, the more important this recommendation becomes.
- Care has to be taken if land use data and population statistics stem from different years of production. Errors can be large if time the time gap is large, particularly if population growth rates are high. In such cases, suitable correction factors need to be applied.

Densidad Poblacional Modificada

Modified Population Density



Vulnerability / Capacity

Economic Potential, Supra-Regional

Map Contents

The supra-regional map shows the economic potential expressed in US dollars per square meter based on figures on the gross regional domestic product (GDP) for El Salvador, Guatemala, and Nicaragua.

Map Purpose with Respect to Disaster Risk Management

This map serves as an indicator map for the spatially varying economic potential of the countries. It thereby visualizes the spatially varying vulnerability of the economy of being affected by possible natural disaster. This map is required for further analysis in order to derive the economic risk exposure (see page 88*f*).

Data Source and Availability

The map and the underlying analysis is based on the following previous steps of data preparation and some additional data sources:

- The administrative boundaries (page 24), the land use data (page 26*ff*) and the categorization of land use classes into economic vulnerability groups (or 'economic land use', page 38);
- GDP statistics on national levels for 2008 (from the Statistical Yearbook 2009 of ECLAC, 2009), see appendix on page 102;
- A population based factor on Municipio level, calculated as the ratio of the population of each Municipio and the total population of the country (see also page 36). There are a total of 1044 Municipios in the project countries. By using that factor the GDP can be distributed (down-scaled) to Municipio level;
- A factor matrix depicting a proportion (1 = 100%) of how much of the GDP of each sector is distributed spatially to one more economic land use class (vulnerability group).

Vulnerability Group *	GDP Sector Code 1 **	GDP Sector Code 2	GDP Sector Code 3	GDP Sector Code 4	GDP Sector Code 5	GDP Sector Code 6	GDP Cector Code 7	GDP Sector Code 8	GDP Sector Code 9
1	0	1	1	0.96	0.92	1	0.7	1	1
2	0.25	0	0	0.01	0.02	0	0.1	0	0
3	0.25	0	0	0.01	0.02	0	0	0	0
4	0.25	0	0	0.01	0.02	0	0.1	0	0
5	0.25	0	0	0.01	0.02	0	0.1	0	0

* refer to page 37 for an explanation of these groups

** refer to page 102 for an explanation of the sectors

Remarks

The values in the table above are rather based on experience and common sense than on hard facts. However, they are considered to be sufficient as a first approach.

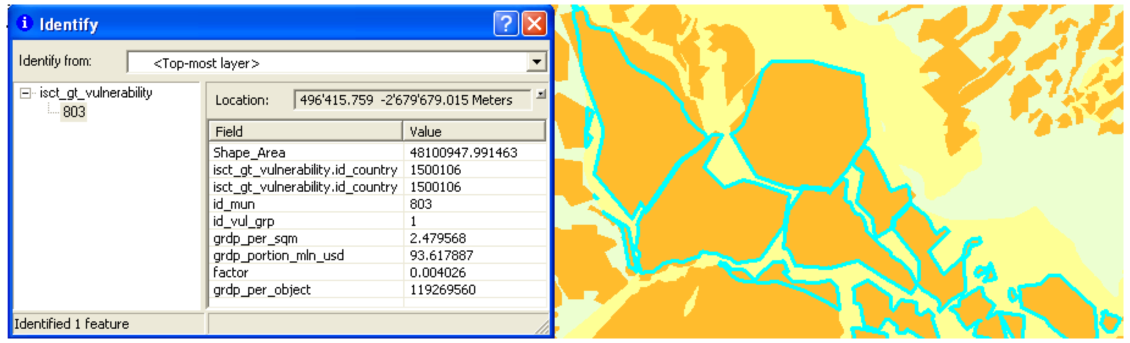
Using these figures for the risk analysis is a first approach to introduce economic aspects into a spatial risk assessment strategy. The GDP has been chosen because it allows to rather easily linking economic activity to spatial data. It is evident, other key economic data can be used too, as long as they reflect economic activity of a certain area.

Methodology

The idea is to have a map and base data that show how the economic potential is spatially distributed in the Central American countries. To achieve this, one has to find out the proportion of total GDP that results from the economic activity on each piece of land. This is most elegantly expresses as the GDP in US dollars per square meter (US$/m²). The following steps need to be rendered:

- Intersecting administrative areas (see page 24) and economic land use (economic classification; page 38).

  After the intersection process, each individual geographic feature has information on three attributes: municipio, vulnerability group, and area size (in m²).
- Based upon these attributes, the previously calculated proportion of the GDP per Municipio can now further be disaggregated by using the factor matrix on the left. The figure below gives an example of the new spatial attributes resulting from the intersection and the related factors.



  The selected spatial object is outlined in blue and comprises of multiple parts. These parts all share the same set of attributes (Country, Municipio, and vulnerability group). The object has an area of 4 810 0947 m², belongs to vulnerability group 1 (industry/service), and is located in Municipio 803 in Guatemala (id_country: 1500106). The Municipio has a portion of 0.4026 percent of the overall GDP (derived from the same figure for the population), that portion of the GDP is 93.617 million US$, and comprises actually of 9 separate figures (not shown here). From that amount, in combination with the factor matrix (refer to the table on the left side) and the sector-specific GDP values (see page 37) the actual GDP or the object can be derived (119 269 560 US$), the final value of interest, the GDP per unit area (m²) is derived by dividing the object-specific value by the area size and results in 2.47 US$/m².

Note, that the calculations presented here are sensitive to the sum of the areas of land use classes. This may cause the following problem: if a particular land use class is over-represented due to miss-classifications (e.g. during the interpretation of remotely sensed satellite imagery), its US$/m² value will be low on a per-area basis. On the contrary, if the total area of a class is small (i.e. it is actually under-represented compared to the real situation), the economic activity per square meter will be over-estimated.

How to read this map

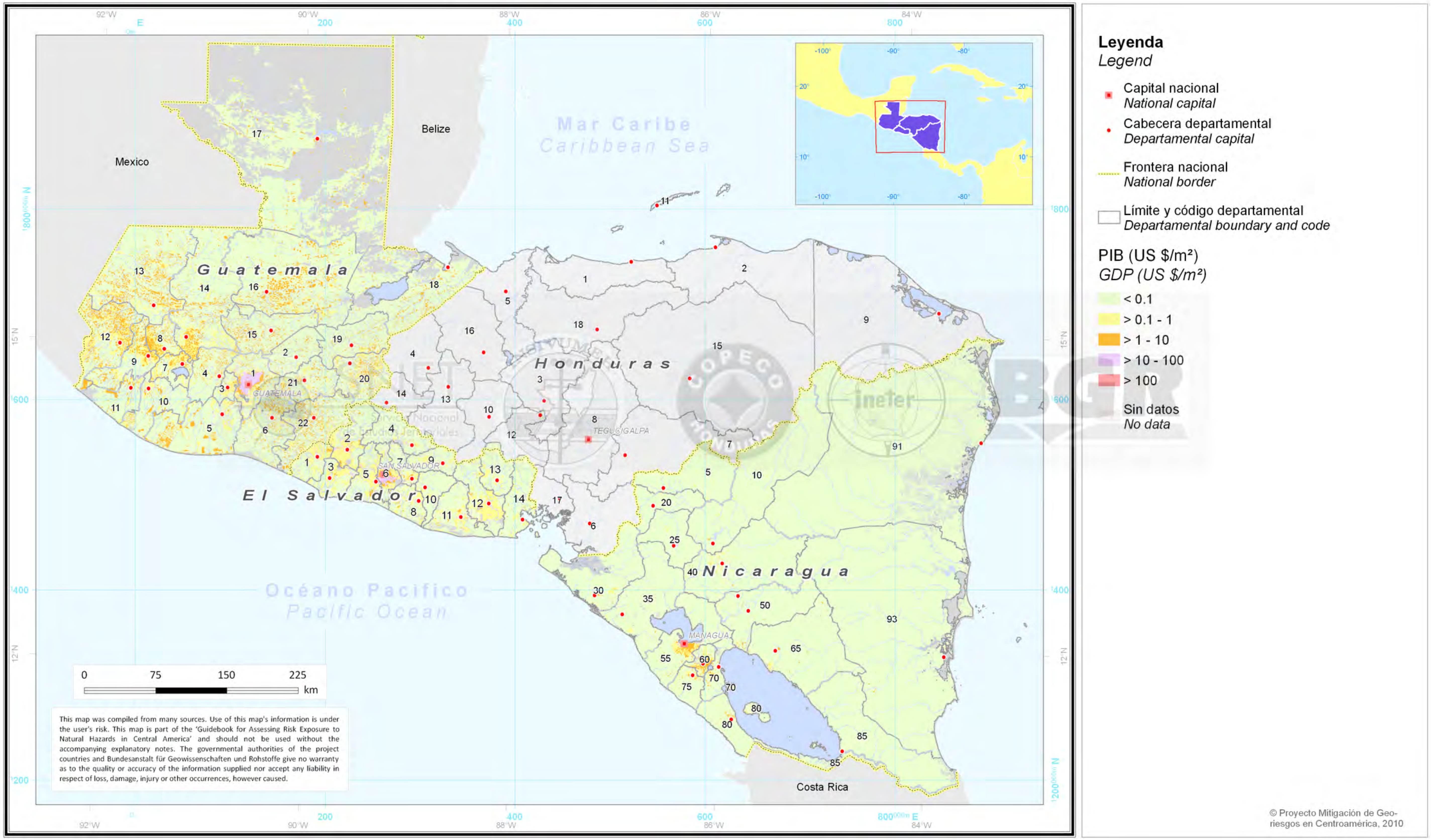
Economic potential is reflected by a spatially varying figure expressed as a weighted GDP/m². Weighting is derived by calculating a factor (on Municipio level) based on the ratio of population per Municipio in relation to the total population. Through this weighting process GDP figures that are given on a national level can be regionalized (down-scaled) to Municipio level. As expected the economic potential figures are high in the urban areas and lower in the rural areas dominated by agricultural activities.

Recommendations

The procedure shown above is an example how to produce spatial data on economic productivity derived from available ECLAC data. This method is based on several assumptions and figures obtained must be considered as rough approximation. For further improvement of these data, it might be advisable to develop a more robust appraisal, which is less sensitive to the area estimates.

Potencial Económico

Economic Potential



Health System Capacity: Example El Salvador

Map Contents

The national map shows for every Municipio in El Salvador how many people need to share one public health facility (hospital or out-patient facility).

Map Purpose with Respect to Disaster Risk Management

Coping with natural disasters requires a resilient public health system, particularly during and after a crisis to perform help in need. However, after a phase of response, public health system information is a significant parameter for assessing the capacity of a Municipio in terms of preparedness in the Disaster Risk Management cycle as well. The map allows decision makers to easily identify where spatial capacity improvements in the health sector are necessary and reasonable. Increasing the capacity in these Municipios would in turn diminish their vulnerability of being ill-prepared in case of harmful events due to the lack of public health facilities.

Data Source and Availability

Information used in this map was provided by the Ministerio de Salud Pública y Asistencia Social (MSPAS) representing the nationwide distribution of public hospitals and out-patient facilities in the year 2006. Additionally, to map the countrywide health care capacity at Municipio level demographic and administrative information is obligatory. All essential information to this topic has already been explained comprehensively on pages 24, 32, and 36.

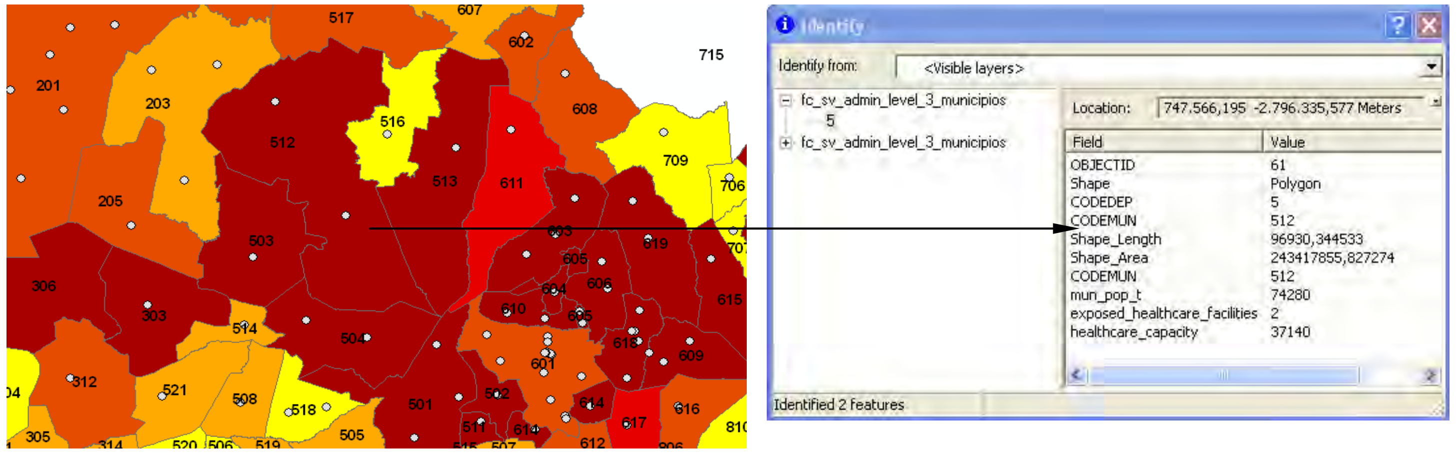
Remarks

According to the MSPAS data set, no further information than the type of public health care facility is provided. More detailed information, e.g. about the medical specification of the facility, the number of operating theatres, or the number of health professionals, is still missing.

Methodology

The map was generated by dividing the total number of people living in a Municipio by the number of public health facilities situated in this Municipio. Due to mathematical reasons, Municipios without any health care facility cannot be taken into account formally. In other words, a health care capacity does not exist.

Obviously, the accuracy of the public health system capacity map mainly depends on the number of public health facilities listed in the MSPAS dataset. The figure below is given to better understand the applied method. It shows an excerpt of the final public health capacity map overlain with the public health care facilities, which are represented by white dots. For example, Municipio San Juan Opico (administrative code: 512) has a total population of 74 280 inhabitants. According to the used MSPAS dataset (status: 2006) only two public health care facilities were reported for this Municipio. Thus, the resulting capacity to public health facilities can be expressed as 37 140 people per health care facility.



How to read this map

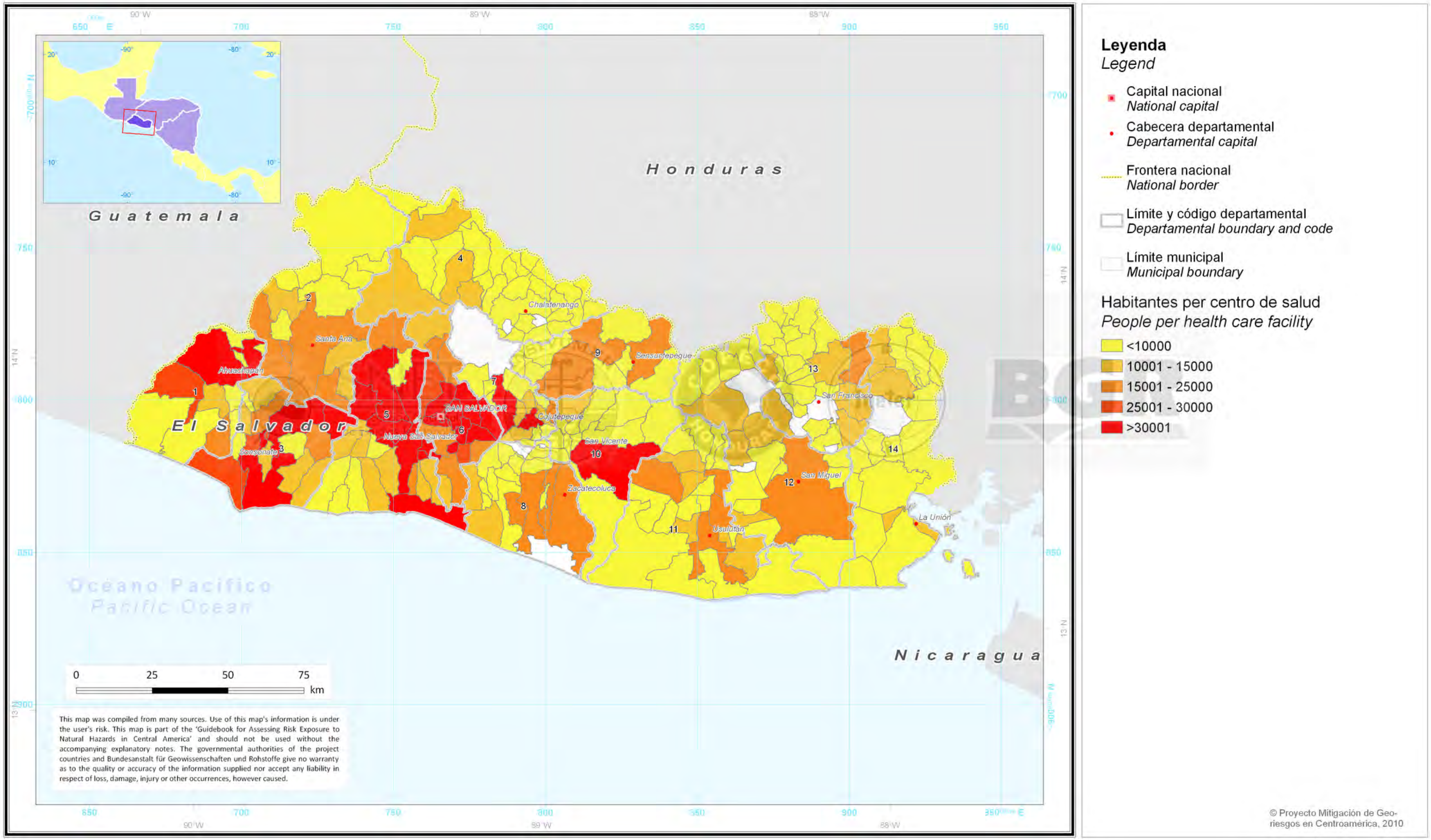
The transition from yellow to deep red colors indicates a trend from fewer to more people which have to share one public health care facility. It can be assumed that where more people have to share one health center, the likelihood of a rapid treatment is limited and longer travel time for the majority of people concerned is necessary to reach the health care facility. White colored Municipios have no capacity (see *Methodology*, left).

Recommendations

- Risk mapping needs authentic information about the capacity, even more for critical infrastructure elements. Therefore, data used for the assessment of the public health system capacity ought to be as current as possible in order to analyze the most real situation, and it also needs to be regularly updated. This is of highest importance for taking adequate preparedness measures;
- To improve the significance of nationwide health care capacity maps, the input data should be specified thematically whenever possible. This would allow a much more differentiated mapping of the capacity, and eventually also of the risk.

Capacidad del Sistema de Salud

Health System Capacity



Risk Exposure

Mapping risk exposure using CARA-GIS requires spatial and attributive information as comprehensively discussed in the previous chapters of this guidebook. Neither any auxiliary data were added, nor were any data hidden. Risk maps are just a professional form of representing the compiled *Baseline, Hazard (H), Vulnerability (V),* and/or *Capacity (C)* information suitable to answer a set of particular questions such as:

- Who or what is exposed to natural hazards?
- How is the exposure to natural hazards in one region distinguishable from the conditions in other regions?
- Which regions/areas have to be prioritized for mitigating disaster risks?
- How would the level of risk change if one could influence the input parameters, e.g. by reducing vulnerability?

There are multifaceted possibilities bringing together mentioned information in order to gain a resilient statement regarding the risk that the society, its population, its infrastructure or its economy is exposed to. Often, the coherence of this information is expressed in the equation Risk (R) = (H*V)/C. However, determining risk to geohazards is more than a scientific evaluation to be tackled by standardized operation procedures. Moreover, risk determination will always need a social and political perspective to decide what level of risk a society is willing to accept and to map out strategies to prioritize risks in case of facing more than only natural risk (e.g. technological).

All risk maps designed by CARA-GIS are exposure maps as they are based on susceptibility information. On these maps the elements at risk are 'counted' in the hazard/susceptibility zones. The risk exposure is represented by a color scheme, typically ranging from red (higher risk exposure) to yellow (lower risk exposure). Having a country-wide or supra-regional perspective in mind, the risk information is condensed to Municipio level. To keep the risk analysis simple at first, this guidebook focuses at examples of this type. The analyses presented below marks an initial step towards more detailed risk analyses, both, at national and supra-regional level that incorporate the temporal distribution of hazards (i.e. the probability of occurrence) and the related economic loss potential of events. Such efforts need to be supported by data collections currently not available. The principal order of the risk exposure maps offered hereinafter is in compliance with the following schema (see also appendix, page 102*f*):

- *Single-Hazard Approach:*
  - *Risk exposure at national level/ Vulnerability Indicator: Population (pages 68 and 70);*
  - *Risk exposure at national level/Vulnerability Indicator: Infrastructure (pages 74, 72, and 76);*
  - *Risk exposure at national level/Vulnerability Indicator: Healthcare Capacity (page 78);*
  - *Risk exposure at supra-regional level/Vulnerability Indicator: Population (page 80, and 82);*
  - *Risk exposure at supra-regional level/Vulnerability Indicator: Infrastructure (page 84, and 86);*
  - *Risk exposure at supra-regional level/Vulnerability Indicator: Economic potential (page 88).*
- *Multi-Hazard Approach:*
  - *Risk exposure at national level/Vulnerability Indicator: Infrastructure (page 90);*
  - *Risk exposure at supra-regional level/Vulnerability Indicator: Population (page 92);*
  - *Risk exposure at supra-regional level/Vulnerability Indicator: Infrastructure (page 94).*

As already mentioned, the national and supra-regional maps reflect only a small selection of scenario-based risk maps theoretically possible. The CARA concept allows the creation of new maps relatively fast by simply incorporating new input data available so far. Such an approach provides important perspectives, particularly for planning purposes. It can be used in order to develop scenarios based on changed population figures or to test 'what-if'-scenarios as a basis for cost-benefit comparisons (e.g. the costs for mitigation to reduce future disaster impact vs. the money saved that is otherwise spent for reconstruction and rehabilitation after a disaster occurred).

