In Cooperation with the Office of U.S. Foreign Disaster Assistance

Mapping Vulnerability to Disasters in Latin America and the Caribbean, 1900–2007

By Miriam C. Maynard-Ford, Emily C. Phillips, and Peter G. Chirico

Open-File Report 2008–1294

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2008
Revised and reprinted: 2008

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Suggested citation:
Maynard-Ford, M.C., Phillips, E.C., and Chirico, P.G., 2008, Mapping vulnerability to disasters in Latin America and the Caribbean, 1900–2007: U.S. Geological Survey Open-File Report 2008–1294, 30 p.

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Mapping Vulnerability to Disasters in Latin America and the Caribbean, 1900–2007

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Introduction

The vulnerability of a population and its infrastructure to disastrous events is a factor of both the probability of a hazardous event occurring and the community's ability to cope with the resulting impacts. Therefore, the ability to accurately identify vulnerable populations and places in order to prepare for future hazards is of critical importance for disaster mitigation programs.

In Latin America and the Caribbean, disasters are a large impediment to growth and development through the loss of life, capital, and food security (Guhu-Sapir and others, 2004). Guhu-Sapir and her colleagues at the Centre for the Research and Epidemiology of Disaster (CRED), in their comprehensive analysis of 34 years of disasters, state that "natural disasters create serious setbacks in the development process." The report cites Hurricane Mitch as an example of a major disaster that sidetracked development resources to reconstruction efforts, the social and economic impact of which set the development process back by 20 years. Disasters such as Hurricane Mitch in 1998 and Hurricane Ivan in 2004 focused international attention on the need for disaster mitigation among vulnerable populations in Latin America and the Caribbean. In April 2008, the U.S. Geological Survey (USGS) conducted an assessment of post Hurricane Mitch recovery and mitigation programs, implemented from 1998 to 2002 and funded by the United States Agency for International Development (USAID). In order to effectively examine mitigation efforts, higher resolution maps of the spatial and temporal spread of disasters at the regional level were necessary. The Office of U.S. Foreign Disaster Assistance (OFDA)/CRED Emergency Events Database (EM-DAT) data, with events aggregated at the country level, enables quick and accurate mapmaking of the number and types of disasters by country. While these maps are useful in deciding what countries are most in need of aid from the international community, they reveal little about the distribution of disasters over the landscape. Because hazards and populations are not uniformly distributed across countries, mapping disasters at smaller regional levels more accurately displays vulnerable departments and population centers by disaster type and frequency.

Based on the extensive disaster database made available by the CRED at the Université Catholique de Louvain, Belgium, and funded by the USAID's OFDA, flood, drought, earthquake, volcano, landslide, tsunami/tidal wave, and windstorm disaster events were disaggregated from country listings into smaller administrative districts and mapped.

Objective

This project created maps of higher spatial resolution of vulnerability to disaster in Latin America and the Caribbean from 1900 to 2007 by mapping disaster data by first-level administrative boundaries with the objective of identifying geographic trends in regional occurrences of disasters and

vulnerable populations. The method of mapping by administrative level is an improvement on displaying and analyzing disasters at the country level and shows the relative intensity of vulnerability within and between countries in the region. Disaster mapping at the country level produces only a basic view of which countries experience various types of natural disasters. Through disaggregation, the data show which geographic areas of these countries, including populated areas, are historically most susceptible to different hazard types.

Background

Mapping Vulnerability

According to the United Nations Development Project (UNDP), vulnerability is the condition "determined by physical, social, economic, and environmental factors or processes, which increase susceptibility to the impact of hazards" (UNDP, 2004). In recent years, there have been increased desire and effort made to map vulnerability to disasters for policy, relief, and decision-making purposes. Considering the organization of the available data, most of these efforts have been conducted at a national level.

Attempts have been made to map vulnerability to disasters at lower administrative scales in other regions, although few published studies have mapped Latin America. The Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS) project, started by the World Food Summit, maps EM-DAT disasters for all of Asia. Similar to this study, the FIVIMS research mapped disaster events on first administrative level but only covered one decade of data, or 992 georeferenced disaster events. Although FIVIMS has provided a much more detailed look at disaster distribution than maps at the country level, literature has noted that challenges exist in assigning political and spatial extents to each disaster event. These challenges have been identified in detail in critical reviews of the FIVIMS work and other disaster mapping efforts.

After having evaluated the EM-DAT data in their review, "Mapping Disastrous Natural Hazards Using Global Datasets," Peduzzi and others (2005) found that up to 82 percent of disaster events could be spatially referenced subnationally using information fields such as the following: country, disaster name, date (year, month, day), location (regions, provinces, and cities), latitude and longitude, and comments (river basin, etc.). The ability to spatially tie events to administrative level boundaries enables the creation of maps with more regional detail. However, Peduzzi and others argue that the methods of mapping by first-level administrative boundaries, as fashioned by Verelst (1999) and the Food and Agriculture Organization (2001), are inappropriate for making comparisons between countries and provinces because of variations in area and population size. According to this thinking, a department in Mexico may appear to be more vulnerable to landslide disasters because it is larger than a department in El Salvador, even though the El Salvadoran department may actually experience more landslides over a smaller area than the Mexican State. Thus, it is imperative to recognize these distortions when interpreting disaster phenomena mapped at the administrative level.