Single Hazard Approach: Population Exposed to Volcanic Hazard, Example Nicaragua

Map Contents

The map shows for each Municipio of Nicaragua the estimated number of people living in potential volcanic hazard (ash fall) zones.

Map Purpose with Respect to Disaster Risk Management

This form of representing population exposure to volcanic ash fall allows for easy comparison of the level of risk on Municipio level throughout Nicaragua. Regions at higher risk and areas where administrative entities could join forces to mitigate risks become evident.

Data Source and Availability

This map has been compiled by intersecting the volcanic hazard map (ash fall) on page 48*f* and the administrative areas (on page 24*f*). This intersection has been subsequently combined with the population figures described on page 36 and 60).

Remarks

This map is based on the one scenario presented in the hazard map on page 48*f*, more scenarios for possible eruptions exist but are not presented here.

The methodology described and utilized here and for the following maps is also applicable for future land use planning or population projections. It is thus very valuable for comparisons or 'what-if' scenarios.

Methodology

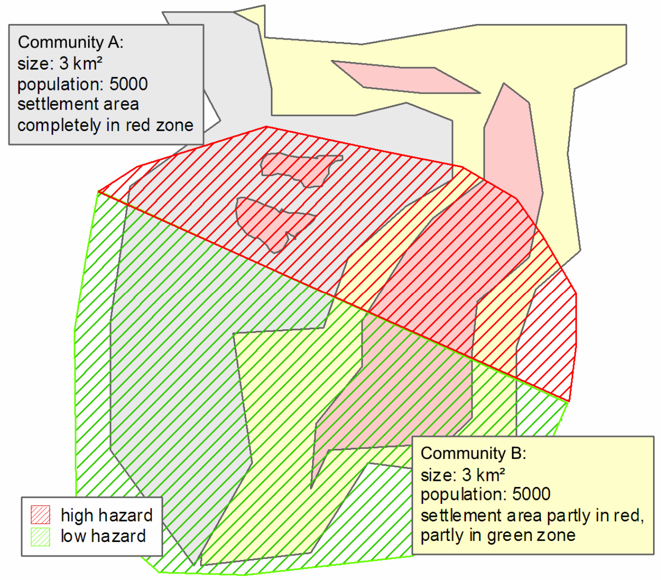
To estimate the number of people that are exposed in a particular hazard zone for each Municipio, two information are required:

- The modified population density of the Municipio, i.e. the population density based merely on the settlement area (see page 60);
- The size of the Municipio settlement area that is lying inside the particular hazard zone.

The inherent assumption made here, is that the population lives in the areas designated in the land use data set as residential and/or settlement areas. The modified population density (in people/km²) needs to be multiplied with the area size of the settlement area that overlaps with a particular hazard zone (in km²). The result is the number of people living in this zone, i.e. the number of people exposed to the particular hazard. This becomes more comprehensible by looking at the example on the right-hand side that has been used before for deriving the modified population density on page 60.

The entire settlement area (red polygons) of Community A (grey) lies within the high hazard zone, i.e. 0.3 km². Therefore the entire population of 5000 inhabitants lives in the high hazard zone. For Community B (yellow) only approximately half of the settlement area overlaps with the high hazard zone, i.e. about 0.6km ² (exact figures are given by the GIS). Therefore, 0.6 km² * 4167 p/km² = 2505 people are exposed to high hazard.

The next step is to assign risk levels to this information. In map representation this is done by using color codes, e.g. green (or no color) for no risk, yellow for moderate risk and red for high risk. However, it is up to the interpreter (or a decision of the representatives of community A and B) how the risk classes should be assigned.



This illustration is based on the figure from page 60 (Modified Population Density). Now, high and low hazard zones are added to the two model communities A and B with their settlements areas depicted as red polygons.

How to read this map

The intention of this map is to give a quick overview for decision makers on national or sub-national level about the risk exposure of the population in volcanic hazard (ash fall) zones.

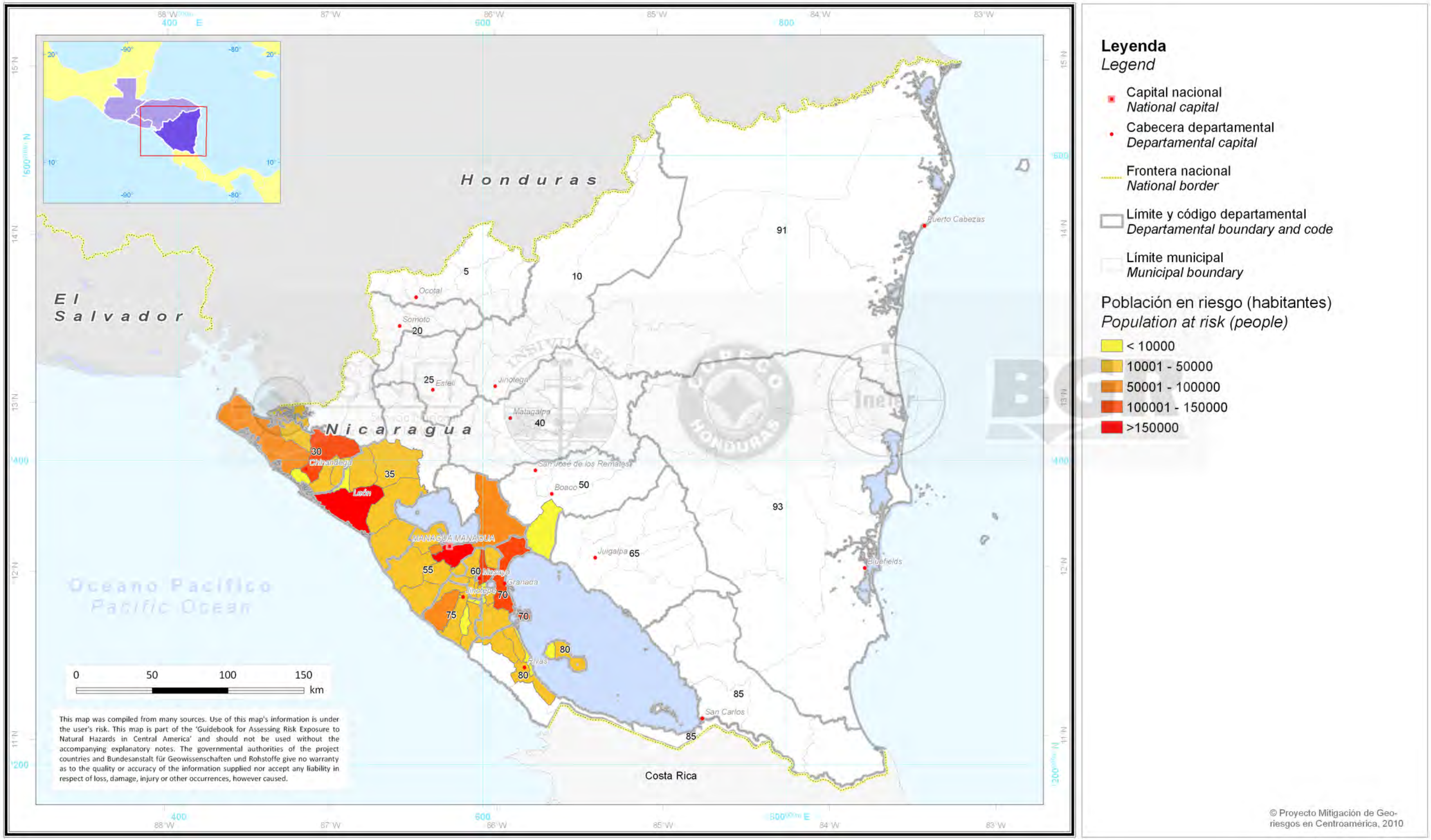
The classification used here runs from yellow (few people exposed) to red (many people exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. The complete and detailed results of this assessment can be accessed in the CARA-GIS database (see *Risk Exposure Mapping Tool: CARA-GIS,* page 17*ff*).

Recommendations

- Ash fall hazard creates certain types of risks to buildings and people. Heavy ash fall in combination with prolonged rainfall may lead to the collapse of roofs due to the accumulated weight. The map can therefore be used for more detailed capacity monitoring: in regions of increased risk it should be checked whether roofs are constructed according to recommended building codes, and whether sufficient shelter facilities for the people exist to protect them from the direct impact of hot ashes during the event of an eruption;
- The level of acceptable risk expressed in this map is reflected in the class width of the population exposure color code. This color code needs to be adjusted so that the maps and assessments reflect the level of acceptable risk agreed upon by society and in accordance with the development goals of the region's government.

Población Expuesta a Amenaza Volcánica (Caída de Ceniza)

Population Exposure to Volcanic Hazard (Ash Fall)



Single Hazard Approach: Population Exposed to Inundation Hazard, Example El Salvador

Map Contents

The national map shows for each Municipio of El Salvador the estimated number of people exposed to inundation hazard zones 'high' and 'very high'.

Map Purpose with Respect to Disaster Risk Management

This form of representing population exposure to inundation hazards allows for easy comparison of the level of risk on Municipio level throughout El Salvador. Regions at higher risk and areas where administrative entities could join forces to mitigate risks become evident.

Data Source and Availability

This map has been compiled by intersecting the inundation hazard map (on page 52*f*) and the administrative areas (on page 24*f*). This intersection has been subsequently combined with the population figures described on page 36 and 60).

Remarks

The methodology described here is also applicable for future land use planning or population projections. It is thus very valuable for comparisons or 'what-if' scenarios.

For additional inundation risk exposure analysis see page 74.

Methodology

To estimate the number of people that are exposed to the flood prone zone 'high' and 'very high' for each Municipio, two sets of information are required:

- The modified population density of the Municipio, i.e. the population density based merely on the settlement areas (see page 60);
- The size of the Municipio's settlement areas lying inside the flood prone zones 'high' and 'very high'.

The intrinsic assumption made here is that the population lives in the areas designated in the land use data set as residential and/or settlement areas. The modified population density (in people/km²) needs to be multiplied with the size of the settlement areas that overlaps within the flood prone zones 'high' or 'very high' (in km²). The result is the number of people living in these zones, i.e. the number of people exposed to the zones of 'high' or 'very high' inundation hazard (for more detailed information it is referred to the explanations regarding population exposure on page 68). The table below is an extract of the database analysis upon which the map is based on.

Code of Departamento	Code of Municipio	Name of Municipio	Number of People Exposed	Percentage within Municipio
...	...	...	...	...
4	<Null>	<Null>	<Null>	<Null>
4	432	SANTA RITA	523	8.7
4	433	TEJUTLA	2844	20.9
5	501	SANTA TECLA	2118	1.7
5	502	ANTIGUO CUSCATLAN	1926	5.7
5	<Null>	<Null>	<Null>	<Null>
5	503	CIUDAD ARCE	6930	11.5
5	<Null>	<Null>	<Null>	<Null>
...	...	...	...	...

How to read this map

The intention of this map is to give a quick overview for decision makers on national or sub-national level about the risk exposure of the population in inundation prone areas.

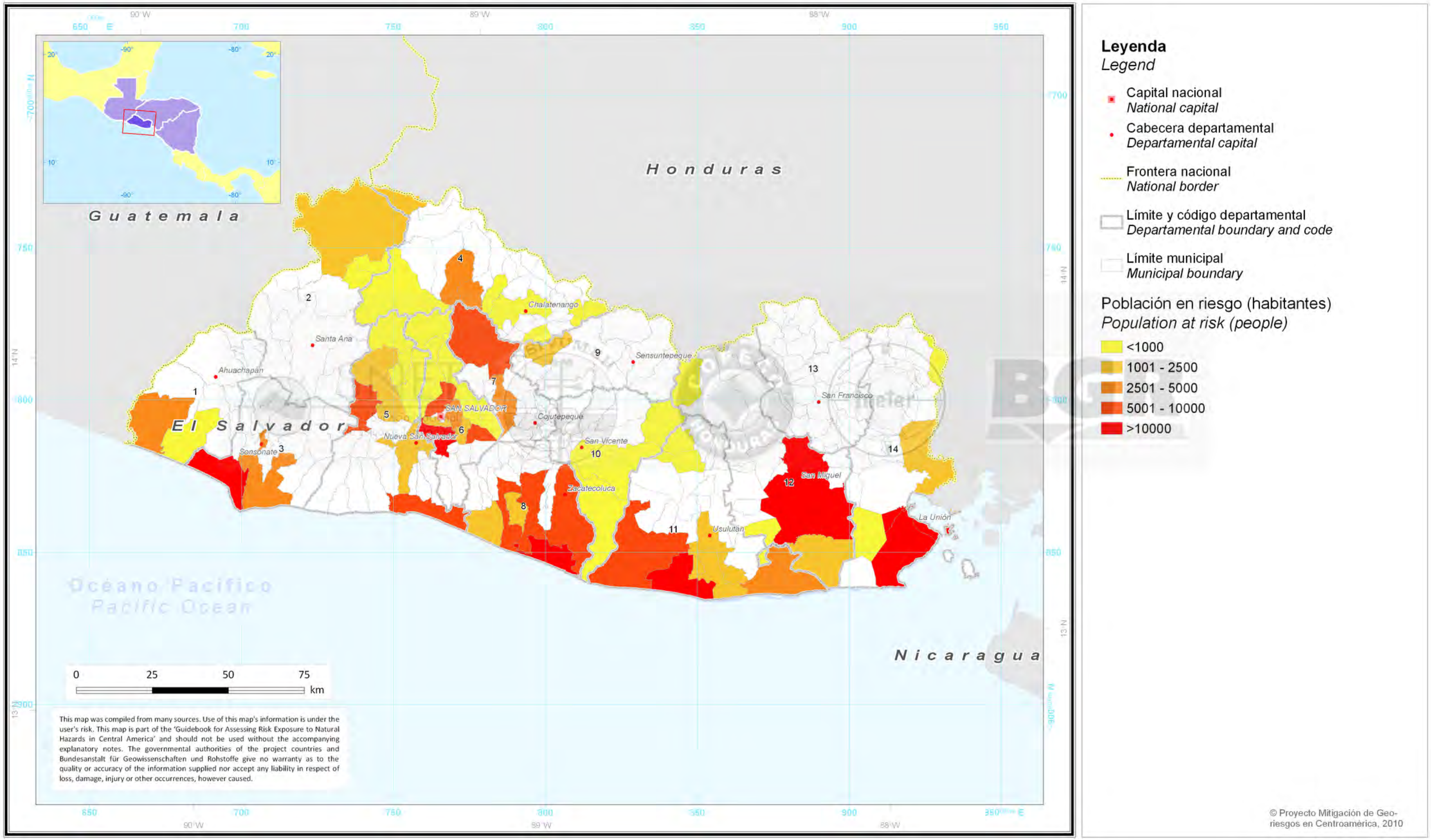
The classification used here runs from yellow (few people exposed) to red (many people exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed settlement areas exposed to the flood prone zones 'high' or 'very high' or the inundation hazard is not relevant, either (in the table above: value <NULL>). The complete and detailed results of this assessment can be accessed in the database (see *Risk Exposure Mapping Tool: CARA-GIS*, page 17*ff*).

Recommendations

This map is a national-scale analysis. That means that the restrictions caused by scale-related issues must be kept in mind.

Población Expuesta a Amenazas de Inundaciones

Population Exposure to Inundation Hazard



Single Hazard Approach: Infrastructure Exposed to Volcanic Hazard, Example Nicaragua

Map Contents

The national map shows for each Municipio of Nicaragua the sum of road kilometers exposed to the specific volcanic hazard scenario presented on page 48*f*.

Map Purpose with Respect to Disaster Risk Management

Risk assessments are not limited to studying how people are exposed to hazards. Infrastructure constitutes another 'element at risk' category. The knowledge about the locations of critical infrastructure as well as the amount of individual objects or their economic values at risk provide important information for planning purposes such as cost-benefit assessments (see also section on *Single Hazard Approach: Infrastructure, Case Study Loss Potential Assessment, Example Nicaragua*, page 76).

Ash fall events can create various problems, some local, and some regional, others even across continental areas.

In addition to that, road infrastructure plays an important role during and after a disaster crisis. During an immediate crisis they can serve as evacuation routes, after a crisis they are needed for access to affected areas and for the delivery of disaster relief supplies.

Data Source and Availability

The road data upon which this map is based on is described in more detail on page 32. Administrative boundaries were taken from the sources mentioned on page 24), volcanic hazard data are listed in the explanations on page 48).

Remarks

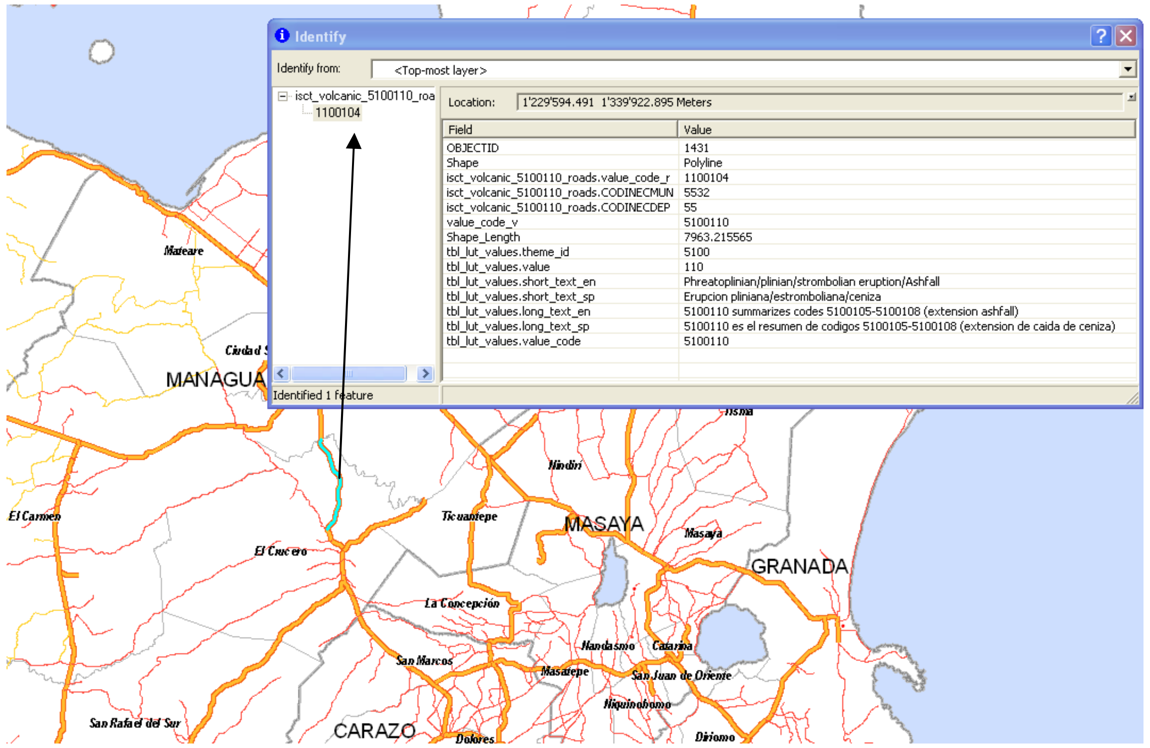
Altogether, there are roughly 5000 km of roads (all categories!) exposed to the ash fall scenario. Further improvement for this map could be achieved by qualifying the road data with more detailed attributes, such as the width of a road, or by specifying cost for construction.

Methodology

The map was derived by intersecting the data layers of the administrative boundaries (page 24), the road network of Nicaragua (partly visible in the map on page 32f) and ash fall hazard (page 42).

The map section in the figure below shows the base data from which the large map has been derived. Every road section is colored according to the type of road it represents.

An example is given in the GIS pop-up dialog: the section of a road marked in turquois runs through the volcanic hazard zone (CARA-GIS value_code: 5100110), has a total length of 7963.2 m and is designated as road type 1110104, which is a paved road, and it is located in Municipio 5532 (El Crucero, part of Departamento Managua). The length values are totaled up for the entire road network and in the map represented on Municipio level.



GIS map and pop-up dialog

How to read this map

The intention of this map is to give a quick overview for decision makers on national or regional level about the risk exposure of the road network to ash fall hazard.

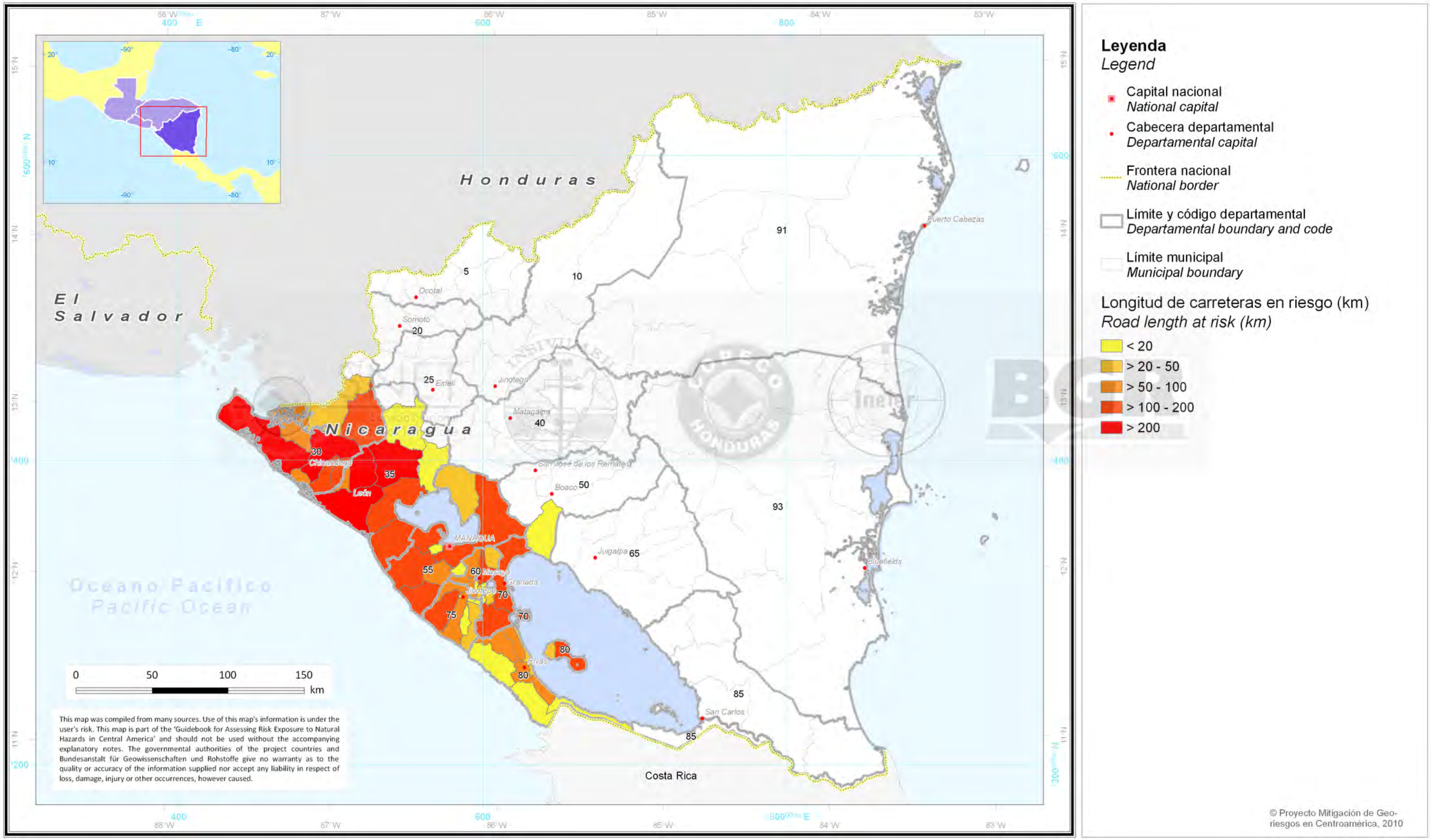
The classification used here runs from yellow (few kilometers exposed) to red (many kilometers exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. The complete and detailed results of this assessment can be accessed in the database (see section *Risk Exposure Mapping Tool: CARA-GIS,* page 17*ff*).

Recommendations

- Similar risk assessment can be done with additional infrastructure elements, such as power transmission lines, pipelines, railroad lines, etc.;
- The risk for the road infrastructure can easily be transferred to economic figures, if the average costs for building or reconstruction of roads are known. Thus, efforts to gather such data are recommended here;
- The level of acceptable risk expressed in this map is reflected in the class width of the road length exposure color code. This color code needs to be adjusted to reflect the level of acceptable risk agreed upon by society.

Longitud de Carreteras (km) Expuestas a Amenaza Volcánica (Caída de Ceniza)

Length of Roads (km) Exposed to Volcanic Hazard (Ash Fall)



Risk Exposure

Single Hazard Approach: Infrastructure Exposed to Inundation Hazard, Example El Salvador

Map Contents

The national map shows for each Municipio of El Salvador the sum of road kilometers exposed to 'high' and 'very high' inundation hazard zones.

Map Purpose with Respect to Disaster Risk Management

Risk assessments are not limited to studying how people are exposed to hazards. Infrastructure constitutes another 'element at risk' category. The knowledge about the locations of critical infrastructure as well as the amount of individual objects or their economic values at risk provide important information for planning purposes such as cost-benefit assessments (see also section on *Single Hazard Approach: Infrastructure, Case Study Loss Potential Assessment, Example Nicaragua*, page 76).

In addition to that, road infrastructure plays an important role during and after a disaster crisis. During an immediate crisis they can serve as evacuation routes, after a crisis they are needed for access to affected areas and for the delivery of disaster relief supplies.

Data Source and Availability

The road data upon which this map is based on is described in more detail on page 32. Administrative boundaries were taken from the sources mentioned on page 24, the inundation hazard map is explained on page 52.

Remarks

In total, there are almost 2 400 km of roads (all categories!) exposed to inundation hazards. Out of the 262 Municipios 107 are affected (ca. 40 %). The highest degree of potential affection is assessed for the Municipios of the coastal environment. Further improvement of this map could be achieved by qualifying the road data with more detailed attributes, such as the width of a road, or by specifying cost for construction.

Methodology

The map was derived by intersecting the data layers of the administrative boundaries (page 24), the road network of El Salvador (partly visible in the map on page 32*f*) and the categories 'high' and 'very high' of the inundation hazard map (page 42).

The intersection process is essentially the same as used for the infrastructure exposure assessment for volcanic hazards in Nicaragua, described in more detail on the previous pages.

The table below is an extract of the database analysis upon which the map is based on. Municipios with the value <NULL> don't have settlement areas exposed to flood prone areas.

Code of Departamento	Code of Municipio	Name of Municipio	Km of Roads Exposed
...	...	...	...
2	210	<Null>	<Null>
2	211	SANTA ROSA GUACHIPILIN	1
2	212	<Null>	<Null>
2	213	TEXISTEPEQUE	0
3	301	SONSONATE	59
3	302	ACAJUTLA	116
3	303	ARMENIA	2
3	304	<Null>	<Null>
3	305	CUISNAHUAT	0
3	306	<Null>	<Null>
...	...	...	...

How to read this map

The intention of this map is to give a quick overview for decision makers on national or sub-national level about the risk exposure of the road network to the inundation hazard zones 'high' and 'very high'.

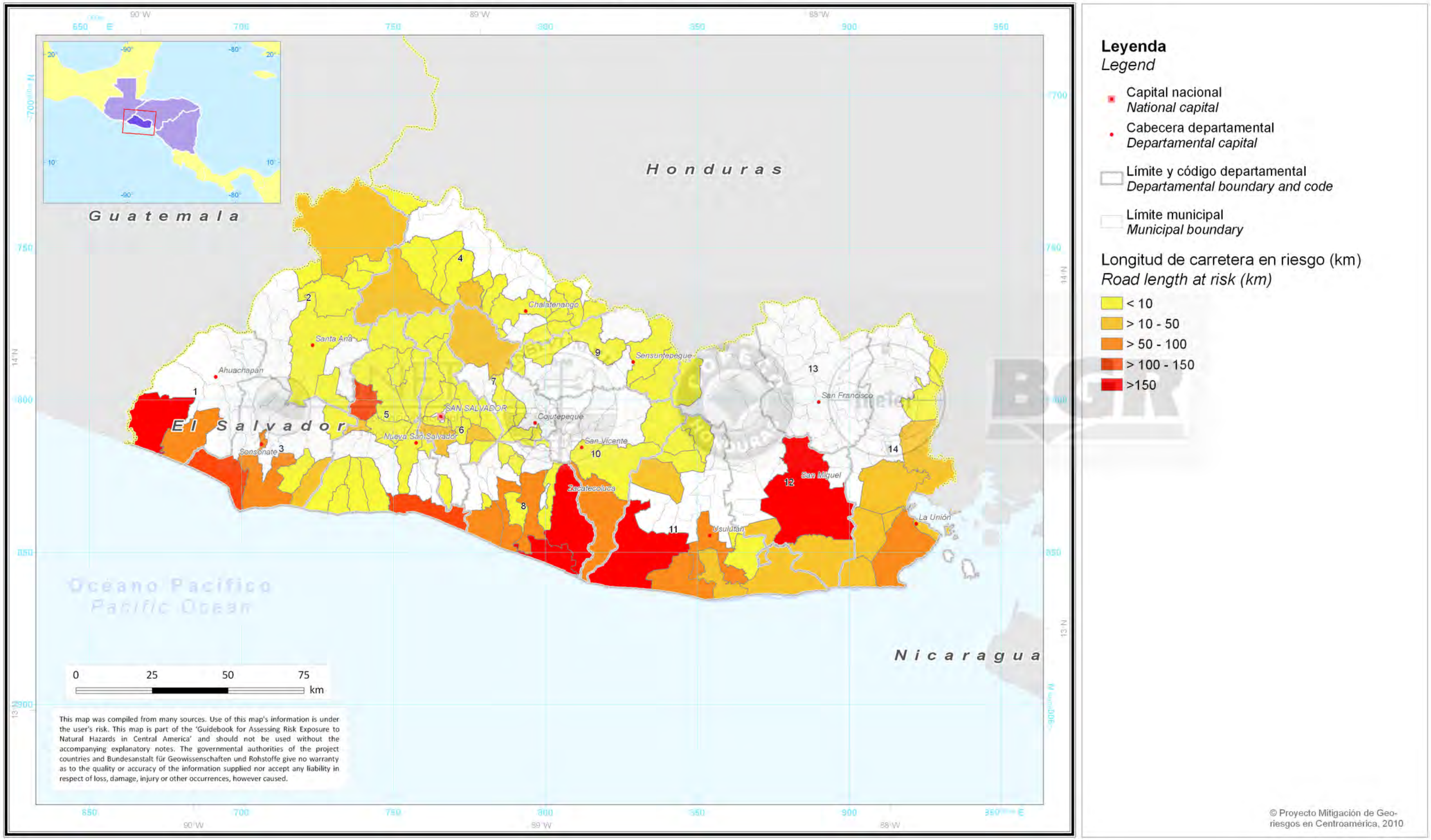
The classification used here runs from yellow (few kilometers exposed) to red (many kilometers exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed roads exposed to flood prone zones 'high' or 'very high' or the inundation hazard is not relevant, either. The complete and detailed results of this assessment can be accessed in the database (see *Risk Exposure Mapping Tool: CARA-GIS,* page 17*ff*).

Recommendations

- Similar recommendations as for the previous risk exposure map can be given;
- Particularly, for disaster preparedness it is recommended to use the underlying database for more detailed analysis of individual hotspots in critical regions. However, the quality of such analyses depends very much on the location quality and on updating and maintenance of the data.

Carreteras (km) Expuestas a Inundaciones (Amenaza Alta y Muy Alta)

Length of Roads (km) Exposed to High and Very High Inundation Hazard



This map was compiled from many sources. Use of this map's information is under the user's risk. This map is part of the 'Guidebook for Assessing Risk Exposure to Natural Hazards in Central America' and should not be used without the accompanying explanatory notes. The governmental authorities of the project countries and Bundesanstalt für Geowissenschaften und Rohstoffe give no warranty as to the quality or accuracy of the information supplied nor accept any liability in respect of loss, damage, injury or other occurrences, however caused.

Single Hazard Approach: Infrastructure, Case Study Loss Potential Assessment, Example Nicaragua

Map Contents

This national map shows the estimated major road (paved) assets exposed to 'high' or 'very high' landslide susceptibility in Nicaragua.

Map Purpose with Respect to Disaster Risk Management

Estimating the costs of infrastructure assets is an important step in any risk assessment study. While on local levels detailed figures for individual roads may be available, this becomes more difficult on broad-scale assessments on national, or even supra-regional scales. At these scales such estimations need either a systematic data collection or a comprehensive modeling approach.

Data Source and Availability

The road data upon which this map is based on is described in more detail on page 32 (part Nicaragua). Administrative boundaries were taken from the sources mentioned on page 24, the landslide susceptibility map is explained on page 50 (part Nicaragua).

The required cost appraisal is based on a recently completed (1/2008 until 2/2009) road project from Diriamba to La Boquita and Casares, respectively. The constructed road has a length of 32 km and according to governmental sources (www.mti.gob.ni/noticias190.html) included an investment of 185 million Nicaraguan Cordobas (NIO). A simple division yields a value of 5.78 million NIO per km of road (approximately 0.3 million US$).

Remarks

This map must be viewed as a first step towards infrastructure asset mapping. Altogether, roads approximately 'worth' 93.6 million US$ are exposed to 'high' and 'very high' landslide susceptibility. Refer to pages 62 and 88 for additional economic topics.

Methodology

The map was derived by intersecting the data layers of the administrative boundaries (page 24), the road network (constraint: paved road) of Nicaragua (partly visible in the map on page 32*f*) and the categories 'high' and 'very high' of the landslide susceptibility map (page 50*f*). The intersection process is described in more detail on page 72. Each km of paved road was then multiplied with the costs of construction and then totaled per Municipio.

The table on the right-hand side below is an extract of the database analysis upon which the map is based on. Municipios with the value <NULL> don't have any major roads exposed to high or very high landslide susceptibility.

Code of Departamento	Code of Municipio	Name of Municipio	Km of Roads Exposed	Total Assets in NIO	Total assets in US$
10	<Null>	<Null>	<Null>	<Null>	<Null>
10	1035	Jinotega	18	104	5.39
20	<Null>	<Null>	<Null>	<Null>	<Null>
20	2010	Totogalpa	1	8	0.4
20	<Null>	<Null>	<Null>	<Null>	<Null>
20	<Null>	<Null>	<Null>	<Null>	<Null>
20	2025	Palacagüina	1	3	0.18
20	2030	Yalagüina	0	3	0.14
20	2035	San Lucas	3	17	0.87

How to read this map

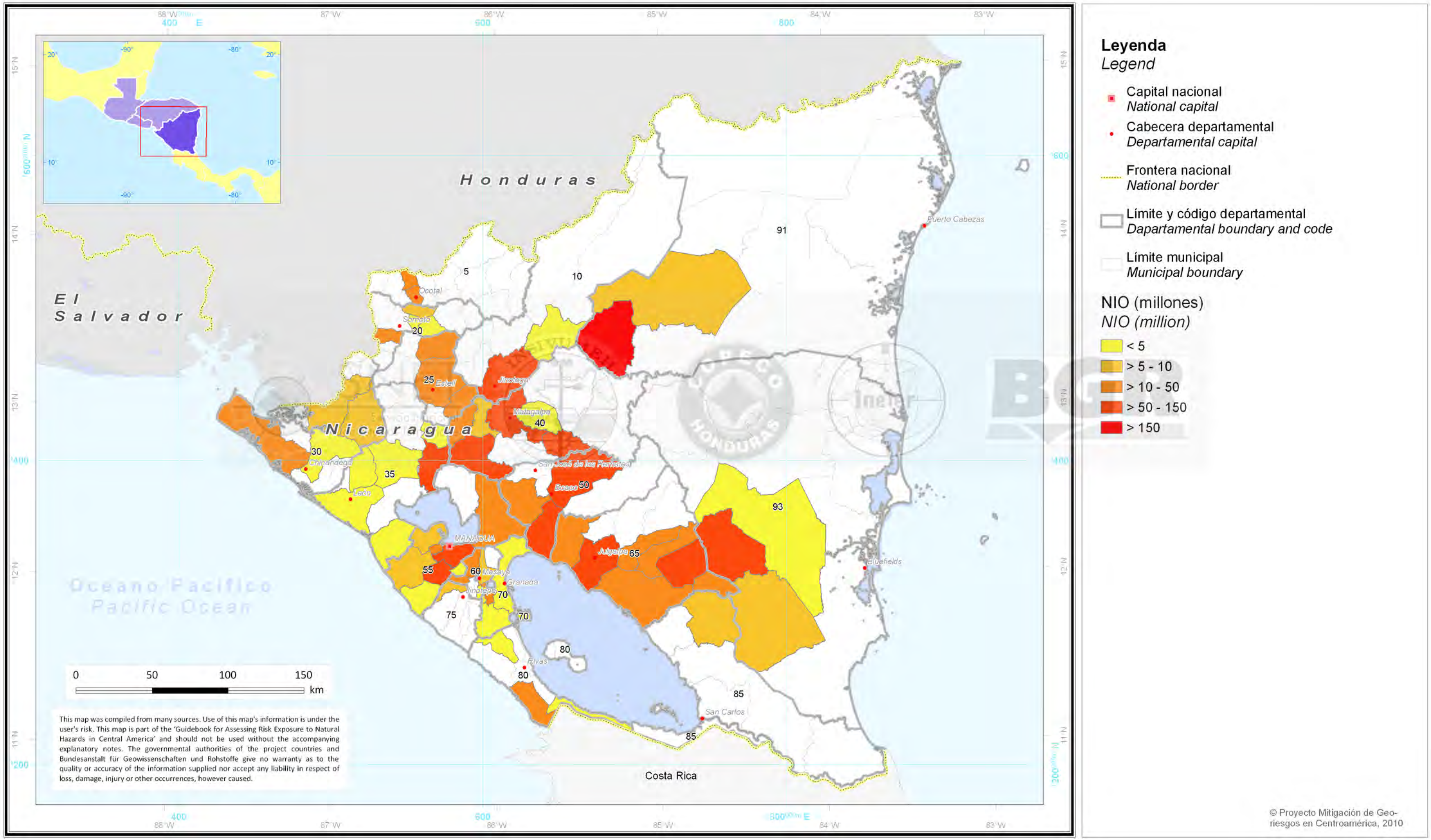
The intention of this map is to give a quick overview for decision makers on national level about the risk exposure of the road network to landslide hazard. The classification used here runs from yellow (few exposed) to red (many people exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed roads exposed to 'high' and 'very high' landslide prone areas or the landslide hazard is not relevant, either. Consequently, there is no road asset exposed to this hazard. The complete and detailed results of this assessment can be accessed in the database (see *Risk Exposure Mapping Tool: CARA-GIS*, page 17*ff*).

Recommendations

Due to the fact, that this map is based on limited data on cost estimates, the results presented here must be viewed as very preliminary. The intention is to sensitize those dealing with georisks for cost related issues. It is recommended performing comparable studies based on more resilient information on road construction and maintenance costs.

Caso de Estudio: Patrimonio de Carreteras Principales Expuestas a Deslizamientos (Susceptibilidad Alta - Muy Alta)

Case Study: Major Road Assets Exposed to High and Very High Landslide Susceptibility



Single Hazard Approach: Healthcare Facilities Exposed to Landslide Hazard, Example El Salvador

Map Contents

The national map shows the number of public health care facilities for every Municipio in El Salvador situated in zones of 'high' or 'very high' landslide susceptibility.

Map Purpose with Respect to Disaster Risk Management

This form of representing health care facility exposure to landslide susceptibility allows for easy comparison of the degree of risk exposure on Municipio level throughout El Salvador. Individual Municipios at higher risk and larger areas where administrative entities could join forces to mitigate risks become evident. Thus, this map should provide motivation to decision makers to scrutinize and to re-evaluate existing mitigation measures to healthcare facilities in landslide prone areas.

Data Source and Availability

This map has been compiled by intersecting the landslide susceptibility information (page 50) and the administrative areas (on page 24*f*). Subsequently, the intermediate outcome has been related to the spatial distribution the healthcare facilities as described on page 64.

Remarks

By provision of spatial related health care facility information for the respective Central American country, comparable national CARA risk exposure maps and after all, a supra-regional map can be created straightforwardly.

Methodology

To be able to determine for each Municipio the number of healthcare facilities that are exposed to 'high' and 'very high' landslide susceptibility zones, two sets of information are essential:

- The proportionate areas of a Municipio lying inside the landslide susceptibility zones 'high' and 'very high';
- The spatial distribution of healthcare facilities per Municipio (see page 64).

The assumption made here, is to count the number of healthcare facilities at Municipio level situated in zones of 'high' or 'very high' landslide susceptibility. From a total of 262 Municipios, 129 have been surveyed fulfilling these constraints. In other words, 129 Municipios have at least one healthcare facility situated in a landslide susceptibility zone 'high' or 'very high'. It is obvious, the probability for a health care facility to be hit by a landslide is higher in those Municipios where the density of health care facilities is much higher in comparison to that one with only a few facilities (see examples in the table: only Municipios having a number of facilities > 5 are listed).

Municipio	Number of Healthcare Facilities (All) per Municipio	Number of Healthcare Facilities per Municipio Exposed to 'High/Very High' Landslide Susceptibility Zones
San Salvador	15	6
San Miguel	11	3
Santa Ana	10	2
Conchagua	7	2
Metapan	6	2
San Francisco Menendez	*6*	*0 (white colored)*
Jiquilisco	*6*	*0 (white colored)*

How to read this map

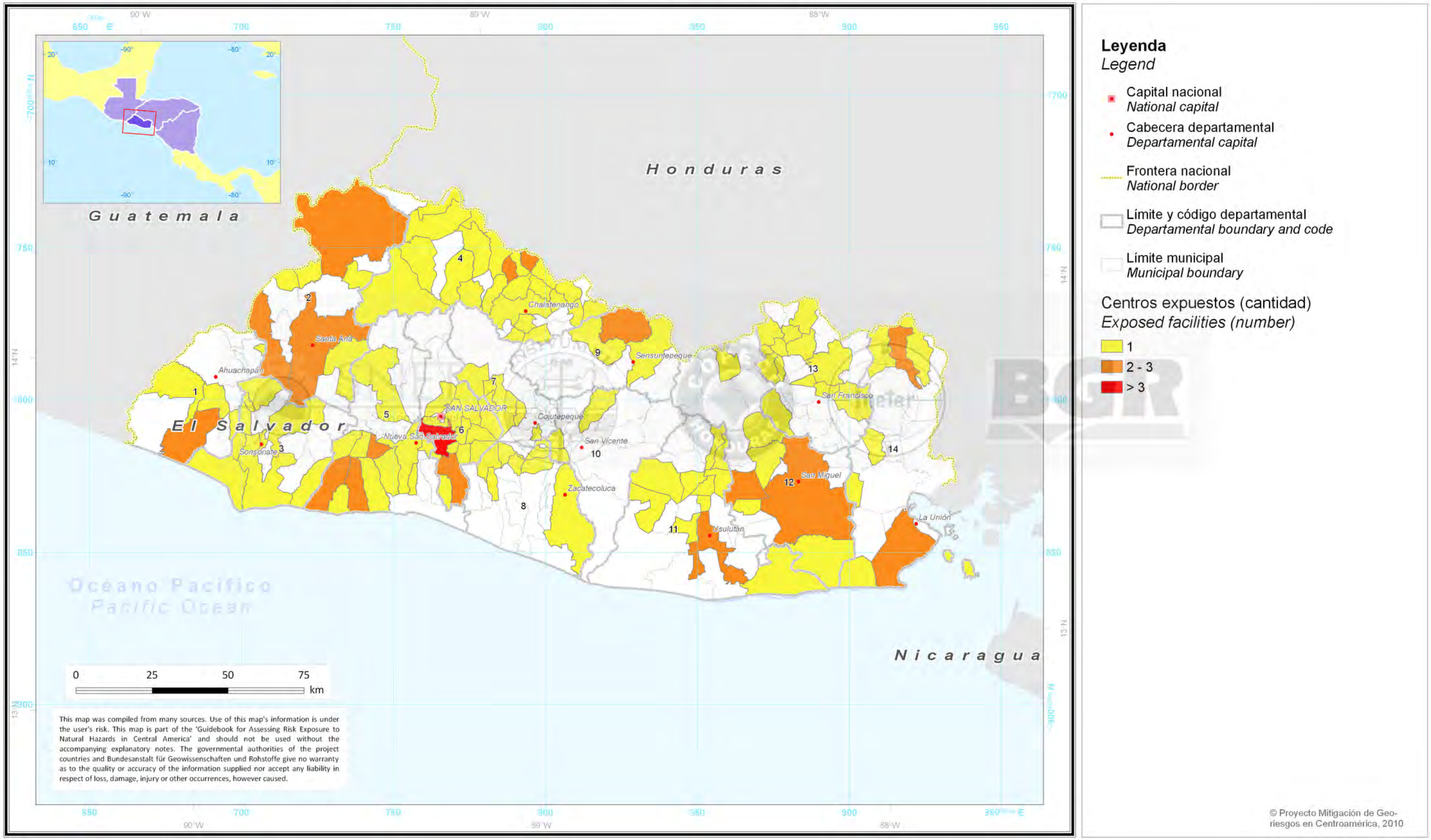
The objective of this map is to give a quick synopsis for decision makers on national and sub-national level about the risk exposure of health care facilities in landslide prone areas ('high'/'very high' susceptibility). The classification used here runs from yellow (one facility is exposed) to red (more than three facilities are exposed). White colored Municipios (see also the examples Municipios *Jiquilisco* and *San Francisco Menendez* in the table above) don't have surveyed healthcare facilities exposed to 'high' and 'very high' landslide prone areas or the landslide hazard is not relevant. The complete and detailed findings of this assessment can be accessed in the CARA-GIS geodatabase (see page 17*ff*).