One recent major endeavor in disaster mapping is the Hotspots global risk mapping project conducted by the World Bank and Colombia University (Dilley and others, 2005). Researchers used EM-DAT data to model global risk for single and multiple hazards at a grid level rather than on the basis of political boundaries. Population is also taken into account, making the model more conducive to concrete comparisons between regions and countries. Risk to natural disaster, as defined by the Hotspots methodology, is a combination of the probability of exposure and historical vulnerability.

In an examination of Hotspots and other global disaster mapping projects, “Assessing global exposure to natural hazards: Progress and future trends,” Lerner-Lam (2007) recognizes the benefits and limitations of mapping at global regional levels, finding that “global synthesis promotes uniformity at the expense of including high-quality regional analysis. The benefit is that region-to-region comparisons can be made.” This ability to facilitate global regions analysis is a strength of both the Hotspots data and the EM-DAT data at the country scale. However, the datasets begin to differ when local regional analysis is needed. The Hotspots data, at the grid level, is fine enough to allow for high-resolution analysis of intercountry regions. The raw EM-DAT data are of too coarse a resolution for this level of analysis. However, through the process of disaggregation and assigning spatial reference to disaster events at the provincial level, the EM-DAT data become an effective corollary to gridded and modeled projects. The disaggregated EM-DAT data mapped within political boundaries show historical vulnerability, unlike the Hotspot data, which use models of probability and therefore maps risk. The EM-DAT identifies areas historically prone to disasters, while the Hotspots project identifies areas at risk of hazards.

The literature for all of these projects agrees on one thing: the need for a more detailed and standardized disaster data collection. Although mapping vulnerability at smaller administrative units may make comparisons between areas of dissimilar size more difficult, comparing the results to other projects like the Hotspots project proves that it is an effective and efficient route to creating detailed disaster maps.

Data Source (EM-DAT)

The EM-DAT is an ongoing global record of disaster events, covering the timeframe 1900 to present, that can be used as a tool to assess vulnerability. This study focuses on measuring vulnerability at the first administrative boundary level as a function of the number of disasters occurring during the time period 1900–2007. In order to qualify as a disaster, one of the following parameters for a hazardous event set by EM-DAT must be met:

1. 10 or more people killed;
2. 100 or more people affected;
3. A call for international assistance; or
4. The national declaration of a state of emergency.

As the most complete and widely available global disaster database, EM-DAT covers the spectrum of disasters from natural to technological. However, subnational mapping of the phenomena is limited by its global scope. The global scope of the database limits mapping disasters at a finer scale because it attempts to record all disasters for the whole world accurately by country, not by smaller subnational units. The database is organized into a series of fields containing information on the disaster date, type, event name (for hurricanes and volcanoes), country name, location, the criteria met for qualifying as a disaster, number of mortalities, the number of people affected, and estimated damage in dollars. Disaster events that occur as a result of a larger ”mother” event are included within the primary event as ”associated disasters.” For example, a flood or landslide caused by a tropical storm would not be considered as a separate flood or landslide event. The extent to which the data can be disaggregated is limited by location information that is often too vague, too specific, or nonavailable. Entries that are too specific generally list the names of small towns or municipalities with no departmental reference, creating difficulty when many towns with the same name exist in the same country. Location information that poses problems to subnational mapping because it is too vague is typified by entries

named by general geographic regions like North or South. In addition to these spatial limitations, the database is known to underreport disasters prior to the 1970s (Charvériat, 2000). Despite these limitations, the database is the most complete source of information available about disaster occurrences, and combined with further research and additional data sources, it is possible to analyze the data at the first administrative level.

Methods

Data Disaggregation and Spatial Referencing

The data were sorted by country and disaster type, creating a separate spreadsheet for each country in which disaster events were organized by type in separate tabs. The raw data classify events by country and one disaster is considered to be a single event. The location column of the raw data describes the geographic areas affected by that disaster and typically specifies one or more locations by first administrative level. Events with this level of detail were the easiest to disaggregate, simply turning the single entry into a multi-entry event, with an additional location column describing the more specific first administrative level boundary. In this way, 92 percent of the disaster event entries were disaggregated to the first-level administrative district using information included in the EM-DAT data.

A portion of entries had location information less specific than administrative districts (for example, North or Southeast provinces) or associated with physiographic regions crosscutting political boundaries (i.e., “Andes region” or “Grand Chaco”). Event locations such as these necessitated a degree of decisionmaking using atlases and cultural resources to determine which provinces were affected, occasionally requiring an estimation of certain locations. Consequently, even as the number of disasters for a district may not be exact, the number of estimated events is small and general trends in the data are still observable.