Recommendations

- In regions where more detailed maps are available, it is recommended to carry out this analysis with those maps. Please consult the responsible authorities for the availability of individual maps;
- It is recommended to update and to enhance health facility information as often as possible;
- According to the relevance of this specific national risk exposure maps it is advised to re-evaluate the landslide susceptibility map in case of having access to improved input data, e.g. a high-resolution DEM based on LIDAR.

Centros de Atención Médica Expuestos a Susceptibilidad por Deslizamientos (Alta-Muy Alta)

Healthcare Facilities Exposed to Landslide Susceptibility (High - Very High)



Single Hazard Approach: Population Exposed to Landslide Hazard, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American countries the estimated number of people exposed to 'high' or 'very high' landslide susceptibility.

Map Purpose with Respect to Disaster Risk Management

This form of representing population exposure to landslide prone areas allows for easy comparison of the level of risk on Municipio level throughout the countries. Regions at higher risk and areas where administrative entities, perhaps even across national borders, could join forces to mitigate risks become evident.

Data Source and Availability

This map has been compiled by intersecting the landslide susceptibility map (page 50) and the administrative areas (on page 24*f*). This intersection has been subsequently combined with the population figures described on page 36 and 60.

Remarks

The methodology described here is also applicable for future land use planning or population projections. It is thus very valuable for comparisons or 'what-if' scenarios. The total sum of people exposed to 'high' or 'very high' landslide susceptibility is slightly above 3.4 Million (not counting Honduras!). There is a certain bias in the data, which is also visible in the map. The values for Guatemala tend to be higher when compared to the rest. A possible explanation could be that the Guatemala land use map shows a much higher area portion for settlement use than the other countries.

Methodology

To be able to estimate the number of people per Municipio, that is exposed to 'high' and 'very high' landslide susceptibility zones, two sets of information are required:

- The modified population density of the Municipio, i.e. the population density based merely on the settlement area (see page 60);
- The space of the Municipio's settlement areas lying inside the landslide susceptibility zone 'high' or 'very high'.

The assumption made here, is that the population lives in the areas designated in the land use data set as residential and/or settlement areas. The modified population density (in people/km²) needs to be multiplied with the area size of the settlement area that overlaps within the 'high' and 'very high' landslide susceptibility zones (in km²). The result is the number of people living in zones of 'high' and 'very high' landslide susceptibility (for more detailed information it is referred to the explanations regarding population exposure on page 68.)

The table on the right is an extract of the database analysis upon which the map is based on. Municipios with the value <NULL> don't have settlement areas exposed to 'high' or 'very high' landslide susceptibility.

Country	Code of Departamento	Code of Municipio	Name of Municipio	People Exposed	Percentage of Municipio Population
El Salvador		....			
El Salvador	1	105	EL REFUGIO	196	2
El Salvador	1	106	<Null>	<Null>	<Null>
El Salvador	1	107	JUJUTLA	13135	46
El Salvador	1	108	SAN FRANCISCO MENENDEZ	3711	9
El Salvador	1	109	<Null>	<Null>	<Null>
El Salvador	1	110	SAN PEDRO PUXTLA	5385	69
El Salvador		...			
Guatemala		...			
Guatemala	11	1105	San Felipe	1275	11
Guatemala	11	1106	San Andres Villa Seca	19139	11
Guatemala	11	<Null>	<Null>	<Null>	<Null>
Guatemala	11	1108	Nuevo San Carlos	18497	11
Guatemala	11	1109	El Asintal	12198	11
Guatemala	12	1201	San Marcos	15298	12
Guatemala	12	1202	San Pedro Sacatepequez	4529	12
Guatemala		...			
Nicaragua		...			
Nicaragua	10	<Null>	<Null>	<Null>	<Null>
Nicaragua	10	1020	San Rafael del Norte	7748	43
Nicaragua	10	1025	San Sebastián de Yalí	15758	58
Nicaragua	10	<Null>	<Null>	<Null>	<Null>
Nicaragua	10	1035	Jinotega	28552	28
Nicaragua	20	2005	Somoto	2100	6
Nicaragua	20	2010	Totogalpa	3578	30
Nicaragua		...			

How to read this map

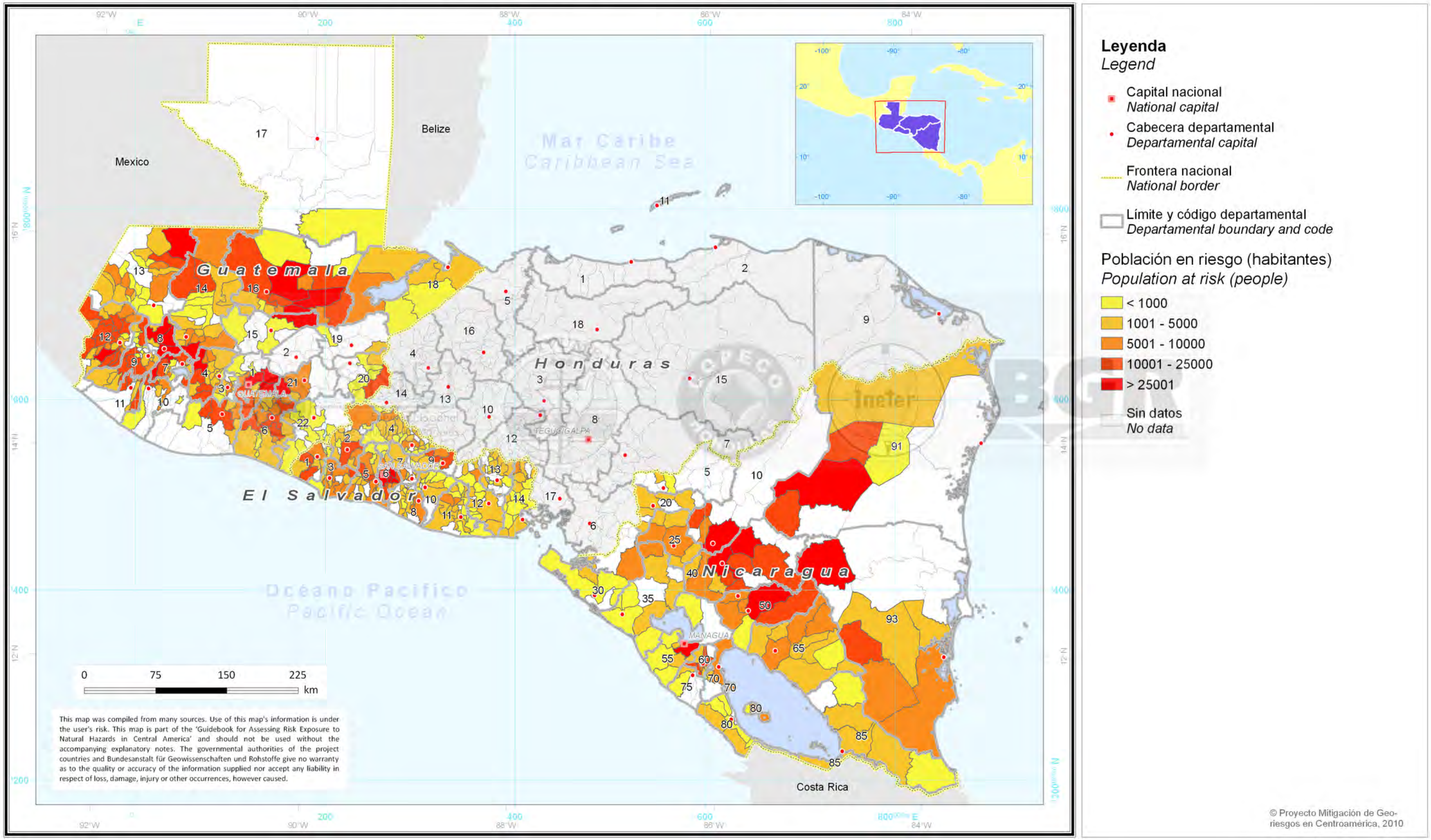
The intention of this map is to give a quick overview for decision makers on a supra-regional or national/sub-national level about the risk exposure of the population in landslide prone areas. The classification used here runs from yellow (few people exposed) to red (many people exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed settlement areas exposed to landslide susceptibility zones 'high' or 'very high' or the landslide hazard is not relevant, either. The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*).

Recommendations

- The level of acceptable risk expressed in this map is reflected in the class width of the population exposure color code. This color code needs to be adjusted so that the maps and assessments reflect the level of acceptable risk agreed upon by society and in accordance with the development goals of the regions government;
- In regions where more detailed maps are available, it is recommended to do this analysis with these maps. Please consult the responsible authorities for the availability of individual maps.

Población Expuesta a Deslizamientos (Susceptibilidad Alta - Muy Alta)

Population Exposure to High and Very High Landslide Susceptibility



Single Hazard Approach: Population Exposed to Seismic Hazard, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American countries the estimated number of people living in zones of 'medium - very high' earthquake (seismic) hazard.

Map Purpose with Respect to Disaster Risk Management

This form of representing population exposure to seismic hazards allows for easy comparison of the level of risk on Municipio level throughout Central America. Regions at higher risk and areas where administrative entities, perhaps even across national borders, could join forces to mitigate risks become evident.

Data Source and Availability

This map has been compiled by intersecting the seismic hazard map (on page 42*f*) and the administrative areas (on page 24*f*). This intersection has been subsequently combined with the population figures described on page 36 and 60).

Remarks

A total of at least 19 million people are exposed to 'medium - very high' seismic hazard zones. Bear in mind, Honduras cannot be evaluated due to the lack of appropriate land use data (see '*A special note to the land use data of Honduras and its impact for the guidebook*", page 28 for more details). All national capitals are situated inside these zones on which the analysis is based on, with the exception of Tegucigalpa/Honduras (for more details see section *Seismic Hazard*, page 42). A summary table on national level is given below:

Country	People Exposed	Portion of Total Population (%)
El Salvador	5 533 427	96
Guatemala	10 665 644	95
Nicaragua	2 644 479	51
Totals	18 843 550	85

These figures show very clearly the importance of disaster preparedness with respect to seismic hazards for the Central American countries.

Methodology

To estimate the number of people that are exposed in the 'medium - very high' seismic hazard zone (all pga-values > 300 gal, see chapter *Seismic Hazard, Supra-Regional* on page 42) for each Municipio, two sets of information are required:

- The modified population density of the Municipio, i.e. the population density based merely on the settlement area (see page 60);
- The size of the Municipio's settlement areas lying inside the 'medium - very high' seismic hazard zone.

The assumption made here, is that the population lives in the areas designated in the land use data set as residential and/or settlement areas. The modified population density (in people/km²) needs to be multiplied with the size of the settlement area that overlaps within the 'medium - very high' seismic hazard zone (in km²). The result is the number of people living in this zone, i.e. the number of people exposed to 'medium - very high' seismic hazard.

How to read this map

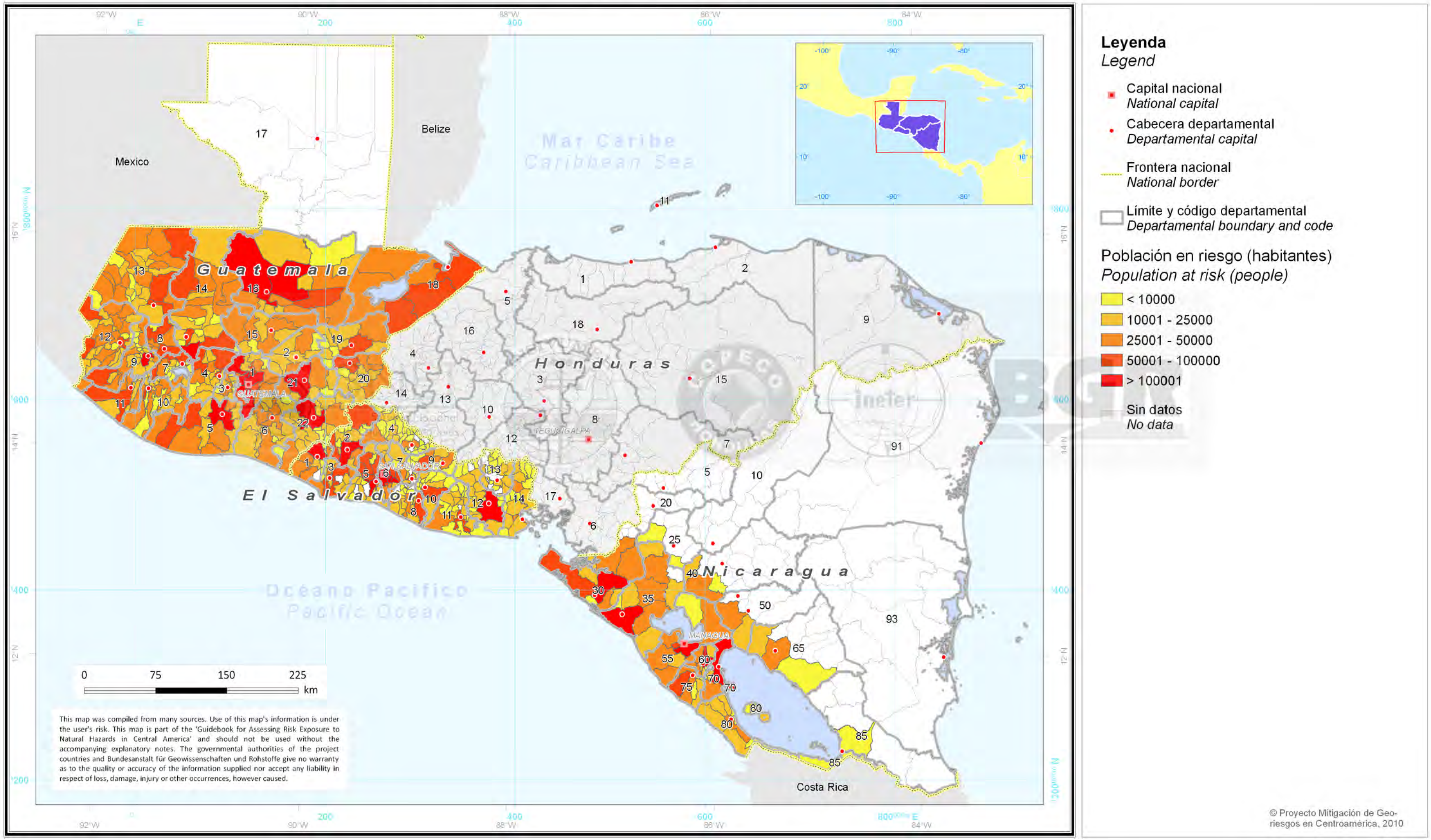
The intention of this map is to give a quick overview for decision makers on national or regional level about the risk exposure of the population in zones of very high seismic hazard. The classification used here runs from yellow (few people exposed) to red (many people exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of values obtained in the assessment. The complete and detailed results of this assessment can be accessed in the database (see *Risk Exposure Mapping Tool: CARA-GIS*, page 17*ff*). White colored Municipios don't have surveyed settlement areas exposed to the seismic hazard zones 'medium - very high' or are located outside the chosen seismic hazard constraint. This is the case for Nicaragua and El Salvador. Please refer to the explanations on these topics on pages 26, 28, and 30.

Recommendations

- Earthquake/seismic risks are directly linked to the resistance of structures and buildings to earthquake shaking and the potential of the subsurface for liquefaction. Detailed building ground suitability analysis cannot be done at national-scales, covering entire countries. However, the information obtained from seismic hazard and risk maps can be used to identify areas where in-depth monitoring of building ground condition need to be done for relevant construction or development projects. Building codes give standards for earthquake resistant structures based on the peak ground accelerations to be expected.
- The level of acceptable risk expressed in this map is reflected in the class width of the population exposure color code. This color code needs to be adjusted so that the maps and assessments reflect the level of acceptable risk agreed upon by society and in accordance with the development goals of the regions government.

Población Expuesta a la Amenaza Sísmica (Media - Muy Alta)

Population Exposure to Medium - Very High Seismic Hazard



Risk Exposure

Single Hazard Approach: Infrastructure Exposed to Landslide Hazard, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American countries the sum of road kilometers that are exposed to 'high' and 'very high' landslide susceptibility. Only major roads have been considered.

Map Purpose with Respect to Disaster Risk Management

Risk assessments are not limited to studying how people are exposed to hazards. Infrastructure constitutes another 'element at risk' category. The knowledge about the locations of critical infrastructure as well as the amount of individual objects or their economic values at risk provide important information for planning purposes such as cost-benefit assessments (see also section on *Single Hazard Approach: Infrastructure, Case Study Loss Potential Assessment, Example Nicaragua*, page 76).

Data Source and Availability

The road data upon which this map is based on are described in more detail on page 32. Administrative boundaries were taken from the sources mentioned on page 24), landslide susceptibility data are listed in the explanations on page 50.

Remarks

Altogether, there are more than 8 000 km of major roads in Central America currently situated in the 'high' and 'very high' landslide susceptibility zones.

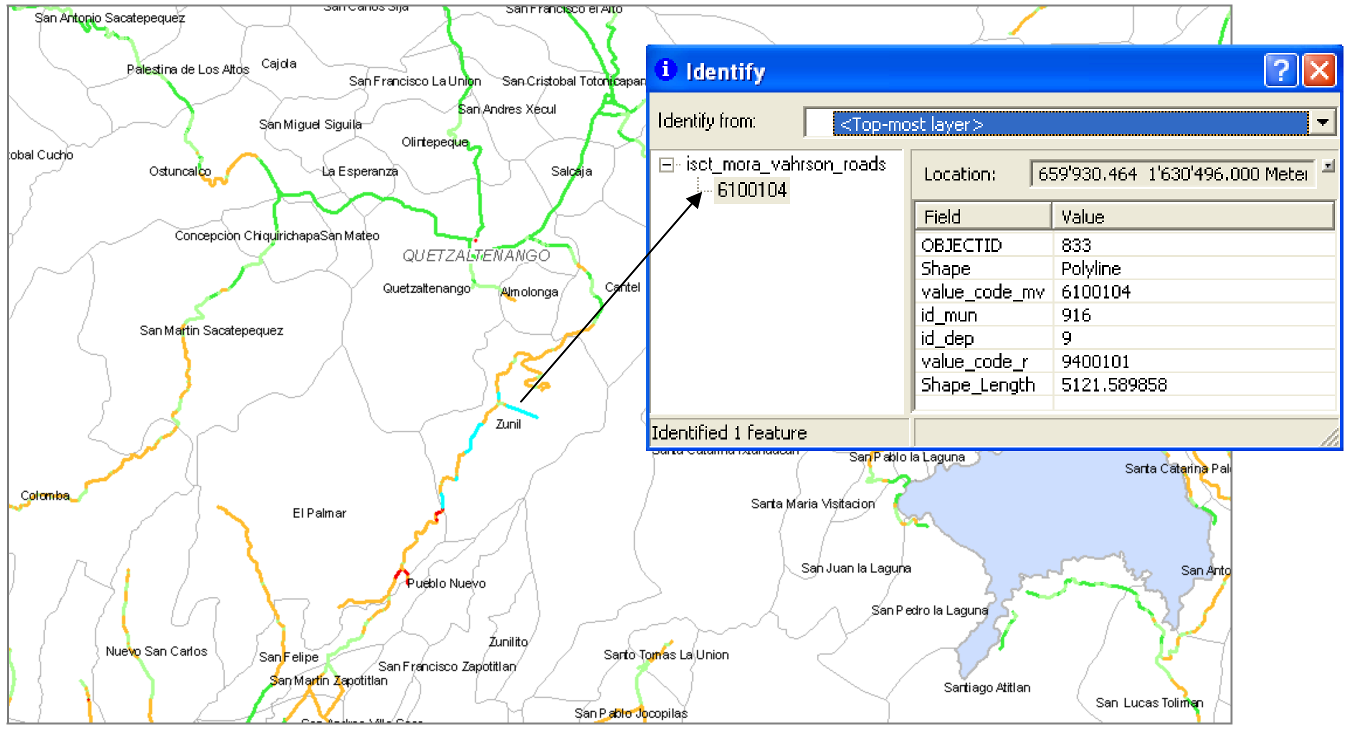
Country	Km of Roads Exposed
El Salvador	2 455
Guatemala	1 994
Honduras	669
Nicaragua	3 120
Total	8 238

Further improvement for this map could be achieved by qualifying the road data with more detailed attributes, such as the width of a road, or by specifying costs for construction.

Methodology

The map was derived by intersecting the data layers of the administrative boundaries (page 24), the road network of national and collector roads (page 28) and 'high' and 'very high' landslide susceptibility (page 50).

The map section below is taken from Guatemala and shows the base data from which the large map has been derived. Every road section is colored according to the landslide susceptibility zone it is passing through. An example is given in the GIS pop-up dialog: the section of a road marked in turquoise runs through a 'very high' landslide susceptibility zone (landslide code 6100104), has a total length of 5121.58 m and is designated as road type 9400101, which is a major road, and it is located in Municipio Zunil of Departemento Quetzaltenango. The length values are summed up for the entire road network and represented on Municipio level.



How to read this map

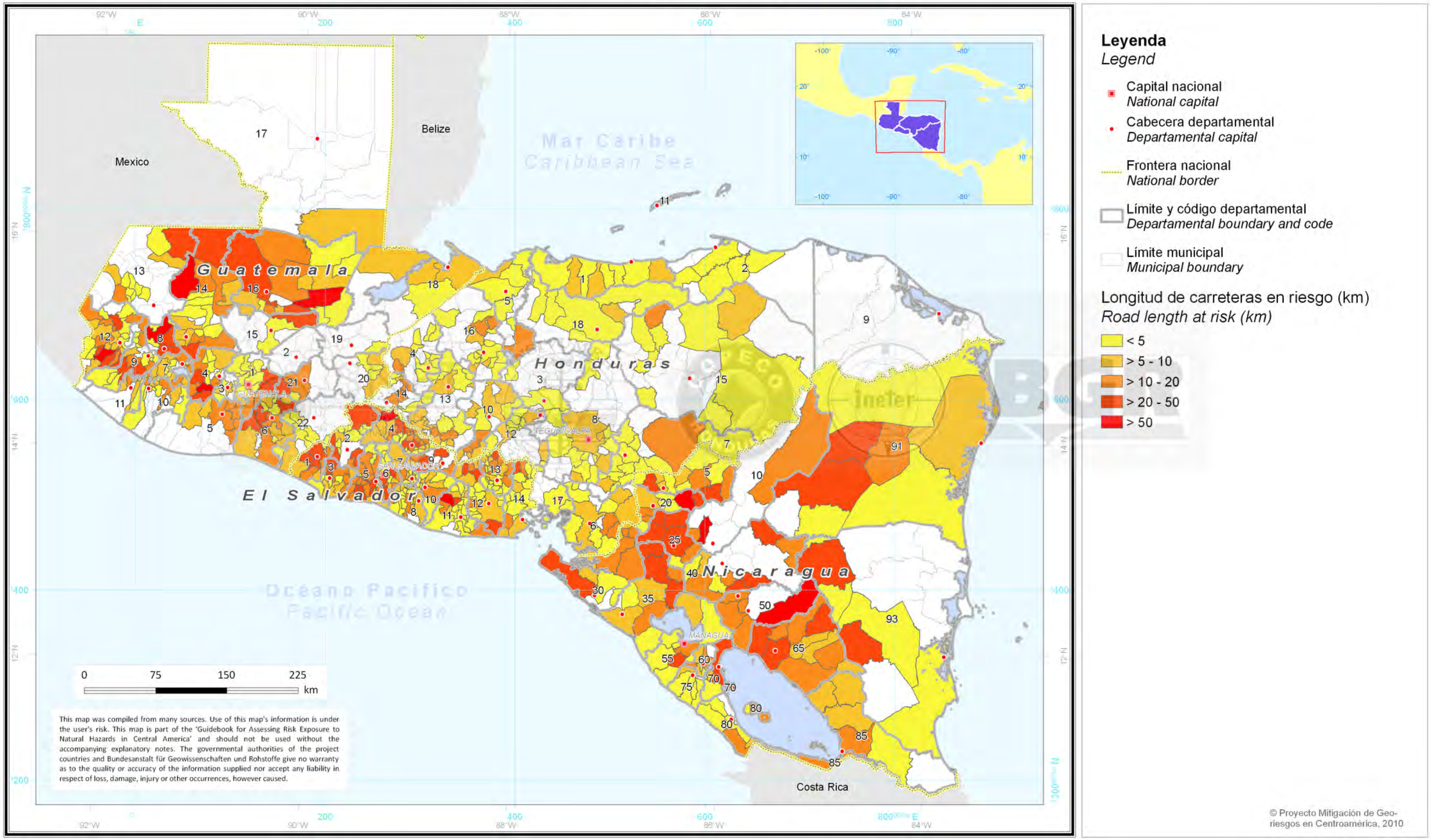
The intention of this map is to give a quick overview for decision makers on a supra-regional, national or sub-national level about the risk exposure of the road network to 'high' and 'very high' landslide susceptibility. The classification used here runs from yellow (few kilometers exposed) to red (many kilometers exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed roads exposed to 'high' and 'very high' landslide prone areas or the landslide hazard is not relevant, either. The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*).

Recommendations

- Similar risk assessment can be done with additional infrastructure elements, such as power transmission lines, pipelines, railroad lines, etc.;
- The risk for the infrastructure can easily be transferred to economic figures, if the average cost for buildings or reconstructing and maintenance of roads are known;
- The level of acceptable risk expressed in this map is reflected in the class width of the road length exposure color code. This color code needs to be adjusted to reflect the level of acceptable risk agreed upon by society.

Longitud Total de Carreteras Principales Expuestas a Deslizamientos (Susceptibilidad Alta - Muy Alta)

Total Length of Major Roads Exposed to High and Very High Landlide Susceptibility



Single Hazard Approach: Infrastructure Exposed to Seismic Hazard, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American countries the total length (kilometers) of roads that are exposed to 'medium - very high' seismic hazard. Only major roads have been considered.

Map Purpose with Respect to Disaster Risk Management

Risk assessment is not limited to study how many people are exposed to hazards. Infrastructure constitutes another 'element at risk' category. The knowledge about the locations of critical infrastructure as well as the amount of individual objects or their economic values at risk provide important information for planning purposes such as cost-benefit assessments (see page 76).

Data Source and Availability

The road data upon which this map is based on are described in more detail on page 32. Administrative boundaries were taken from the sources mentioned on page 24), details on the seismic hazard data are listed in the explanations on page 42.

Remarks

Altogether, almost 30 000 km of major roads are presently located in 'medium - very high' seismic hazard zones.

Country	Km of Roads Exposed
El Salvador	10 724
Guatemala	12 002
Honduras	1 423
Nicaragua	5 278
Total	29 427

These figures must be interpreted with care, because the underlying data are very inhomogeneous when compared between countries.

Methodology

The map was derived by intersecting the data layers of the administrative boundaries (page 24), the road network of national and collector roads (page 28) and the seismic hazard map (constraints: 'medium - very high' seismic hazard zones) (page 42).

For the details of the intersection process refer to the explanations of the previous map on landslide susceptibility exposure.

How to read this map

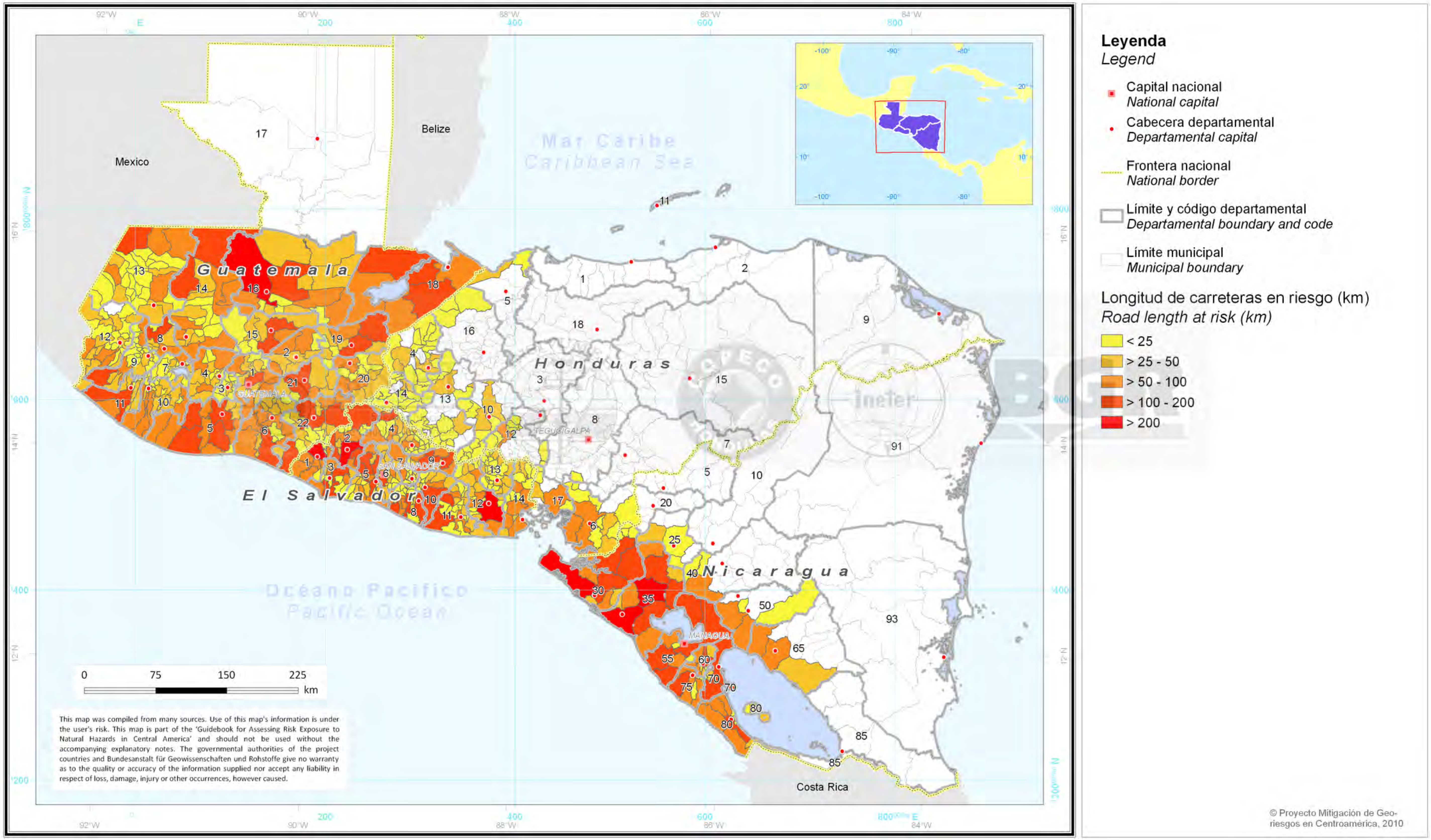
The intention of this map is to give a quick overview for decision makers on national or regional level about the risk exposure of the road network to 'medium – very high' seismic hazard zones. The classification used here runs from yellow (few kilometers exposed) to red (many kilometers exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed roads exposed to 'medium - very high' seismic hazard prone areas or the chosen seismic hazard is not relevant, either. The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*).

Recommendations

- Similar risk assessment can be done with additional infrastructure elements, such as power transmission lines, pipelines, railroad lines, etc.;
- The risk for the infrastructure can easily be transferred to economic figures, if the average cost for buildings or reconstructing and maintenance of roads are known;
- The level of acceptable risk expressed in this map is reflected in the class width of the road length exposure color code. This color code needs to be adjusted to reflect the level of acceptable risk agreed upon by society.

Longitud de Carreteras Principales Expuestas a la Amenaza Sísmica (Media - Muy Alta)

Total Length of Major Roads Exposed to Seismic Hazard (Medium - Very High)



Single Hazard Approach: Economic Potential Exposed to Landslide Susceptibility, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American the aggregated amount of the Gross Domestic Product (GDP) expressed in Mio US$ that is exposed to 'high' and 'very high' landslide susceptibility zones.

Map Purpose with Respect to Disaster Risk Management

Risk assessments are not limited evaluating on how many people are exposed to hazards. Economic potential constitutes another 'element at risk' category. Knowing about the areas where economic activities are potentially disrupted by hazards is an important part of the disaster risk management cycle. By comparing the Municipios or the Departamentos among each other, economic risk hotspots can be easily identified. Such a comparable data source can be a valuable tool for decision makers when it comes to allocate limited resources in a responsible way.

Data Source and Availability

The data used for the assessment of economic potential risk are entirely based on official statistics of ECLAC of the year 2008 (see pages 62 and the appendix on page 102) about the economic productivity of industrial and agricultural sectors.

Remarks

Evaluating economic risk exposure to natural hazards on these scales is a rather new approach in Central America. Up to now, there exist only few attempts to do this kind of economic assessments. The approach and the maps presented here have the intention to stimulate the discussion on how such maps can contribute to a harmonized regional assessment of the risks associated with natural hazards and on how this can improve economic development.

Country	GDP Exposed (in Million US$)
El Salvador	4 394
Guatemala	5 516
Honduras	Not evaluated
Nicaragua	996
Total	10 906

Methodology

The methodology to derive the figures of economic risk exposure is comparable to the method for estimating the figures for population risk exposure: consider the values shown on the economic potential map (page 62), given as GDP in US$ per m² to be a density value. The GDP of a particular area is then obtained by simply multiplying the size of the area with this density figure.

For the risk assessment presented here, this calculation is done only for the 'high' and 'very high' landslide hazard zones. The resulting value is a measure of relative economic potential risk expressed in US$ per Municipio. The procedure thus requires a spatial data set (i.e. a GIS layer) that holds the following three information:

- Administration codes (see page 24);
- Economic potential derived from land cover (see pages 38, 62, and 102);
- Landslide susceptibility (page 50).

How to read this map

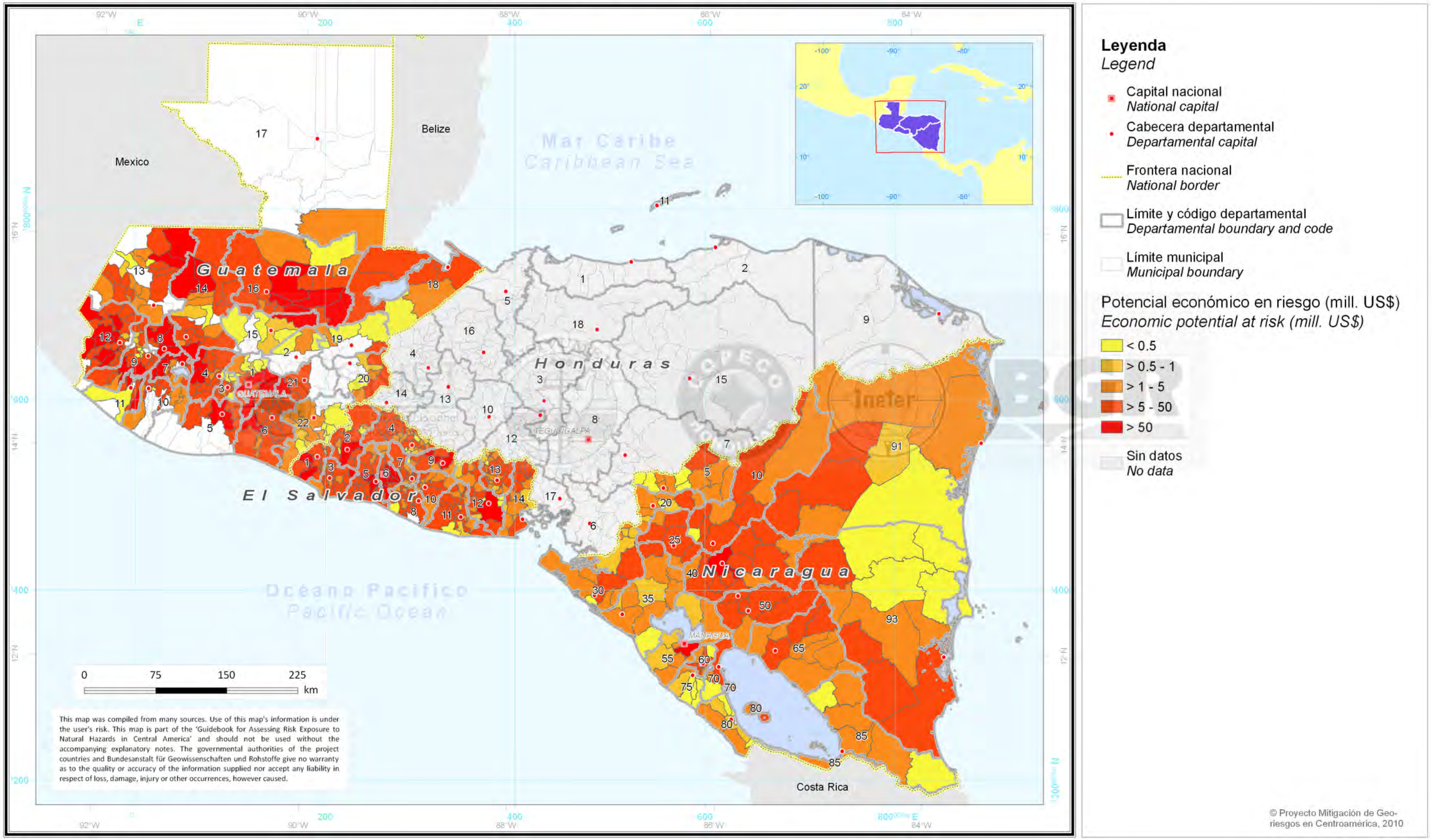
The intention of this map is to give a quick overview for decision makers on a supra-regional and national/sub-national level about the economic potential that is at risk due to exposure to 'high' and 'very high' landslide susceptibility. The map actually summarizes the total amount of GDP exposed to high and very high susceptibility for each Municipio. The classification used here runs from yellow (economic potential exposed is low) to red (economic potential exposed is high) expressed in million US$. The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment and to get a harmonized impression across national borders. White colored Municipios indicate that the chosen hazard ('high' and 'very high' landslide hazard) is not relevant, or in other words, the economic potential is not at risk. The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*).

Recommendations

- The map can be used as an overview map for strategic planning purposes. Those areas shown in red colors can be studied in-depth and possibly checked for possibilities of relocating or improving landslide prone structures or businesses;
- The level of acceptable risk expressed in this map is reflected in the class width of the exposure color code. This color code needs to be adjusted so that the maps and assessments reflect the level of acceptable risk agreed upon by society and in accordance with the development goals of the governments;
- The fact, that the figures in some countries are lower than in other countries does not necessarily mean that the risk exposure is lower in general. The figures must also be evaluated within the entire economic context.

Potencial Económico Amenazado por Deslizamientos (Susceptibilidad Alta y Muy Alta)

Economic Potential at Risk – High and Very High Landslide Susceptibility



Multi-Hazard Approach: Infrastructure Exposed to Seismic and Landslide Hazard, Example Guatemala

Map Contents

The national map shows for each Municipio of Guatemala the number of bridges exposed to 'medium - very high' seismic hazard zones, *AND* 'high' or 'very high' landslide susceptibility zones.

Map Purpose with Respect to Disaster Risk Management

Risk assessment is not only constrained to study the exposure of any vulnerability indicator to one specific hazard (single-hazard approach). In many cases, elements at risk, e.g. population, infrastructure, economic potential may be threatened by several hazards concurrently (multi-hazard approach).

For example, a mountain village is located in an earthquake prone area may also be hit by landslides, if one is triggered by an earthquake (see next risk exposure map). For Disaster Risk Management purposes risk exposure maps based on a multi-hazard approach are imperative to develop risk scenarios and to recognize the spatial distribution of multi-risk potentials.

The given example focuses on bridges that constitute an infrastructural 'element at risk' category. Bridges play an important role during and after a crisis related to natural disasters. Thus, the knowledge about the locations of critical infrastructure as well as the amount of individual objects or their economic values at risk provide important information for planning purposes.

Data Source and Availability

The data for bridge locations upon which this map is based on, was provided by INSIVUMEH. The dataset contains almost 700 records with information on the type of the building material. Administrative boundaries were taken from the sources mentioned on page 24, seismic hazard data are listed in the explanations on page 42, and landslide susceptibility data on page 50.

CARA-GT-GIS Value Code	Description *English Version*	Description *Spanish Version*
9410101	concrete	concreto
9410102	concrete and iron/steel	concreto y hierro
9410103	brickwork	mampostería
9410104	concrete and rock	concrete y losa
9410105	wood	madera
9410106	wood and steel	medera y acero/hierro
9410107	wood and concrete	madera y concreto
9410108	wood and brickwork	madera y mampostería
9410109	wood and rocks	madera y piedra
9410110	concrete and brickwork	concreto y mampostería
9410111	steel/iron	acero/hierro
9410112	suspension	hamaca
9410113	stone and steel	losa y hierro
9410114	steel and brickwork	hierro y mampostería
9410115	stone and brickwork	losa y mampostería
9410116	stone	losa
9410999	unknown	oscuro

Remarks

Currently, information on number, type and location of bridges do only exist for Guatemala.

Methodology

The map was derived by spatial intersection of the data layers of the administrative boundaries (page 24), the mentioned bridge location data of Guatemala, and the two mentioned hazard data layers. After the intersection process, the bridge location points can be evaluated as to the chosen hazard constraints mentioned before. Finally, the number of bridges fulfilling these constraints was totalized for each Municipio.

How to read this map

The intention of this map is to give a quick overview for decision makers on national and sub-national level about the risk exposure of the bridge infrastructure to 'medium - very high' seismic hazard zones *AND* 'high' or 'very high' landslide susceptibility zones. The classification used here runs from yellow (few bridges exposed) to red (many bridges exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. Only Municipios with bridges exposed simultaneously to both hazard types will be displayed because the underlying data analysis is based on an AND-function. In simple terms, it has been found the least common denominator. White colored Municipios don't have surveyed bridges exposed to the combined hazards noted earlier or the chosen hazards are not spatially relevant at the bridges sites, either.