When disaster events included no location information, other sources were consulted using secondary information provided in the database, such as date, disaster name, and comments. Flood events without precise location information were assigned to provinces by referencing the name of the river basin cited in the “Comments” column. The Board of Geographic Names Gazetteer was used in locating many smaller rivers and towns not included in atlases. The attribute ”Disaster name” was useful in locating the provinces affected by hurricanes and volcanoes. For volcanic disasters with no formerly attributed location data, and where the name of the volcano was provided, the immediate district was assumed to be the affected area. When hurricane events were not attributed with specific location information but the name of the event was given, the National Oceanic and Atmospheric Administration’s historical storm tracker (*http://www.stormtracker.noaa.gov*) was used to estimate the probable affected districts using an overlay analysis of the storm tracks on maps of provincial boundaries to determine which areas would be most affected by a storm of a particular intensity. Using the data and disaster type, it was often possible to research archived news articles on the disasters to find additional location information. When further research was impossible, the event was not included in the final database and was not mapped.

EM-DAT disaster events are initially organized at the country level and, through disaggregating to the provincial level, some important information is lost, such as the number of people killed, the number of people affected, and the estimated damage costs. These figures are impossible to divide into smaller affected provinces. In total, only 119 out of 1,547 (7.7 percent) disaggregated vulnerability events were not mapped because of insufficient geographic information.

Visualization of Vulnerability to Disaster Events

Attaining a correct and up-to-date first administrative boundary layer required the compilation of several base map data sources. In order to map the disaster data, the number of disaggregated disaster events was tallied for each administrative district and compiled into a database. The new database includes a field of unique identifiers for each first administrative level division that matches the GIS boundary shapefile ID. For example, the data entry for La Paz, Honduras, includes the identifier HND-LPA. The boundary shapefile has a polygon representing La Paz with the same distinguishing identifier. The disaster data were linked to the digital first-level administrative map boundaries in GIS using the "JOIN" command. The data were mapped according to disaster type and frequency in ESRI ArcMap 9.2. The natural breaks classification method was used to classify disaster subsets, excluding zero values that were mapped as a separate class. Zero values were mapped as a standard off-white across all disaster types, and appropriate color ramps were chosen for each disaster type so that departments in classes with a higher frequency of experiencing disasters were represented by darker colors.

The 2007 LandScan™ data obtained from Oak Ridge National Laboratory's Global Population Project is used to explore the relationship between populated areas and disaster frequency. The overlay of the two datasets in a GIS allows the visualization of highly populated areas in relation to areas with high disaster frequency. To visualize disasters within the context of human settlement and physiographic features, base map layers with major rivers and bodies of water, major cities, and active volcanoes were inserted. All cities with populations above 500,000 were included in the maps and represent major population centers in the maps that are not able to include the LandScan™ data.

It is expected that disasters such as landslides predominate in areas of high slope, while flooding occurs in coastal and riparian lowlands. The digital elevation model (DEM) underlying the disaster maps articulates this connection between disaster location, concentration, and landscape. Most importantly, when overlaying the topographic content with the occurrence of vulnerability to disaster, it is possible to discern between areas with physiographic risk for natural hazards with areas that actually experienced the resulting natural disaster.

Results

Disaster Profile by Country

The disaster profile for all countries is shown in figure 1 by proportional pie charts representing the breakdown of disaster events into their frequency of occurrence, where pie chart size reflects the total number of disasters experienced by each country. Displaying the data in this way highlights the dominant disaster types affecting each country. For example, Brazil's disaster profile includes drought, landslides, floods, and storms, with the flood-related disaster making up 63 percent of the total. However, in Mexico, all disaster types, except tsunami/tidal waves, affect vulnerable populations, with the predominant disaster type being windstorms at 40 percent. In the Caribbean, many islands' sole disaster type is windstorms.

Figure 1. Natural disasters by country, with population density, from 1900–2007.

Overlaying the disaster profile of the countries with the LandScan™ population data highlights the high correspondence between population density and sheer number of disasters. Because larger countries are more likely to have high numbers of disasters, it is expected that countries like Mexico, Brazil, and Argentina would have a proportionally larger number of disasters when compared to the Caribbean islands. However, after factoring the areal extent of a country into the total number of disasters occurred, it is interesting to note that many of the smaller countries experience more disasters per 100 square kilometers (km^2) than do larger countries and therefore experience a larger concentration of disastrous events (table 1). Also shown in table 1, the 5 countries with the highest population density (population/km^2) are all within the top 21 of countries ranked in order of highest disasters per 100 km^2.

Table 1. Natural disaster occurrences and population as a factor of area in Latin America and the Caribbean.

Natural Disasters and Population Data per Square Kilometer in Latin America and the Caribbean, 1900-2007[1]

[Six countries with the highest population/km^2 are highlighted in yellow]

Country	Area (km^2)	Disaster/100 km^2	Population	Population/km^2
Anguilla	102	7.843	14,108	138
Montserrat	102	6.863	9,638	94
St. Vincent and the Grenadines	389	3.856	118,432	304
St. Kitts and Nevis	261	3.448	39,619	152
Antigua and Barbuda	443	2.259	69,842	158
St. Lucia	606	2.145	172,884	285
Barbados	431	2.088	281,968	654
Guadeloupe[2]	629	2.067	399,002	634
Grenada	344	2.035	90,343	263
British Virgin Islands	153	1.961	24,004	157
Dominica	754	1.592	72,514	96
Cayman Islands	262	1.527	47,862	183
Martinique[2]	1,060	1.132	447,002	422
Virgin Islands	346	0.867	108,210	313
Turks and Caicos Islands	430	0.698	22,352	52
Netherlands Antilles	960	0.417	225,369	235
Jamaica	10,831	0.397	2,804,332	259
Haiti	27,560	0.258	8,924,553	324
Puerto Rico	8,870	0.237	3,958,128	446
Trinidad and Tobago	5,128	0.234	1,047,366	204
El Salvador	20,720	0.174	7,066,403	341
Bahamas, The	10,070	0.169	307,451	31
Costa Rica	50,660	0.091	4,195,914	83
Dominican Rep	48,380	0.076	9,507,133	197
Belize	22,806	0.061	301,270	13
Cuba	110,860	0.053	11,423,952	103
Honduras	111,890	0.046	7,639,327	68
Guatemala	108,430	0.044	13,002,206	120
Panama	75,990	0.042	3,292,693	43
Nicaragua	120,254	0.035	5,785,846	48
Ecuador	276,840	0.022	13,927,650	50
Colombia	1,038,700	0.012	45,013,674	43
Uruguay	173,620	0.010	3,477,778	20
Chile	748,800	0.010	16,454,143	22
Peru	1,280,000	0.009	29,180,899	23
Mexico	1,923,040	0.009	109,955,400	57
Paraguay	397,300	0.005	6,831,306	17
Bolivia	1,084,390	0.004	9,247,816	9
Venezuela	882,050	0.004	26,414,815	30
Guyana	196,850	0.004	770,794	4
Argentina	2,766,690	0.002	40,677,348	15
French Guiana*	89,150	0.002	201,996	2
Brazil	8,456,510	0.002	191,908,598	23
Suriname	161,470	0.001	475,996	3

[1] Population and area data from CIA World Factbook at https //www.cia.gov/library/publications/the-world-factbook/geos/nt.html.

[2] Population data for French over-seas departments from the Institut National de la Statistique et des Etudes Economiques (NSEE) at http://www.insee.fr/fr/home/home_page.asp.

Floods

Flooding in Latin America and the Caribbean is widespread and is probably the most commonly experienced disaster type (fig. 2). It is important to note, however, that floods mapped here do not include flooding that occurs as a result of a larger source disaster. There were few areas that experienced no flood disasters, while others have been affected by as many as 21 flood events over the past century. Provinces in inland Guyana, coastal Suriname, southeast Mexico on the Yucatan, inland Ecuador, much of the Caribbean, Nicaragua, and several Andean and Patagonian provinces of Chile and Argentina have not experienced any flooding disasters in the time period 1900–2007. Other areas experiencing few (one to two) flood disasters comprise much of the Amazon region of Brazil, southern Venezuela, Guerrero and Michoacán States in western Mexico, along with Coahuila in the North. Departments with large numbers of flood disasters occurred in coastal Brazil, eastern Argentina, southern Mexico, Colombia, and the Atlantic coast of Costa Rica. The mean number of flood disasters per department was 2.88, which is by far the highest occurrence of any of the disaster types. Again, it is important to point out that flood events include only those floods that were reported as disasters, thereby excluding any flood events where the damage did not meet the determined threshold.

Figure 2. Flood disaster occurrences by first administrative level boundary, 1900–2007.

Volcanoes

Vulnerability to volcanic disasters is limited to the western coasts of South and Central America, dictated by the presence of an active chain of volcanoes and the volcanic islands of the Caribbean. The most active districts of central Mexico (Jalisco and Pueblo departments), the Guatemala department in Guatemala, Ecuador (Chimborazo and Tungurahua departments), and Araucania in southern Chile each experienced five or six volcano-related disasters.

Figure 3. Volcanic disaster occurrences by first administrative level boundary, 1900–2007.

Windstorms

According to EM-DAT, the category ”Windstorms” encompasses cyclone, hurricane, storm, tornado, tropical storm, typhoon, and winter storm disasters. Hurricanes or tropical storms comprise 80 percent of the historic windstorm disaster events in Latin America and the Caribbean. The prevailing areas of vulnerability to windstorm disasters are the East Coast of Mexico and the Caribbean (13–22 events), although all of Central America is at least moderately affected (8–12 events) (fig. 4). Figure 5 displays windstorm disasters overlaid with the storm tracks of the nine greatest hurricane disasters in terms of number of people affected as recorded by EM-DAT. These tracks emphasize the vulnerability of this area. Relative to Central America and the Caribbean, South America experienced relatively few windstorm disasters.

Figure 4. Windstorm disaster occurrences by first administrative level boundary, 1900–2007.