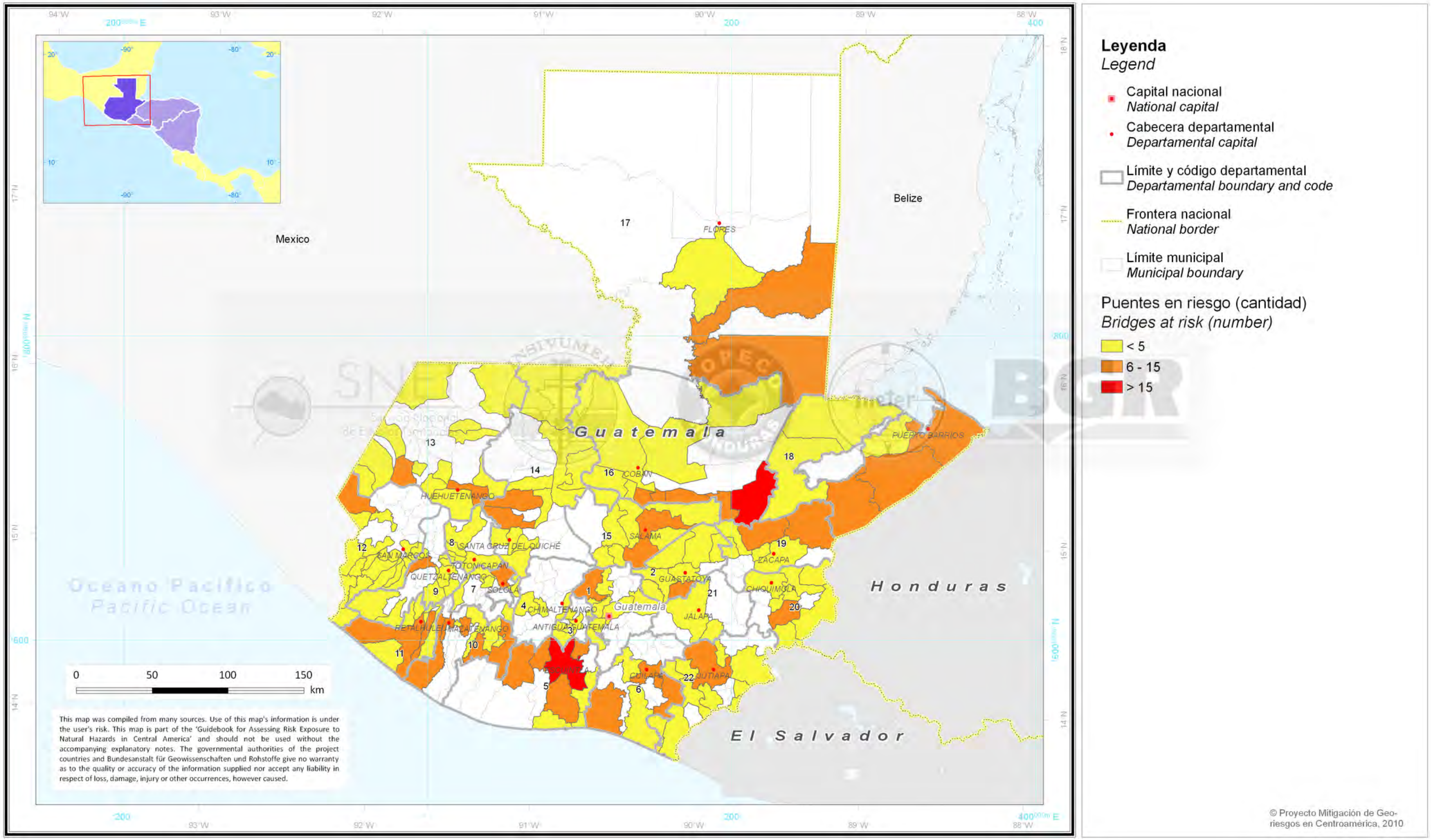
Although the map itself does not show the results separately for each type of bridge, the underlying database can of course be utilized to accomplish such queries. The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*).

Recommendations

- Similar risk assessment can be done with additional infrastructure elements, such as power transmission lines, pipelines, etc.;
- The risk for the infrastructure can easily be transferred to economic figures, if the average cost for building or reconstructing are known or can be estimated.

Puentes Expuestos a Amenaza Sísmica (Media-Muy Alta) y a Deslizamientos (Susceptibilidad Alta-Muy Alta)

Bridges Exposed to Seismic Hazard (Medium-Very High) and Landslide Susceptibility (High-Very High)



Risk Exposure

Multi-Hazard Approach: Population Exposed to Seismic and Landslide Hazard, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American countries the estimated number of people exposed to 'high' or 'very high' landslide susceptibility zones, AND 'medium - very high' seismic hazard zones.

Map Purpose with Respect to Disaster Risk Management

It is referred to the general notes on the previous page.

This form of representing population exposure to several hazards allows for easy comparison of the level of risk on Municipio level throughout the investigated Central American countries. Regions at higher risk and areas where administrative entities could join forces to mitigate risks become evident.

Data Source and Availability

This map has been compiled by intersecting the landslide susceptibility map (page 50), the seismic hazard map (page 42), and the administrative areas (page 24*f*). This intersection has been combined subsequently with the population figures described on page 36 and 60.

Remarks

The methodology described here is also applicable for future land use planning or population projections. It is thus very valuable for comparisons or 'what-if' scenarios.

Country	People Exposed	Portion of Total Population (%)
El Salvador	954 084	17
Guatemala	5 391 650	48
Honduras	no data	-
Nicaragua	178 795	3
Totals	6 524 529	29

These figures, based on the multi-hazard approach, show very clearly that considerable portions of the population are exposed to these two hazards. The relatively high values for Guatemala and the relatively low values for Nicaragua are the result of inhomogeneous land use data.

Honduras has not been evaluated because of the lack of appropriate land use data (see page 28 for more details).

Methodology

To estimate the number of people that are exposed to two particular hazard zones for each Municipio, two sets of information are required:

- The modified population density of the Municipios, i.e. the population density based merely on the settlement area (see page 60);
- The size of the Municipio settlement areas lying inside the two particular hazard zones: 'high' or 'very high' landslide susceptibility zones, AND 'medium - very high' seismic hazard zones.

The assumption made here is, that the population lives in the areas designated in the land use data set as residential and/or settlement areas. The modified population density (in people/km²) needs to be multiplied with the area size of the settlement area that overlaps within the above mentioned hazard zones (in km²). The result is the number of people living in these zones, i.e. the number of people exposed to the zones of 'high' or 'very high' landslide susceptibility, AND 'medium - very high' seismic hazard (for more detailed information refers to the explanations regarding population exposure to on page 68). The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*).

How to read this map

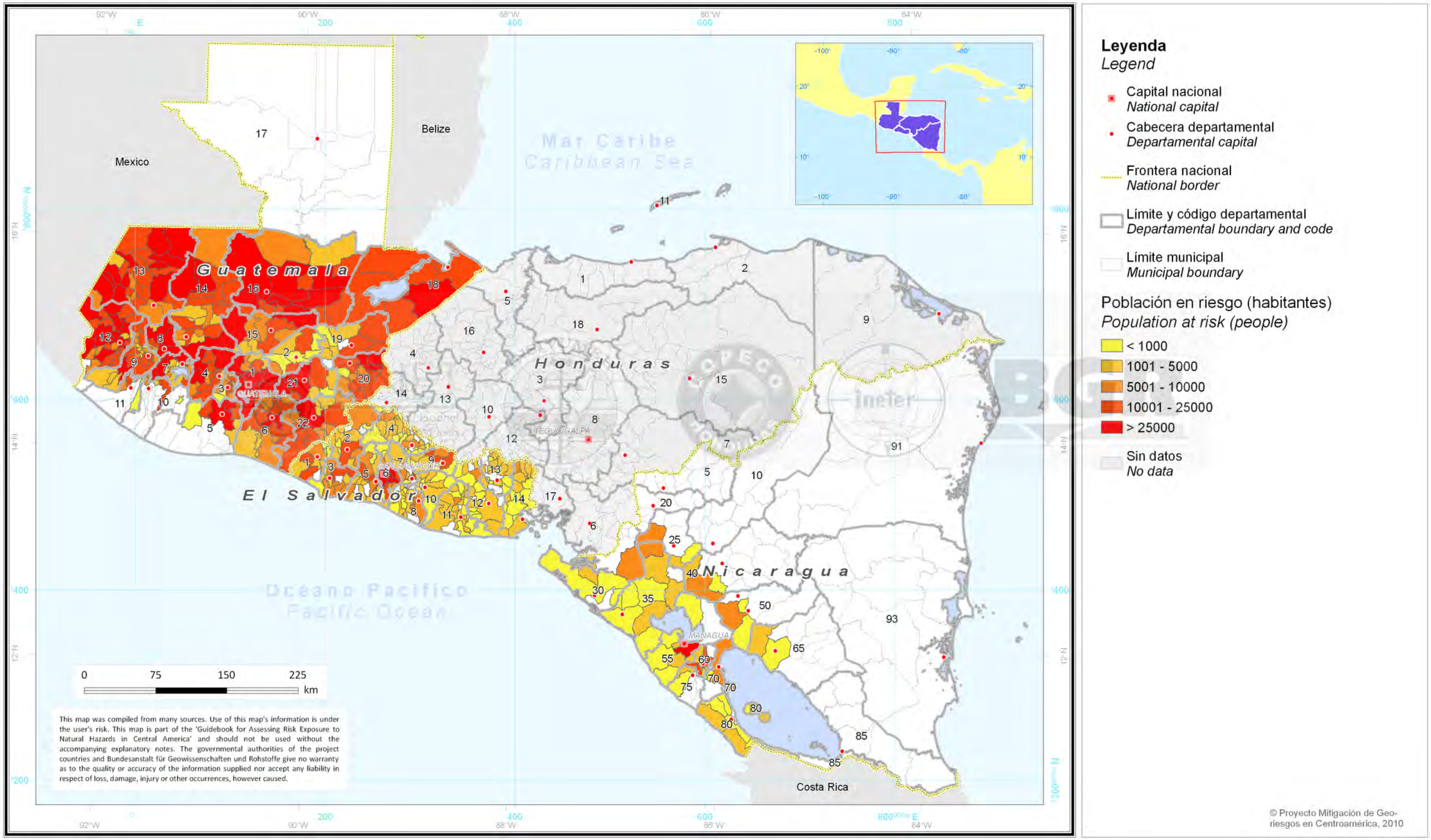
The intention of this map is to give a quick overview for decision makers on supra-regional or national level about the risk exposure of the population to seismic hazards and landslide susceptibility. The classification used here runs from yellow (few people exposed) to red (many people exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment. White colored Municipios don't have surveyed settlement areas exposed to the combined hazards just mentioned or the chosen hazards are not spatially relevant at the settlement area sites, either.

Recommendations

- The level of acceptable risk expressed in this map is reflected in the class width of the population exposure color code. This color code needs to be adjusted so that the maps and assessments reflect the level of acceptable risk agreed upon by society and in accordance with the development goals of the regions government;
- In regions where more detailed maps are available, it is recommended to do this analysis with these maps. Please consult the responsible authorities for the availability of individual maps;
- We recommend comparing this map with the risk exposure maps for the individual hazards.

Población Expuesta a Deslizamientos (Susceptibilidad Alta - Muy Alta) y Amenaza Sísmica (Media - Muy Alta)

Population Exposure to Landslide Susceptibility (High, Very High) and Seismic Hazard (Medium - Very High)



Multi-Hazard Approach: Infrastructure (Roads) Exposed to Seismic / Landslide Hazard, Supra-Regional

Map Contents

The supra-regional map shows for each Municipio of the Central American countries the sum of major road kilometers that are exposed to 'high' or 'very high' landslide susceptibility zones, AND 'medium - very high' seismic hazard zones.

Map Purpose with Respect to Disaster Risk Management

It is referred to the general notes on page 72.

Data Source and Availability

The major road data upon which this map is based on is described in more detail on page 32. Administrative boundaries were taken from the sources mentioned on page 24, landslide susceptibility data are listed in the explanations on page 50, and the seismic hazard data are taken from page 42.

Remarks

Summed up, almost 6700 km of major roads are threatened by the combination of the 'high' or 'very high' land-slide susceptibility AND 'medium - very high' seismic hazard.

Country	Km of Roads Exposed
El Salvador	2 437
Guatemala	1 971
Honduras	317
Nicaragua	1 971
Totals	6 696

Due to the inhomogeneous structure of the underlying road data, this analysis has to be interpreted with some care.

Methodology

The map was derived by intersecting the data layers of the administrative boundaries (page 24), the road network (page 32), 'high' and 'very high' landslide susceptibility (page 50), and 'medium - very high' seismic hazard (page 42).

It is pointed to the explanations on page 72 for a detailed description of the intersection process and the subsequent procedure.

How to read this map

The intention of this map is to give a quick overview for decision makers on national or regional level about the risk exposure of the road network to 'high' and 'very high' landslide susceptibility and 'medium - very high' seismic hazard. The classification used here runs from yellow (few kilometers exposed) to red (many kilometers exposed). The class width of the yellow-to-red division has been chosen to facilitate the visual representation of the variability of values obtained in the assessment.

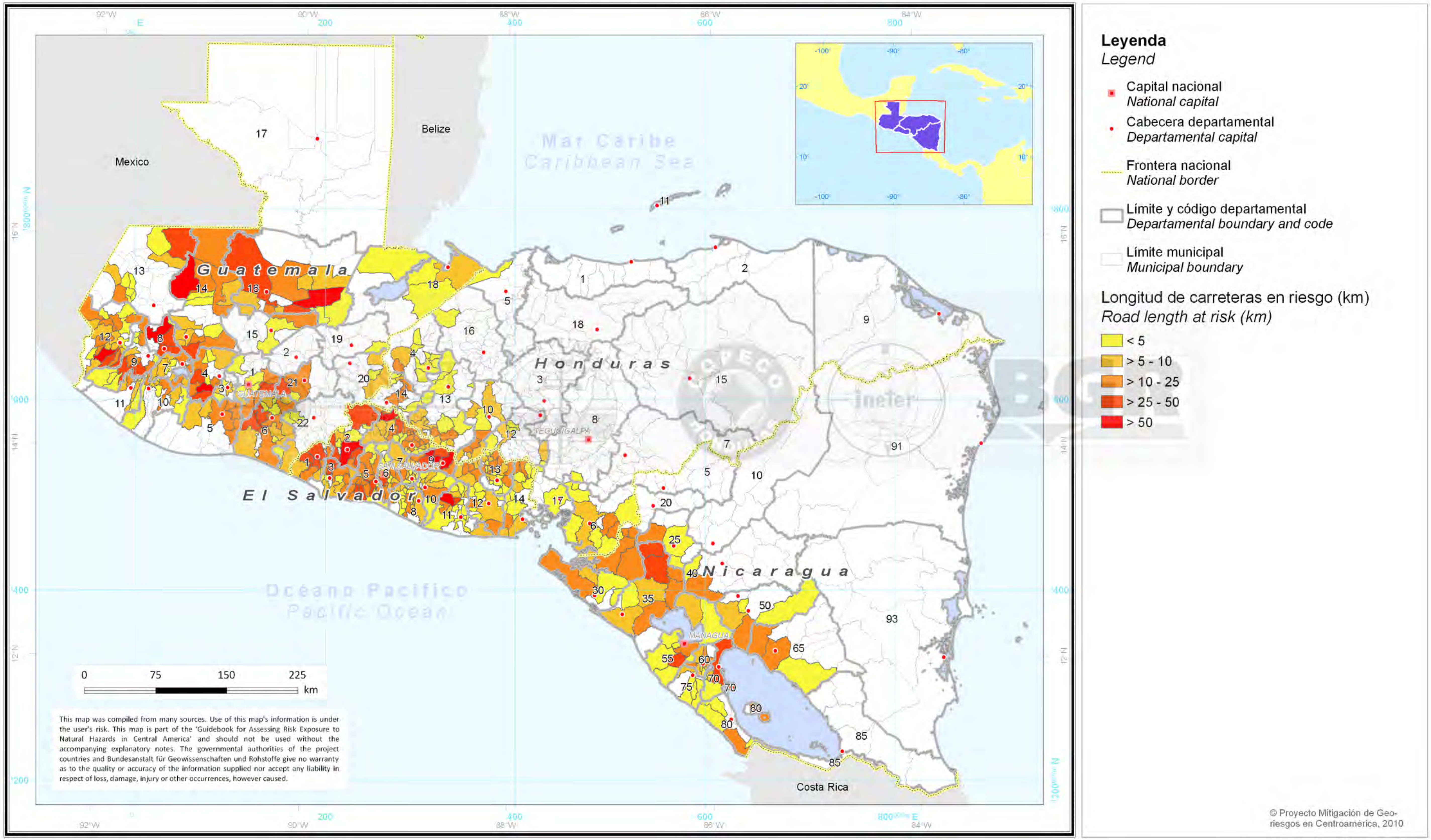
The complete and detailed results of this assessment can be accessed in the database (see page 17*ff*). White colored Municipios don't have surveyed major road exposed to the combined hazards mentioned above or the chosen hazards are not spatially relevant along the major roads, either.

Recommendations

- Similar risk assessment can be done with additional infrastructure elements, such as power transmission lines, pipelines, railroad lines, etc.;
- The risk for the infrastructure can easily be transferred to economic figures, if the average cost for buildings or reconstructing and maintenance of roads are known;
- The level of acceptable risk expressed in this map is reflected in the class width of the road length exposure color code. This color code needs to be adjusted to reflect the level of acceptable risk agreed upon by society.

Carreteras Principales Expuestas a Deslizamientos (Susceptibilidad Alta - Muy Alta) y Amenaza Sísmica (Media - Muy Alta)

Total Length of Major Roads Exposed to Landslide Susceptibility (High, Very High) and Seismic Hazard (Medium - Very High)



Risk Exposure

Outlook

The ‚Guidebook for Assessing Risk Exposure to Natural Hazards in Central America – El Salvador, Guatemala, Honduras, and Nicaragua –' illuminates the main activities to assess/map the spatial risk exposure to geological (hydro-meteorological) hazards on a national and supra-regional scale by using a coupled database/GIS tool called CARA-GIS. It is described what kind of information is essential to map risks with Disaster Risk Management in mind.

The process of GIS based risk analysis can be principally down-scaled to sub-national and local scales as well. However, data requirements on these levels might be considerably higher. For example, if a local flood hazard and risk assessment were to be carried out, detailed elevation data and hydraulic data would be required on the hazard side, and detailed building-specific data on the vulnerability side. Some of these data requirements may only be available through detailed and expensive field campaigns and modeling procedures.

However, in order to mitigate the risk exposure to geohazards sustainably, the ultimate ambition of all risk assessment and mapping activities can solely be to transfer and to implement risk assessment outcomes into regular spatial and development planning processes at all administrative levels (see page 2).

As the risk assessment results should contribute to make land use and development planning risk-sensitive, it is inevitable bringing together practitioners, policy makers, stakeholder and geoscientists to develop a common vision about the practical benefit of such analyses. In the descriptions of the individual risk exposure maps, the fact has been stressed that the analysis procedure can be used for 'what-if'-scenarios. Such scenarios are particularly important with respect to rapidly increasing population figures and/or social vulnerabilities in general.

Thus, in order to internalize the complex relationships between natural hazard, vulnerability and risk and to recognize why risk relevant information at different scales has to be kept up-to date, a capacity building in CARA, involving all line authorities appears to be a logical consequence. Having both, a profound methodological and an expert knowledge, an initial step toward the establishment of a subsequent sound political advisory service has been taken.

Having the Central American region in mind, the geographical and institutional expansion of CARA-specific activities to Costa Rica and Panama should be envisaged to accomplish the risk specific requirements of the 'Regional Plan of Disaster Reduction 2006-2015' established by SICA/CEPREDENAC (2007).

Identifying population or infrastructure at risk to different geological hazards, as elaborated in the guidebook, might be an essential step toward the target-oriented implementation of new or adjustment of existing early warning systems by providing any desired risk exposure maps on demand.

In principle, the geo-spatial CARA procedures necessary to carry out the data preparation and subsequent analysis can also be applied to other types of hazards and resulting risk potentials, given that these hazards are of spatial nature.

Global climatic change provides a wide field, where the presented methodology can be used for impact modeling. Both, changes in the hazard probabilities and changes in the vulnerability components could be modeled with such a tool. For example, the risk exposition of population to recent drought prone areas using adequate information like precipitation distribution, soil types, and other relevant indicators (vegetation) can be modeled.

Beyond natural hazards, also technological (e.g. dispersion of toxic substances) or biological (e.g. epidemic plagues) hazards of spatial nature can be assessed as to their risk potential. It is evident, that the methodology presented can only be a first order approach to appraise the exposition potential of elements at risk rapidly. Many other investigations and modelling activities are imperative.

Technologically, the CARA tools presented here are based on desktop GI systems. This is mainly owed to the project's framework. However, the underlying ideas as well as the data model can be transferred to web-accessible systems. With such systems the data and maps could effortlessly be made available to a broad range of clients, both in the public and in the administrative sectors. The use of web-based Geographic Information Technology would also enable the line agencies to contribute their findings to a regional geospatial data infrastructure.