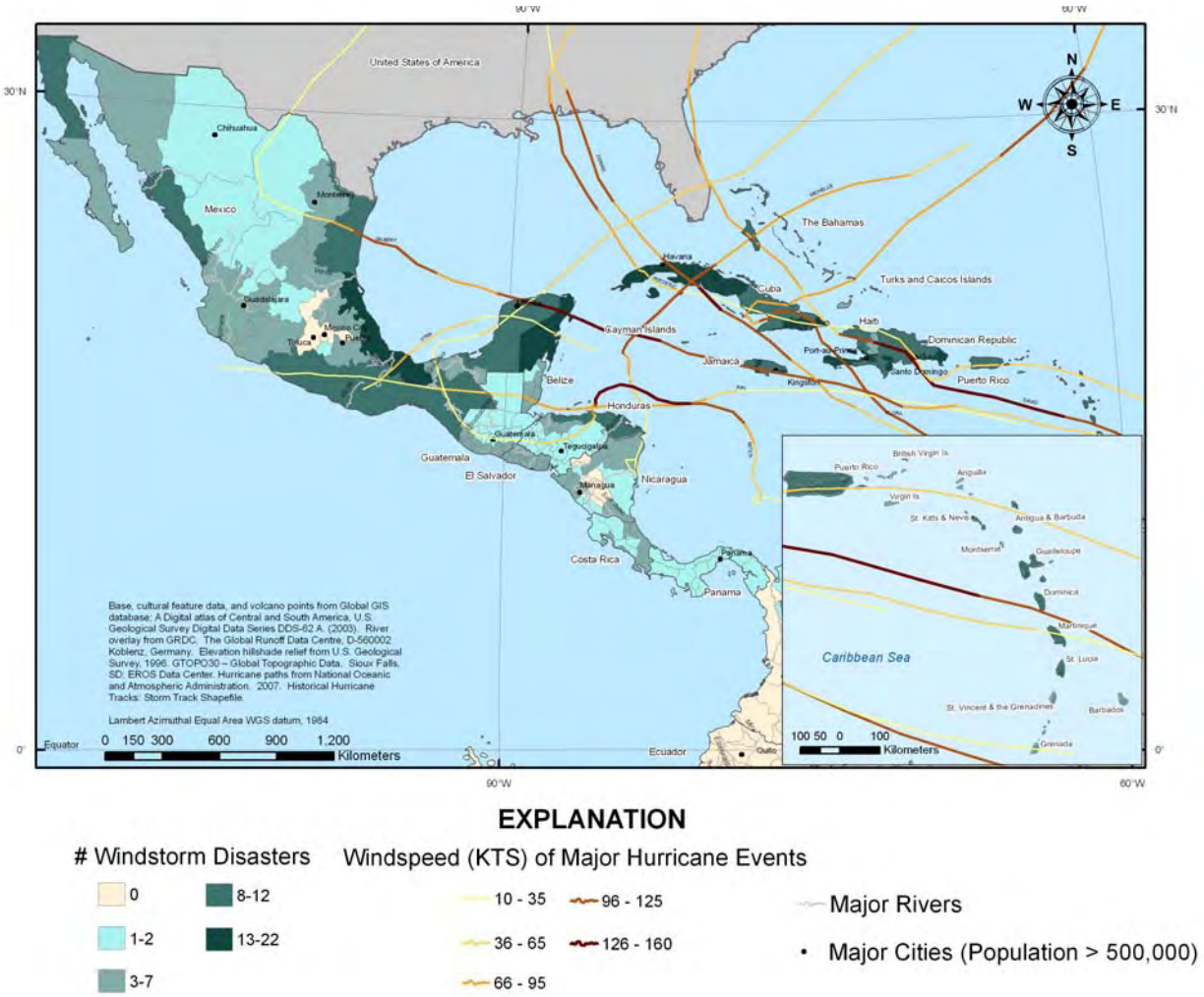

Figure 5. Windstorm disaster occurrences in Central America and the Caribbean by first administrative level boundary, with major hurricane tracks, 1900–2007.

Earthquakes

Vulnerability to earthquake disasters is mostly confined to the active fault lines where the Cocos and Nazca plates converge with the South American plate on the western coasts of South and Central America. In the Caribbean, the offshore Puerto Rico and Hispaniola active trenches have created a recorded one to three disasters in Caribbean departments. Although rare, there is also earthquake activity in northeastern Brazil, causing one recorded disaster in that region in 1986.

Figure 6. Earthquake and wave disaster occurrences by first administrative level boundary, 1900–2007.

Wave/Surge

Wave/surge disasters are also shown in figure 6. Wave/surge is a data category comprising both tsunamis and tidal waves. Tsunami and tidal wave disasters are uncommon but do occur in Latin America. Over the past century, four tsunamis and one tidal wave disastrously affected the Pacific coasts of South and Central America. There are historical records of tsunamis disasters affecting the Caribbean after 1900, but these events were not recorded in EM-DAT (2007) [NOAA /WDC Historical Tsunami Database at NGDC (*http://www.ngdc.noaa.gov/hazard/tsu_db.shtml*)].