Appendix

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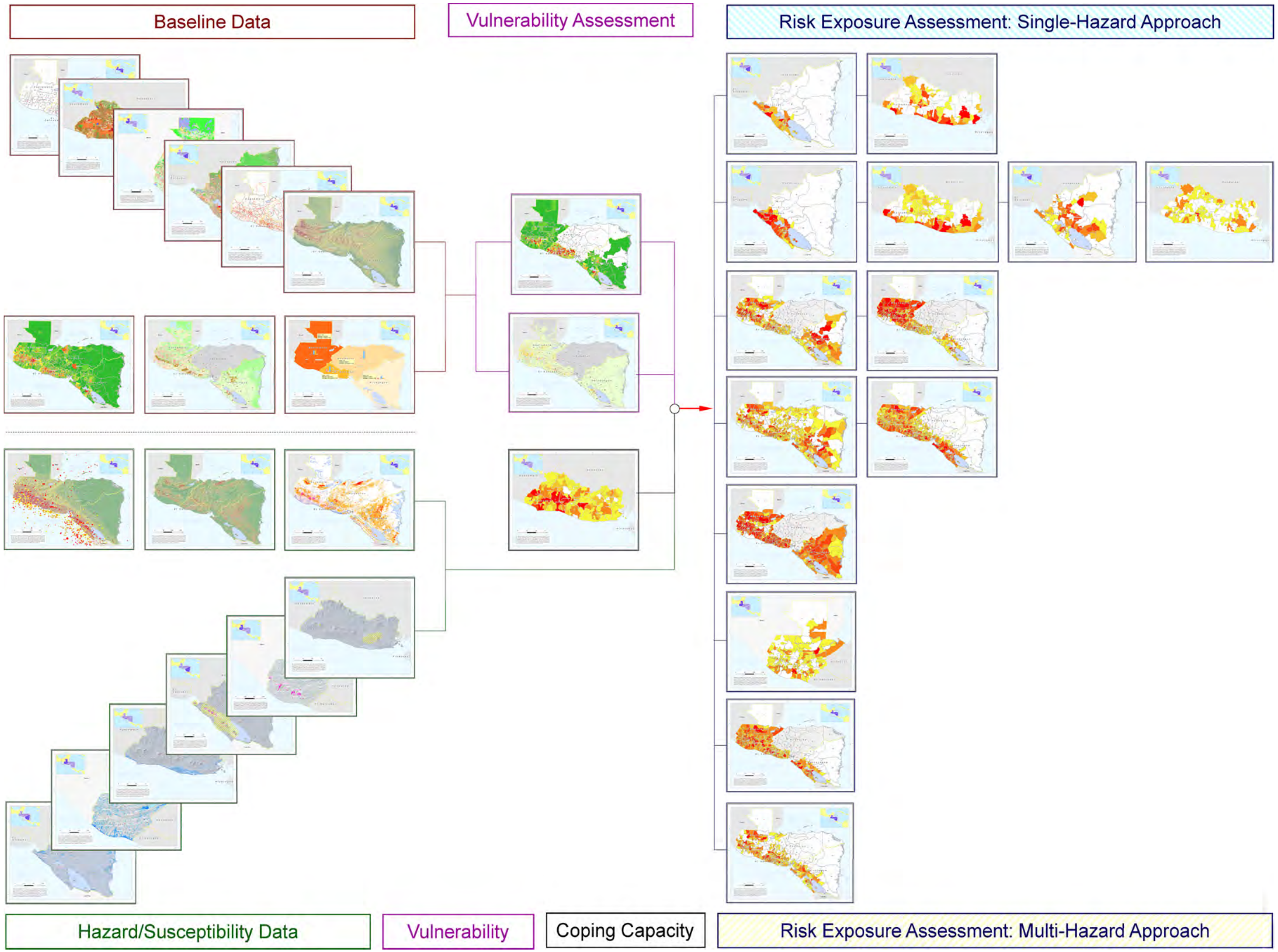
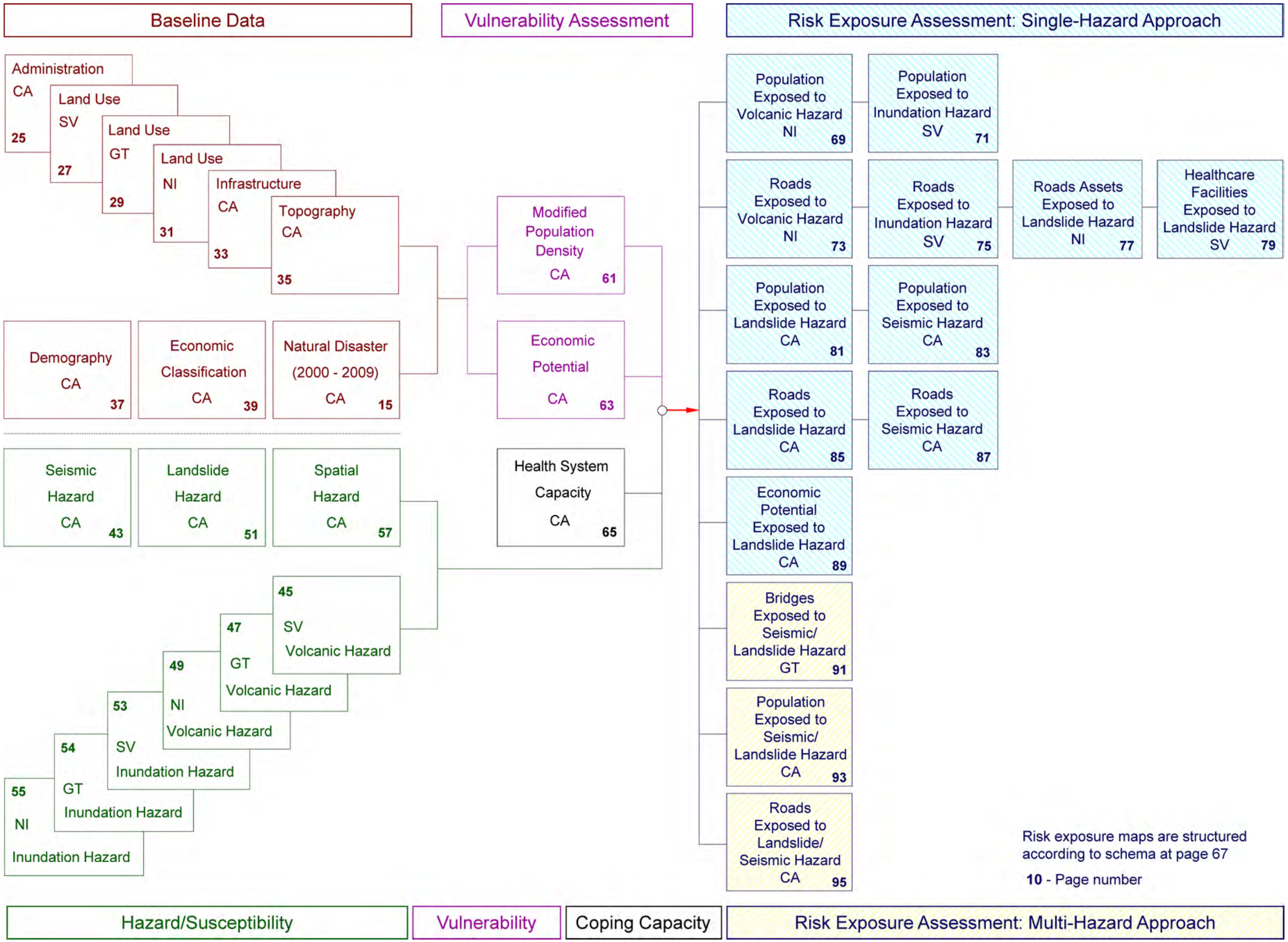
Methodological Workflow

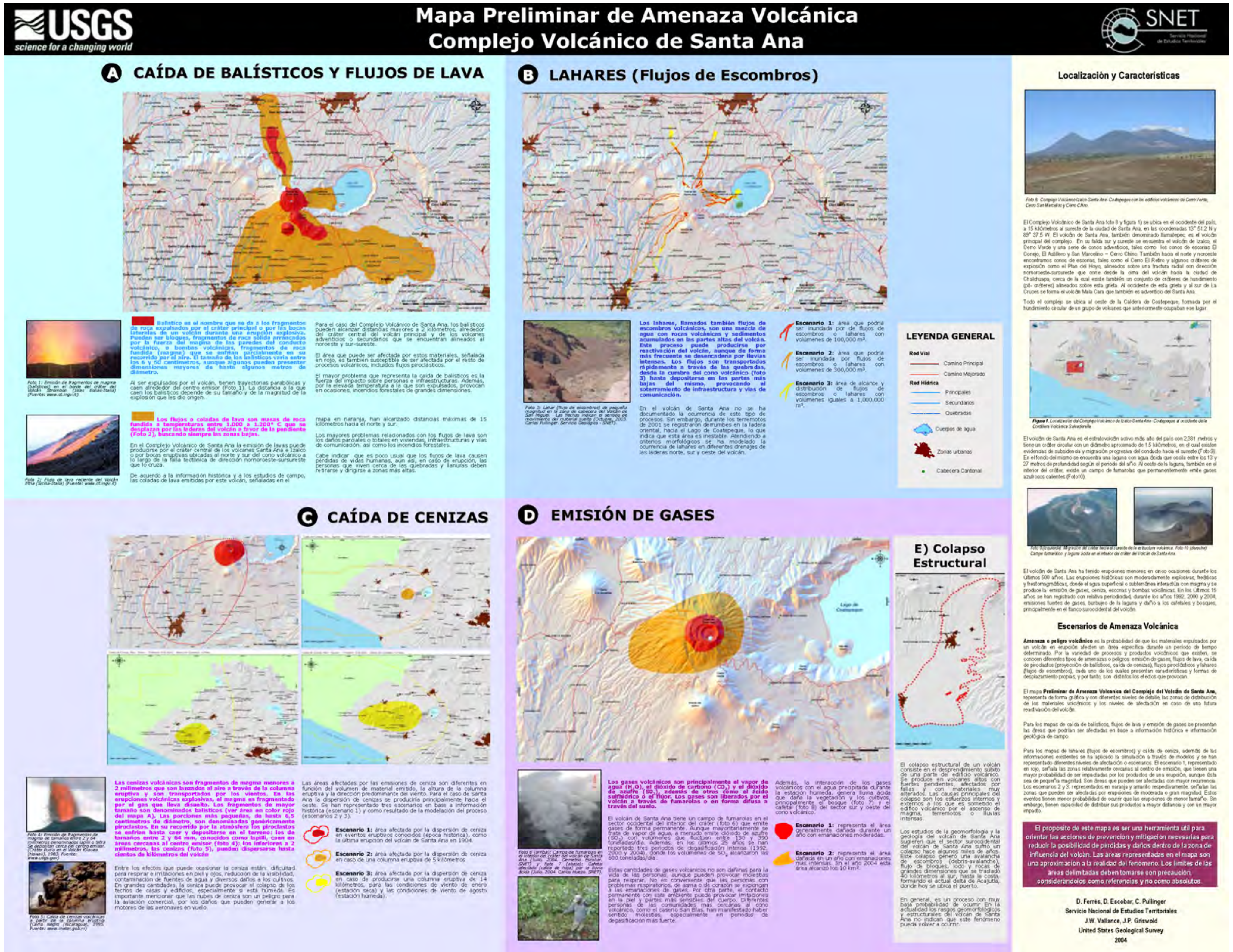




Baseline Data
Vulnerability Assessment
Risk Exposure Assessment: Single-Hazard Approach
Administration CA 25
Land Use SV 27
Land Use GT 29
Land Use NI 31
Infrastructure CA 33
Topography CA 35
Demography CA 37
Economic Classification CA 39
Natural Disaster (2000 - 2009) CA 15
Modified Population Density CA 61
Economic Potential CA 63
Health System Capacity CA 65
Seismic Hazard CA 43
Landslide Hazard CA 51
Spatial Hazard CA 57
45 SV Volcanic Hazard
47 GT Volcanic Hazard
49 NI Volcanic Hazard
53 SV Inundation Hazard
54 GT Inundation Hazard
55 NI Inundation Hazard
Population Exposed to Volcanic Hazard NI 69
Population Exposed to Inundation Hazard SV 71
Roads Exposed to Volcanic Hazard NI 73
Roads Exposed to Inundation Hazard SV 75
Roads Assets Exposed to Landslide Hazard NI 77
Healthcare Facilities Exposed to Landslide Hazard SV 79
Population Exposed to Landslide Hazard CA 81
Population Exposed to Seismic Hazard CA 83
Roads Exposed to Landslide Hazard CA 85
Roads Exposed to Seismic Hazard CA 87
Economic Potential Exposed to Landslide Hazard CA 89
Bridges Exposed to Seismic/ Landslide Hazard GT 91
Population Exposed to Seismic/ Landslide Hazard CA 93
Roads Exposed to Landslide/ Seismic Hazard CA 95
Risk exposure maps are structured according to schema at page 67
10 - Page number
Hazard/Susceptibility
Vulnerability
Coping Capacity
Risk Exposure Assessment: Multi-Hazard Approach

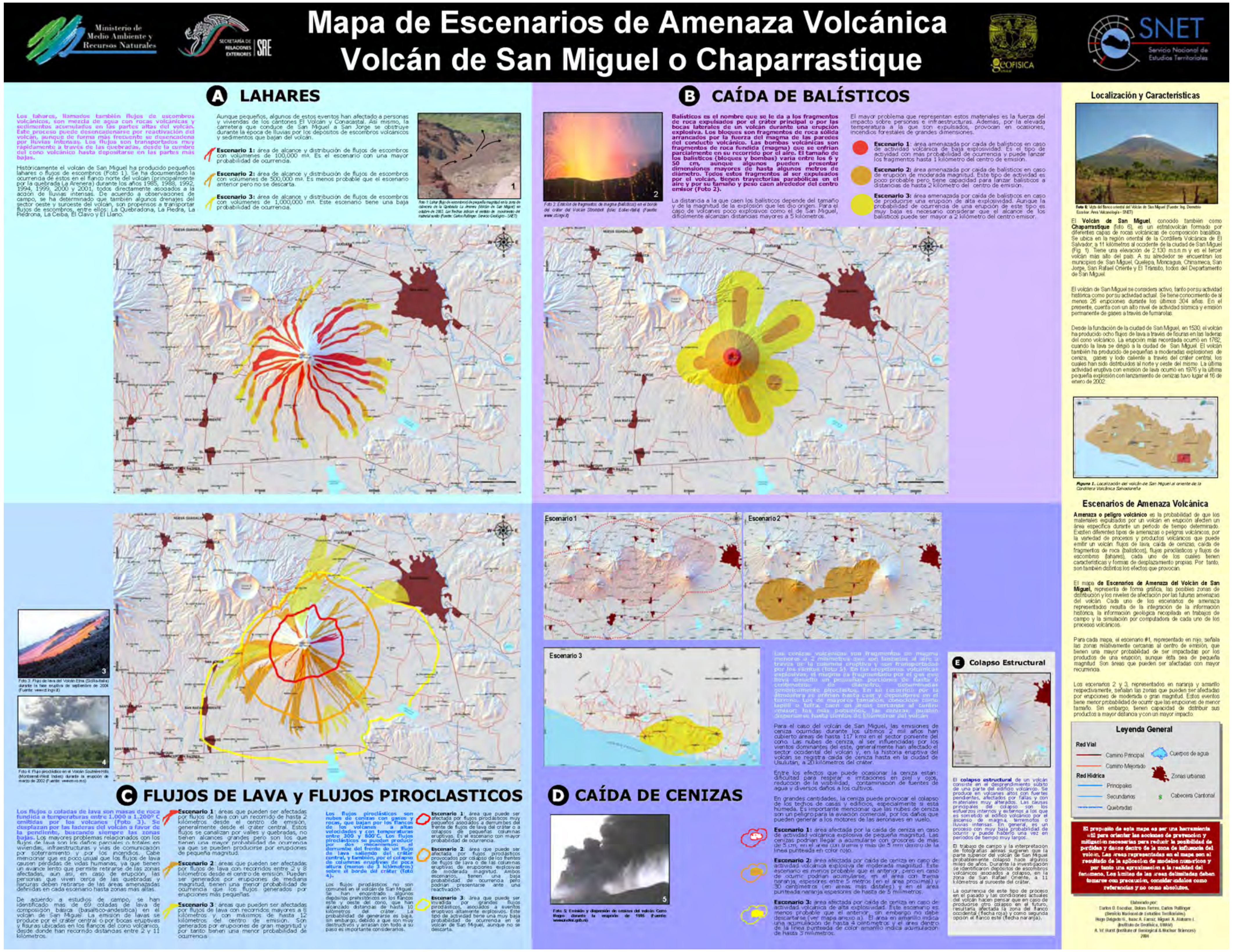
Appendix

Detailed Volcanic Hazard Maps of El Salvador



Volcanic Hazard Map of the Santa Ana volcanic complex, El Salvador (refer also to page 44)

source: SNET (http://www.snet.gob.sv/Geologia/Vulcanologia/amenazas/MAPAVSA.pdf)



Volcanic Hazard Map of the Santa Ana volcanic complex, El Salvador (refer also to page 44)

source: SNET

(http://www.snet.gob.sv/Geologia/Vulcanologia/amenazas/MAPAVSM.pdf)

GDP Values

Country	Sector Code	Sector	GDP (US$)*	GDP (Million of National Currency)**
Nicaragua				
	1	AB Agriculture, hunting, forestry and fishing	985 083 840	21 049
	2	C Mining and quarrying	66 399 840	1 419
	3	D Manufacturing	979 917 120	20 938
	4	E Electricity, gas and water	169 673 400	3 626
	5	F Construction	320 102 640	6 840
	6	GH Wholesale and retail trade, restaurants and hotels	795 478 320	16 997
	7	I Transport, storage and communications	308 547 720	6 593
	8	JK Finance, insurance, real estate and business services	710 672 040	15 185
	9	LMNOPQ Community, social and personal services	1 094 628 600	23 390
Honduras				
	1	AB Agriculture, hunting, forestry and fishing	1 710 093 930	32 823
	2	C Mining and quarrying	155 294 470	2 981
	3	D Manufacturing	2 739 735 810	52 586
	4	E Electricity, gas and water	159 639 610	3 064
	5	F Construction	850 808 630	16 330
	6	GH Wholesale and retail trade, restaurants and hotels	2 348 558 590	45 078
	7	I Transport, storage and communications	963 474 880	18 493
	8	JK Finance, insurance, real estate and business services	2 269 455 160	43 560
	9	LMNOPQ Community, social and personal services	2 529 996 840	48 560
El Salvador				
	1	AB Agriculture, hunting, forestry and fishing	2 693 100 000	2 693
	2	C Mining and quarrying	85 500 000	86
	3	D Manufacturing	4 452 400 000	4 452
	4	E Electricity, gas and water	417 100 000	417
	5	F Construction	860 100 000	860
	6	GH Wholesale and retail trade, restaurants and hotels	4 434 200 000	4 434
	7	I Transport, storage and communications	1 991 600 000	1 992
	8	JK Finance, insurance, real estate and business services	3 296 000 000	3 296
	9	LMNOPQ Community, social and personal services	2 999 000 000	2 999
Guatemala				
	1	AB Agriculture, hunting, forestry and fishing	3 892 146 000	31 695
	2	C Mining and quarrying	638 326 680	5 198
	3	D Manufacturing	6 787 180 560	55 270
	4	E Electricity, gas and water	874 753 520	7 123
	5	F Construction	1 733 125 520	14 113
	6	GH Wholesale and retail trade, restaurants and hotels	5 559 020 920	45 269
	7	I Transport, storage and communications	2 757 768 720	22 457
	8	JK Finance, insurance, real estate and business services	4 448 466 840	36 225
	9	LMNOPQ Community, social and personal services	7 827 124 640	63 739

* For conversion exchange rates from March 2010 were applied

** The value reflect the market prices of 2008

Source: ECLAC (2009)

Acronyms

a.s.l.	above sea level
CAFFG	Central American Flash Flood Guidance
COSUDE	Agencia Suiza para el Desarrollo y la Cooperación (Swiss Agency for Development and Cooperation)
DEM	Digital Elevation Model
GDP	Gross Regional Domestic Product
GIS	Geographic Information System
IGOS	Integrated Global Observing Strategy
IRS	Indian Remote Sensing
ISDR	International Strategy for Disaster Reduction
ISO	International Organization for Standardization
JICA	Japan International Cooperation Agency
LIDAR	Light detection and ranging
NASA	National Aeronautics and Space Administration, USA
NIO	Nicaraguan Cordoba
OECD	Organization for Economic Cooperation and Development
PIB	Producto Interior Bruto
SHP	Filename extension for ESRI GIS shape-files
SRTM	Shuttle Radar Topographic Mission
UNDP	United Nation Development Program
USD	US Dollar
USGS	United States Geological Survey

Data Sources

The following table lists the data used and mentioned in this guidebook.