Drought

Dilley and others (2005) found that about 38 percent of the world's land area has some level of drought exposure. According to EM-DAT, in the past 100 years (since 1900), certain administrative departments have experienced as many as 10 drought events (fig. 7). Particular regions experiencing intense drought disasters include Northeast Brazil, the Andes region, and the parts of Central America sometimes referred to as the "drought corridor." The Caribbean region has experienced very few disasters due to drought with the exception of Cuba and Jamaica.

Figure 7. Drought disaster occurrences by first administrative level boundary, 1900–2007.

As is true with several of the disaster types, many of the areas highly affected by drought events coincide with heavily populated areas. This is especially true for the Northeast region of Brazil and parts

of Guatemala and El Salvador. The mean number of drought disasters per department is 0.60; more departments have not experienced drought disasters than the number of those that have.

Landslides

The occurrence of most of the reported landslide disasters, including one avalanche and one mudflow, is congruent with high-relief terrain with heavily populated slopes (fig. 8). The department that was hardest hit by landslide disasters was Antioquia, Colombia, whose population has been affected by nine landslides since 1900. Another area of frequent events is eastern Brazil, especially the district Rio de Janeiro. The majority of administrative zones that were disastrously affected by landslides only experienced one or two events, although parts of Peru, El Salvador, Ecuador, and Brazil all experienced three to five.

Figure 8. Landslide disaster occurrences by first administrative level boundary, 1900–2007.

Natural Disaster Frequency by First Administrative Level

Looking at aggregate vulnerability to natural disasters at the subnational level reveals which departments are most affected by disasters of all types. Figure 9 shows the total occurrence of natural disasters in South America from 1900–2007. The number of disasters experienced at the department level ranges from zero to 31, with an average number of disasters per department of 9.2. The few departments that experienced no disasters are in southern Paraguay, Guyana, and Suriname.

Four departments stand out as being the most vulnerable with 26–31 disasters: Rio de Janeiro and Minas Gerais, Brazil, along with Antioquia and Cordoba, Colombia. Departments along the Atlantic and Pacific coasts have experienced more disasters than most inland departments, with the exception of departments in Bolivia. Most of the Amazon and Patagonian regions of South America experienced very few disasters.