Type of Data	Source	Year of Data Compilation	Scale	Distribution Format	Average Cost
Baseline Data					
Administrative Areas	El Salvador: Centro Nacional de Registros (CNR)/Instituto Geográfico y del Catastro Nacional (IGCN)	Updated continuously	1:25 000	GIS file format: shp; dgn	upon request
	Guatemala: Instituto Geográfico Nacional (IGN)/Instituto Nacional de Estadística (INE)	2002	1:250 000	GIS file format: shp	upon request; governmental authorities for free
	Honduras: Instituto Geográfico Nacional (IGN)	1974	1:200 000 - 1:350 000	GIS file format: shp	no information
	Nicaragua: Instituto Nicaragüense de Estudios Territoriales (INETER)	2006	1:525 000	GIS file format: shp; dgn	20 US$
Land use/Land cover	El Salvador: Ministerio de Medio Ambiente y Recursos Naturales (MARN) and IGCN	2003	LANDSAT 15 m	GIS file format: shp	upon request; free of charge
	Guatemala: Unidad des Planificacion y Gestion del Riesgo/Ministerio de Agricultura y Alimentacion (MAGA)	2005	1:50 000	GIS file format: shp	upon request; free of charge
	Honduras: no data available	-	-	-	-
	Nicaragua: Ministerio Agropecuario y Forestal (MARN)/INETER	2000	1:50 000	GIS file format: shp	upon request
Infrastructure (only road network)	El Salvador: Ministerio de Obras Públicas (MOP)	Updated continuously	1:25 000	GIS file format: shp	upon request
	Guatemala: Ministerio de Comunicaciones, Infraestructura y Vivienda (CIV)	2009	1:250 000	GIS file format: shp	upon request
	Honduras: National geodatabase of 'Proyecto Mitigación de Desastres Naturales' (PMDN)'	Unknown	unknown	ESRI feature class	upon request
	Nicaragua: Ministerio de Transporte e Infraestructura (MTI)	2004	1:525 000	GIS file format: shp; dgn	20 US$
Topography	El Salvador: Centro Nacional de Registros (CNR)/Instituto Geográfico y del Catastro Nacional (IGCN)	2000/2005 (SRTM-3)	90 m	GRID	Public domain USGS
	Guatemala: Instituto Geográfico Nacional (IGN)	2000/2005 (SRTM-3)	90 m	GRID	Public domain USGS
	Honduras: Instituto Geográfico Nacional (IGN)?	2000/2005 (SRTM-3)	90 m	GRID	Public domain USGS
	Nicaragua: Instituto Nicaragüense de Estudios Territoriales (INETER)	2000/2005 (SRTM-1/3)	30 m/90 m	GRID	Public domain USGS (90 m)/upon request (30m)
	INETER/Japan International Development Agency (JICA)	2004	20 m	GRID	350 C$ per quadrant according topo map 1:50 000
Demography	El Salvador: Ministerio de Economía (MINEC) (carried out by Dirección General de Estadística y Censos)	2007	-	Alphanumeric	Free access
	Guatemala: Instituto Nacional de Estadística (INE)	2002	-	Alphanumeric	Free access
	Honduras: Instituto Nacional de Estadística (INE)	2001	-	Alphanumeric	Free access
	Nicaragua: Instituto Nacional de Estadística y Censos de Nicaragua (INEC)/ Instituto Nacional de Información de Desarrollo (INIDE)	2005	-	Alphanumeric	Free access
Economic Potential	El Salvador: Economic Commission for Latin America and the Caribbean (ECLAC)	2009	-	Alphanumeric	Free access
	Guatemala: Economic Commission for Latin America and the Caribbean (ECLAC)	2009	-	Alphanumeric	Free access
	Honduras: Economic Commission for Latin America and the Caribbean (ECLAC)	2009	-	Alphanumeric	Free access
	Nicaragua: Economic Commission for Latin America and the Caribbean (ECLAC)	2009	-	Alphanumeric	Free access
Hazard/Susceptibility Data					
Seismic Hazard	Supra-Regional: RESIS-II	2008	Relative scale	GRID	Free access/Report with CD
Volcanic Hazard	El Salvador: Servicio Nacional de Estudios Territoriales (SNET)	2004 (Santa Ana, San Miguel)	Relative scale	GIS file format: shp	Free access
	Guatemala: Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH)/JICA	2000-2003	1: 25 000	GIS file format: shp	Free access
	Honduras: -	-	-	-	-
	Nicaragua: Instituto Nicaragüense de Estudios Territoriales (INETER)	1995	1:400 000	GIS file format: shp	50 US$ (printed version)
Landslide Susceptibility	El Salvador: Servicio Nacional de Estudios Territoriales (SNET)	2002	Relative scale	GRID	Free access
	Guatemala: Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH)	2008	Relative scale	GRID	No information
	Honduras: Comisión Permanente de Contingencias (COPECO)	2008	Relative scale	GRID	-
	Nicaragua: Instituto Nicaragüense de Estudios Territoriales (INETER)	2004	Relative scale	GRID	Free access
Inundation Hazard	El Salvador: Servicio Nacional de Estudios Territoriales (SNET)	2002	1:25 000 (topographic)	GIS file format: shp	Free access
	Guatemala: Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH)	2001	1: 250 000 (topographic)	GIS file format: shp	No information
	Honduras: (Comisión Permanente de Contingencias (COPECO))	-	-	-	-
	Nicaragua: Instituto Nicaragüense de Estudios Territoriales (INETER)	1999	1:750 000 (topographic)	GIS file format: shp	Free access

Appendix

National Institutions

Listed here are national governmental institutions and agencies that are important in the broader context of disaster risk management by either formulating the regulatory framework, providing relevant data or being responsible for implementation. Institutions are listed alphabetically with reference to their abbreviations, as these are most commonly used.

Name of the Institution/Nombre de la Institución	**Dirección/*Address***	**Web**
El Salvador		
Direcciòn General de Protección Civil	15 Avenida Norte y 9a Calle Oriente, Torre del Ministerio de Gobernación; Centro de Gobierno San Salvador, El Salvador	www.coen.gob.sv
IGCN Instituto Geográfico y del Catastro Nacional	Centro Nacional de Registros 1a Calle Poniente y 43 Av. Norte #2310; San Salvador, El Salvador	www.cnr.gob.sv
MARN Ministerio de Medio Ambiente y Recursos Naturales	Kilómetro 5 ½ Carretera a Santa Tecla, Calle y Colonia Las Mercedes Edificio MARN (anexo al edificio ISTA) No. 2; San Salvador, El Salvador	www.marn.gob.sv
MINEC Ministerio de Economía - Dirección General de Estadísticas y Censos	Alameda Juan Pablo II y Calle Guadalupe Edificio C1 - C2, Centro de Gobierno; San Salvador, El Salvador	www.minec.gob.sv
MSPAS Ministerio de Salud Pública y Asistencia Social	Calle Arce No. 827; San Salvador, El Salvador	www.mspas.gob.sv
SNET Servicio Nacional de Estudios Territoriales	Km. 5 ½ Carretera a Nueva San Salvador; Avenida Las Mercedes San Salvador, El Salvador	www.snet.gob.sv
Guatemala		
CONRED Coordinadora Nacional para la Reducción de Desastres	Avenida Hincapié 21-72, zona 13; Ciudad de Guatemala, Guatemala	conred.gob.gt
IGN Instituto Geográfico Nacional	Avenida Las Américas 5-76, zona 13; Ciudad de Guatemala, Guatemala	www.ign.gob.gt
INE Instituto Nacional de Estadística	8a. calle 9-55 z.1; Ciudad de Guatemala, Guatemala	www.ine.gob.gt
INSIVUMEH Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología	Edificio Central, 7a. Av. 14 -57, zona 13; Ciudad de Guatemala, Guatemala	www.insivumeh.gob.gt
MAGA Ministerio de Agricultura, Ganadería y Alimentación	Dirección: 7a Avenida 12-90, zona 13; Ciudad de Guatemala, Guatemala	portal.maga.gob.gt
SEGEPLAN Secretaría de Planificación y Programación de la Presidencia	9 calle 10-44, zona 1; Ciudad de Guatemala, Guatemala	www.segeplan.gob.gt

Name of the Institution/Nombre de la Institución	**Dirección/ *Address***	**Web**
Honduras		
COPECO Comisión Permanente de Contingencias Centro Nacional de Informción en Gestión de Riesgos	Aldea el Ocotal, 300 mts. adelante del Hospital Militar; Tegucigalpa M.D.C., Honduras	www.copeco.hn cnigr.copeco.gob.hn
INE Instituto Nacional de Estadística (INE)	Lomas del Guijarro, edificio Plaza Guijarro, 5to. Piso; Tegucigalpa M.D.C., Honduras	www.ine-hn.org
ING Instituto Nacional Geográfico	Barrio La Bolsa Comayaguela Apartado, Postal 20706; Tegucigalpa M.D.C., Honduras	
Nicaragua		
INEC Instituto Nacional de Estadística y Censos de Nicaragua	see INIDE	
INETER Instituto Nicaragüense de Estudios Territoriales	Frente a la Clinica Metrópoli Xolotlán Postal 2110; Managua, Nicaragua	www.ineter.gob.ni
INIDE Instituto Nacional de Información de Desarrollo		www.inide.gob.ni
MAGFOR Ministerio Agropecuario y Forestal	Km. 8 ½ Carretera Masaya; Managua, Nicaragua	www.magfor.gob.ni
MINED Ministerio de Educación		www.mined.gob.ni
MINSA Ministerio de Salud	Complejo Nacional de Salud 'Dra. Concepción Palacios' Costado Oeste Colonia Primero de Mayo; Managua, Nicaragua	www.minsa.gob.ni
MTI Ministerio de Transporte e Infraestructura		mti.gob.ni
SINAPRED Sistema Nacional para la Prevención, Mitigación y Atención de Desastres	Edificio SINAPRED, Rotonda Colón 50 metros al Norte, frente a Avenida Bolívar; Managua, Nicaragua	www.sinapred.gob.ni

Supra-Regional Institutions

Listed here are some institutions on a supra-national level with links to topics related to disaster risk management in Central America. Please refer to the respective websites for more information on the tasks and functions of these institutions.

Nombre	*Name*	Dirección/*Address*	
CEPREDENAC Centro de Coordinación para la Prevención de Desastres Naturales en América Centra	Coordination Center for Natural Disaster Prevention in Central America		www.cepredenac.org
CEPAL Comisión Económica para América Latina y el Caribe	ECLAC Economic Commission for Latin America and the Caribbean	Secretaría Ejecutiva Av. Dag Hammarskjold 3477 Vitacura; Santiago, Chile	www.cepal.cl
CCAD Comisión Centroaméricana de Ambiente y Desarrollo			www.ccad.ws
SICA Sistema de la Integración Centroaméricana	Central American Integration System	Secretaría General Bulevar Orden de Malta No. 470, Urbanización Santa Elena; Antiguo Cuscatlán, El Salvador	www.sica.int

Appendix

Glossary

This list contains the most recent terminological definitions of terms related to risk assessment. These definitions were taken from ISDR's website (www.unisdr.org/eng/library/UNISDR-terminology-2009-eng.pdf).

The UNISDR Terminology aims to promote common understanding and common usage of disaster risk reduction concepts and to assist the disaster risk reduction efforts of authorities, practitioners and the public.

Acceptable risk

The level of potential losses that a society or community considers acceptable given existing social, economic, political, cultural, technical and environmental conditions.

Comment: In engineering terms, acceptable risk is also used to assess and define the structural and non-structural measures that are needed in order to reduce possible harm to people, property, services and systems to a chosen tolerated level, according to codes or 'accepted practice" which are based on known probabilities of hazards and other factors.

Building code

A set of ordinances or regulations and associated standards intended to control aspects of the design, construction, materials, alteration and occupancy of structures that are necessary to ensure human safety and welfare, including resistance to collapse and damage.

Comment: Building codes can include both technical and functional standards. They should incorporate the lessons of international experience and should be tailored to national and local circumstances. A systematic regime of enforcement is a critical supporting requirement for effective implementation of building codes.

Capacity

The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals.

Comment: Capacity may include infrastructure and physical means, institutions, societal coping abilities, as well as human knowledge, skills and collective attributes such as social relationships, leadership and management. Capacity also may be described as capability. Capacity assessment is a term for the process by which the capacity of a group is reviewed against desired goals, and the capacity gaps are identified for further action.

Capacity Development

The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions.

Comment: Capacity development is a concept that extends the term of capacity building to encompass all aspects of creating and sustaining capacity growth over time. It involves learning and various types of training, but also continuous efforts to develop institutions, political awareness, financial resources, technology systems, and the wider social and cultural enabling environment.

Coping capacity

The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

Comment: The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during crises or adverse conditions. Coping capacities contribute to the reduction of disaster risks.

Corrective disaster risk management *

Management activities that address and seek to correct or reduce disaster risks which are already present.

Comment: This concept aims to distinguish between the risks that are already present, and which need to be managed and reduced now, and the prospective risks that may develop in future if risk reduction policies are not put in place. See also 'Prospective risk management".

Critical facilities

The primary physical structures, technical facilities and systems which are socially, economically or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency.

Comment: Critical facilities are elements of the infrastructure that support essential services in a society. They include such things as transport systems, air and sea ports, electricity, water and communications systems, hospitals and health clinics, and centers for fire, police and public administration services.

Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

Comment: Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.

Disaster risk

The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

Comment: The definition of disaster risk reflects the concept of disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socio-economic development, disaster risks can be assessed and mapped, in broad terms at least.

Disaster risk management

The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.

Comment: This term is an extension of the more general term 'risk management" to address the specific issue of disaster risks. Disaster risk management aims to avoid, lessen or transfer the adverse effects of hazards through activities and measures for prevention, mitigation and preparedness.

Disaster risk reduction

The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.

Comment: A comprehensive approach to reduce disaster risks is set out in the United Nations-endorsed Hyogo Framework for Action, adopted in 2005, whose expected outcome is 'The substantial reduction of disaster losses, in lives and the social, economic and environmental assets of communities and countries." The International Strategy for Disaster Reduction (ISDR) system provides a vehicle for cooperation among Governments, organizations and civil society actors to assist in the implementation of the Framework. Note that while the term 'disaster reduction" is sometimes used, the term 'disaster risk reduction" provides a better recognition of the ongoing nature of disaster risks and the ongoing potential to reduce these risks.

Early Warning System

The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

Comment: This definition encompasses the range of factors necessary to achieve effective responses to warnings. A people-centered early warning system necessarily comprises four key elements: knowledge of the risks; monitoring, analysis and forecasting of the hazards; communication or dissemination of alerts and warnings; and local capabilities to respond to the warnings received. The expression 'end-to-end warning system" is also used to emphasize that warning systems need to span all steps from hazard detection through to community response.

Environmental degradation

The reduction of the capacity of the environment to meet social and ecological objectives and needs.

Comment: Degradation of the environment can alter the frequency and intensity of natural hazards and increase the vulnerability of communities. The types of human-induced degradation are varied and include land misuse, soil erosion and loss, desertification, wildland fires, loss of biodiversity, deforestation, mangrove destruction, land, water, and air pollution, climate change, sea level rise, and ozone depletion.

Exposure

People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Comment: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

Geological hazard

Geological process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Geological hazards include internal earth processes, such as earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows. Hydrometeorological factors are important contributors to some of these processes. Tsunamis are difficult to categorize; although they are triggered by undersea earthquakes and other geological events, they are essentially an oceanic process that is manifested as a coastal water-related hazard.

Hazard

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: The hazards of concern to disaster risk reduction as stated in footnote 3 of the Hyogo Framework are '… hazards of natural origin and related environmental and technological hazards and risks." Such hazards arise from a variety of geological, meteorological, hydrological, oceanic, biological, and technological sources, sometimes acting in combination. In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis.

Hydrometeorological hazard

Process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Hydrometeorological hazards include tropical cyclones (also known as typhoons and hurricanes), thunderstorms, hailstorms, tornados, blizzards, heavy snowfall, avalanches, coastal storm surges, floods including flash floods, drought, heatwaves and cold spells. Hydrometeorological conditions also can be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics, and in the transport and dispersal of toxic substances and volcanic eruption material

Land-use planning

The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses.

Comment: Land-use planning is an important contributor to sustainable development. It involves studies and mapping; analysis of economic, environmental and hazard data; formulation of alternative land-use decisions; and design of long-range plans for different geographical and administrative scales. Land-use planning can help to mitigate disasters and reduce risks by discouraging settlements and construction of key installations in hazard-prone areas, including consideration of service routes for transport, power, water, sewage and other critical facilities.

Mitigation

The lessening or limitation of the adverse impacts of hazards and related disasters.

Comment: The adverse impacts of hazards often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness. It should be noted that in climate change policy, 'mitigation" is defined differently, being the term used for the reduction of greenhouse gas emissions that are the source of climate change.

National platform for disaster risk reduction

A generic term for national mechanisms for coordination and policy guidance on disaster risk reduction that are multi-sectoral and inter-disciplinary in nature, with public, private and civil society participation involving all concerned entities within a country.

Comment: This definition is derived from footnote 10 of the Hyogo Framework. Disaster risk reduction requires the knowledge, capacities and inputs of a wide range of sectors and organizations, including United Nations agencies present at the national level, as appropriate. Most sectors are affected directly or indirectly by disasters and many have specific responsibilities that impinge upon disaster risks. National platforms provide a means to enhance national action to reduce disaster risks, and they represent the national mechanism for the International Strategy for Disaster Reduction.

Natural hazard

Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Natural hazards are a sub-set of all hazards. The term is used to describe actual hazard events as well as the latent hazard conditions that may give rise to future events. Natural hazard events can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent. For example, earthquakes have short durations and usually affect a relatively small region, whereas droughts are slow to develop and fade away and often affect large regions. In some cases hazards may be coupled, as in the flood caused by a hurricane or the tsunami that is created by an earthquake.

Preparedness

The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

Comment: Preparedness action is carried out within the context of disaster risk management and aims to build the capacities needed to efficiently manage all types of emergencies and achieve orderly transitions from response through to sustained recovery. Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems, and includes such activities as contingency planning, stockpiling of equipment and supplies, the development of arrangements for coordination, evacuation and public information, and associated training and field exercises. These must be supported by formal institutional, legal and budgetary capacities. The related term 'readiness" describes the ability to quickly and appropriately respond when required.

Prevention

The outright avoidance of adverse impacts of hazards and related disasters.

Comment: Prevention (i.e. disaster prevention) expresses the concept and intention to completely avoid potential adverse impacts through action taken in advance. Examples include dams or embankments that eliminate flood risks, land-use regulations that do not permit any settlement in high risk zones, and seismic engineering designs that ensure the survival and function of a critical building in any likely earthquake. Very often the complete avoidance of losses is not feasible and the task transforms to that of mitigation. Partly for this reason, the terms prevention and mitigation are sometimes used interchangeably in casual use.

Prospective disaster risk management *

Management activities that address and seek to avoid the development of new or increased disaster risks.

Comment: This concept focuses on addressing risks that may develop in future if risk reduction policies are not put in place, rather than on the risks that are already present and which can be managed and reduced now. See also 'Corrective disaster risk management'.

Public awareness

The extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards.

Comment: Public awareness is a key factor in effective disaster risk reduction. Its development is pursued, for example, through the development and dissemination of information through media and educational channels, the establishment of information centers, networks, and community or participation actions, and advocacy by senior public officials and community leaders.

Recovery

The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

Comment: The recovery task of rehabilitation and reconstruction begins soon after the emergency phase has ended, and should be based on pre-existing strategies and policies that facilitate clear institutional responsibilities for recovery action and enable public participation. Recovery programs, coupled with the heightened public awareness and engagement after a disaster, afford a valuable opportunity to develop and implement disaster risk reduction measures and to apply the 'build back better" principle.

Residual risk

The risk that remains in unmanaged form, even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained.

Comment: The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, preparedness, response and recovery together with socio-economic policies such as safety nets and risk transfer mechanisms.

Resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Comment: Resilience means the ability to 'resile from" or 'spring back from" a shock. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need.

Response

The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Comment: Disaster response is predominantly focused on immediate and short-term needs and is sometimes called 'disaster relief'. The division between this response stage and the subsequent recovery stage is not clear-cut. Some response actions, such as the supply of temporary housing and water supplies, may extend well into the recovery stage.

Retrofitting

Reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards.

Comment: Retrofitting requires consideration of the design and function of the structure, the stresses that the structure may be subject to from particular hazards or hazard scenarios, and the practicality and costs of different retrofitting options. Examples of retrofitting include adding bracing to stiffen walls, reinforcing pillars, adding steel ties between walls and roofs, installing shutters on windows, and improving the protection of important facilities and equipment.

Risk

The combination of the probability of an event and its negative consequences.

Comment: This definition closely follows the definition of the ISO/IEC Guide 73. The word 'risk' has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in 'the risk of an accident'; whereas in technical settings the emphasis is usually placed on the consequences, in terms of 'potential losses' for some particular cause, place and period. It can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks.

See other risk-related terms in the Terminology: Acceptable risk; Corrective disaster risk management; Disaster risk; Disaster risk management; Disaster risk reduction; Disaster risk reduction plans; Extensive risk; Intensive risk; Prospective disaster risk management; Residual risk; Risk assessment; Risk management; Risk transfer.

Risk assessment

A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

Comment: Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.

Risk management

The systematic approach and practice of managing uncertainty to minimize potential harm and loss.

Comment: Risk management comprises risk assessment and analysis, and the implementation of strategies and specific actions to control, reduce and transfer risks. It is widely practiced by organizations to minimize risk in investment decisions and to address operational risks such as those of business disruption, production failure, environmental damage, social impacts and damage from fire and natural hazards. Risk management is a core issue for sectors such as water supply, energy and agriculture whose production is directly affected by extremes of weather and climate.

Risk transfer

The process of formally or informally shifting the financial consequences of particular risks from one party to another whereby a household, community, enterprise or state authority will obtain resources from the other party after a disaster occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party.

Comment: Insurance is a well-known form of risk transfer, where coverage of a risk is obtained from an insurer in exchange for ongoing premiums paid to the insurer. Risk transfer can occur informally within family and community networks where there are reciprocal expectations of mutual aid by means of gifts or credit, as well as formally where governments, insurers, multi-lateral banks and other large risk-bearing entities establish mechanisms to help cope with losses in major events. Such mechanisms include insurance and re-insurance contracts, catastrophe bonds, contingent credit facilities and reserve funds, where the costs are covered by premiums, investor contributions, interest rates and past savings, respectively.

Socio-natural hazard*

The phenomenon of increased occurrence of certain geophysical and hydrometeorological hazard events, such as landslides, flooding, land subsidence and drought, that arise from the interaction of natural hazards with overexploited or degraded land and environmental resources.

Comment: This term is used for the circumstances where human activity is increasing the occurrence of certain hazards beyond their natural probabilities. Evidence points to a growing disaster burden from such hazards. Socio-natural hazards can be reduced and avoided through wise management of land and environmental resources.

Structural and non-structural measures

Structural measures: Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems;

Non-structural measures: Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Comment: Common structural measures for disaster risk reduction include dams, flood levies, ocean wave barriers, earthquake-resistant construction, and evacuation shelters. Common non-structural measures include building codes, land use planning laws and their enforcement, research and assessment, information resources, and public awareness programs. Note that in civil and structural engineering, the term 'structural' is used in a more restricted sense to mean just the load-bearing structure, with other parts such as wall cladding and interior fittings being termed non-structural.

Sustainable development

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Comment: This definition coined by the 1987 Brundtland Commission is very succinct but it leaves unanswered many questions regarding the meaning of the word development and the social, economic and environmental processes involved. Disaster risk is associated with unsustainable elements of development such as environmental degradation, while conversely disaster risk reduction can contribute to the achievement of sustainable development, through reduced losses and improved development practices.

Vulnerability

The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Comment: There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure. However, in common use the word is often used more broadly to include the element's exposure.

* Emerging new concepts that are not in widespread use but are of growing professional relevance; the definition of these terms remain to be widely consulted upon and may change in future.

Appendix