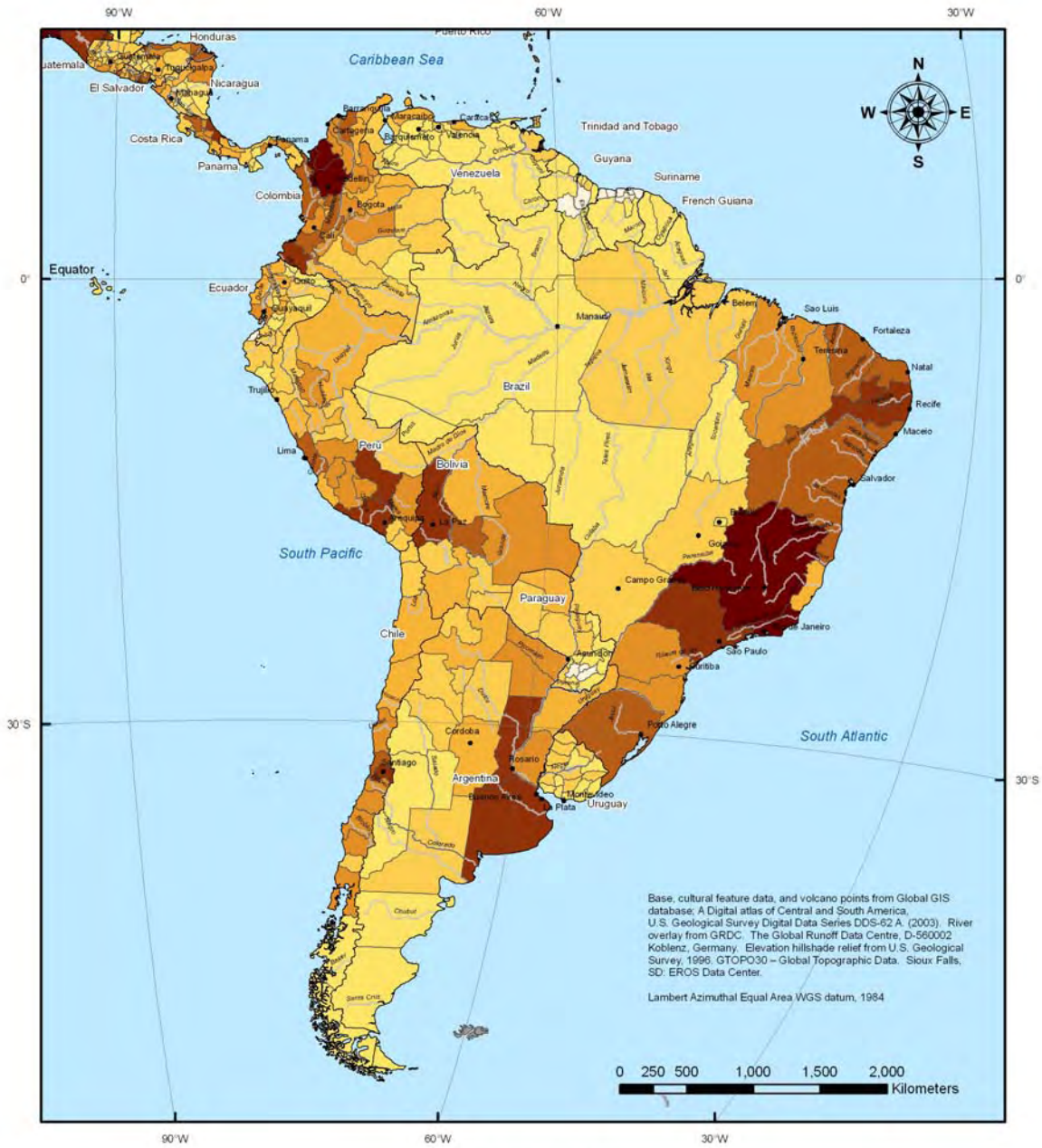

Figure 9. Natural disaster occurrences in South America by first administrative level boundary, 1900–2007.

Figure 10 displays the cumulative number of disasters experienced by the first administrative level in Central America, Mexico, and the Caribbean from 1900–2007. In the Caribbean, departments in Cuba, Jamaica, and Puerto Rico all have high counts of total disasters per department. In Central America, many coastal departments have experienced a moderate to high number of disasters, particularly in El Salvador, Honduras, and Costa Rica. Southern Mexican States, especially Oaxaca and Veracruz, are among the most vulnerable.

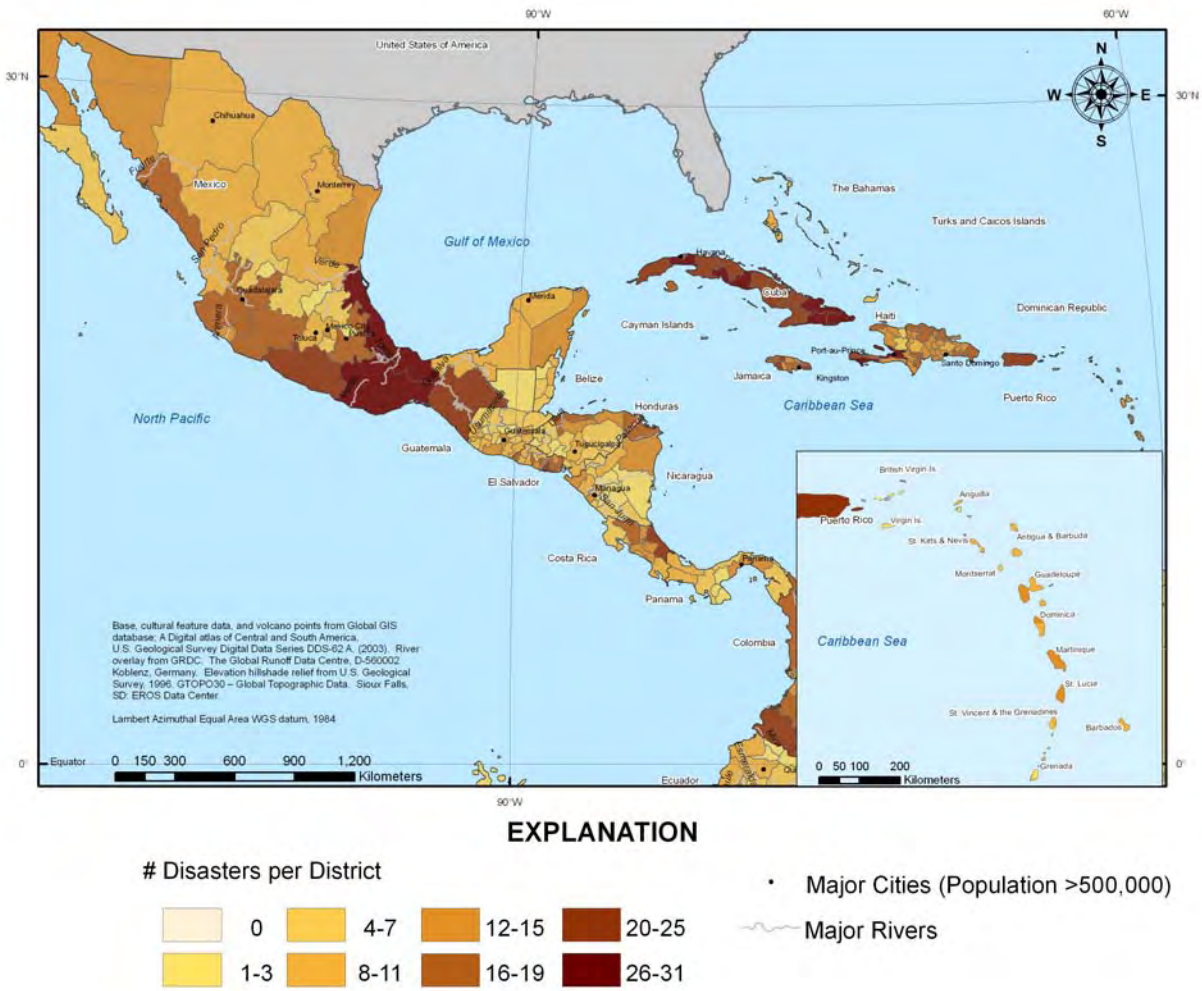

Figure 10. Natural disaster occurrences in Central America and the Caribbean by first administrative level boundary, 1900–2007.

Discussion

The product of mapping vulnerability to disasters at the administrative level enables the viewer to see a more localized resolution of past vulnerable populations. It is evident in these maps that natural disasters affect populations at drastically different scales. Some disaster types (for example, floods) are widespread across Latin America, whereas volcanic eruption disasters are localized to the most active regions along the plate boundary zone.

Trends in the data suggest that disasters occur most often in places that are highly populated. The pattern created by the distribution of disasters, showing higher densities along the coasts of South

America, affecting eastern Brazil, western Peru, Ecuador, and Colombia, throughout Central America, and in Mexico, is consistent with populated areas displayed in figure 1. This pattern is expected because in order for an event to qualify as a disaster, according to EM-DAT standards, a certain number of people must be affected. Without the presence of populations, major events are not devastating and not considered to be disasters. In addition, high concentrations of populations can also create a more vulnerable environment. The ability of populations to change and exert forces on their landscape through the building of infrastructure, the movement and draining of land for settlement or agricultural purposes, and the building of dams, for example, can all lead to increased vulnerability to natural disasters. Similarly, areas with relatively few or no disasters of any type are historically consistent with unpopulated areas. This is true for the Amazon region in western Brazil and eastern Peru, eastern Colombia, southern Venezuela, as well as the Patagonian region of Argentina and Chile and inland Guyana, Suriname, and French Guiana. Table 1 expands upon this theme. Bigger countries have historically experienced more disasters, but when country area and population density are taken into account, they actually have experienced fewer disasters per square kilometer. This could be a result of a higher density of infrastructure and settlement in smaller countries. Future trends in these areas of low population, however, would require hazards risk studies in order to determine the results of development in terms of vulnerability.

While population is a major factor where hazards become disasters, there are other important factors in the vulnerability trends. Earthquake disasters do not follow the same trends consistently, as the concentration of earthquakes does not necessarily coincide with the largest population centers, suggesting that populated rural areas could be especially vulnerable to earthquake devastation. This is easy to see in the Mexican States of Guerrero and Michoacán.

As expected, major concentrations of flood disaster events are associated with coastal zones and large river basins. Flooding disasters would benefit most from being mapped at a different level, specifically by watershed or river basin. The shape of the administrative boundaries highly distorts the appearance of the spatial distribution of floods where river basins would provide a much more accurate level of detail. That being said, there still appears to be correlation between districts with major cities and high occurrences of flooding disasters.

Perhaps the strongest application of the disaggregated data is for the examination of disaster spread within a single country. A limitation of disaggregation to the first administrative level, as opposed to the grid level used by the Hotspots method, is that the sizes of the districts vary immensely between countries. A district in Mexico, for example, may be three times the size of the entire country of Honduras. Therefore, examining the spread of disasters within a single country is more useful. Also, when dealing with a smaller subset of the data, the statistical breaks are smaller and categories contain more information.

While broadening the current understanding of the spatial distribution of vulnerability to natural disasters, the data displayed in these maps should not be taken as an authoritative count of hazard events occurring in any one administrative district. Another limitation of the data reflected in the mapping disasters at the administrative level is that information about the severity or intensity of events is lost in the process of disaggregation. Event severity, as measured in terms of lives lost, number of people affected or homeless, and economic losses, is available at the country level for each disaster, but the information is collective for the country, with no way to disaggregate it along with the location data.

Conclusion

The vulnerability of populations and infrastructure to disastrous events as displayed in these maps is the product of disaggregating and spatially referencing historical disaster data. These data, while collected and organized on a global scale, contain attributes that enable intercountry regional spatial disaggregation. Identifying vulnerable populations and places should be the first step in preparing for and mitigating against the effects of future hazards. Mapping vulnerability to natural disasters by administrative zones is useful not only to help identify the regions with the greatest vulnerability but also to compare and contrast this with decision-making and the amount of resources used for relief and mitigation. The disaggregated data are especially useful for studying historic geographic distribution of disasters within each country and how vulnerability differs from the coast to the mountains, in conjunction with population and other physiographic variations. In addition to aiding in the critical assessment of the historical distribution of resources in terms of vulnerability, the focuses of this research on historic patterns of vulnerability enable researchers to target areas for further studies and areas that may be at risk for disaster in the future. As the EM-DAT data are unfit for predicting future trends, these targeted areas would then benefit from a natural hazard assessment in order to better inform regional planning and development.

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