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Disaster Risks to Infrastructure in El Salvador

Toward a sustained national framework for infrastructure risk assessment

El Salvador is a small and densely populated country in Central America that is highly vulnerable to natural hazards. The devastating impacts of Hurricane Mitch in 1998 and two earthquakes in 2001 catapulted the need for disaster risk management to the national policy agenda. Assessing disaster risks to infrastructure is an essential step in minimizing the effects of disasters and in protecting people, nature and economic assets from loss and damage should infrastructure fail.

By request from the Government of El Salvador, the Climate and Development Knowledge Network (CDKN) funded a national multi-hazard study on existing infrastructure of strategic, economic and social importance for the country. Based on historic observations, the study modelled almost 100 different hazard scenarios (landslides, flooding, tsunamis, earthquakes and volcanic hazards) and the physical vulnerability of major roads, highway bridges, transmission towers, electrical sub-stations, water & sewer infrastructure, schools, and healthcare facilities. The total long term average annual loss to the infrastructure included in the analysis is estimated to be US$35.5 million, representing 0.41% of the total value of infrastructure stock. Earthquakes and floods represent nearly 80% of expected losses. Among infrastructure types and considering annual average losses alone, schools are most at risk.

Besides undertaking further, detailed risk assessments, recommended strategies to build on results of this study are as follows: (1) use initial risk estimates to set priorities for infrastructure reinforcements and retrofits; (2) ensure national-level results inform local planning; (3) broaden risk metrics beyond infrastructure replacement costs; (4) analyze the influence of climate change on vulnerability to flooding, landslide risk, and tsunamis; and (5) nurture and sustain collaboration across ministries responsible for infrastructure.

This policy brief summarizes a study undertaken between February 2015 and April 2016 to identify the risks presented by a range of natural hazards on infrastructure of strategic importance in El Salvador.

Natural hazard risk in El Salvador

El Salvador is highly vulnerable to natural hazards. It is the smallest and most densely populated country in Central America, with 66% of its 6.1 million people living in cities and nearly 30% of them in slums.[1] Not only is the country located in one of the most earthquake-prone global regions.[2] It is also exposed to extreme weather events that cause damage through intense rainfall, floods, landslides and debris flows/lahars. Over 90% of El Salvador's population lives in areas of high risk to natural disasters[3] and approximately 96% of the country's gross domestic product (GDP) is linked with these locations. Aside from the concentration of people, assets and economic activity in at-risk areas, factors that shape vulnerability include environmental degradation, poverty and a weakened institutional capacity to confront scarcity and resilience challenges resulting from the legacy of civil war.[4]

The devastating impacts of Hurricane Mitch in 1998 and two earthquakes in 2001 catapulted disaster risk management to the national policy agenda.[5] The Government of El Salvador created the National Land Studies Service in 2001 (*Servicio Nacional de Estudios Territoriales*, later renamed the Environmental Observatory or *Observatorio Ambiental*). Through it, assuming government roles and building capacity in providing information for decision-making before, during and after disasters (e.g., hazard mapping, risk assessment studies, early warning systems, among others). The *Civil Protection, Disaster Prevention and Mitigation Law* came into effect in 2005, breathing life into the national system for disaster risk management that exists today.[6] This system includes multi-tiered, multi-stakeholder committees, policies, plans and a national disaster fund.

Why is infrastructure risk assessment important?

Well-functioning infrastructure systems, such as road networks, water, power and communications infrastructure, are core to a country's disaster risk management (DRM) response. A starting point for reducing disaster risk due to infrastructure destruction and service disruption is to understand what the hazards and the physical, social, economic and environmental vulnerabilities are; how both hazards and vulnerabilities can change over time; and then decide on what actions to take on the basis of that information.

In El Salvador, and elsewhere, studies and data available to support national infrastructure risk assessment can be limited. National analyses frequently rely on historical event data to provide snapshots of impact relative to return intervals of major events. This "top-down" approach, however, is not designed to explore the evolving nature of vulnerabilities. In contrast, bottom-up approaches build on inventories of vulnerability and hazard information to facilitate analysis of specific infrastructure components and plausible (yet untested) hazard scenarios.

A new study highlights infrastructure values at risk

By request from the Government of El Salvador, the Climate and Development Knowledge Network (CDKN) and its implementation partners ESSA Technologies Ltd. and WESA-BluMetric Environmental Services Inc. worked collaboratively with the Ministry of Environment and Natural Resources - that houses the Environmental Observatory - as well as with Salvadorian agencies responsible for infrastructure to produce initial estimates of values at risk and a national framework for sustained infrastructure risk assessment.[7]

The team used a bottom-up approach to estimate infrastructure values at risk. Based on historic observations, the study modelled almost 100 different hazard scenarios (landslides, flooding, tsunamis, earthquakes, volcanic) and the physical vulnerability of an inventory of seven infrastructure categories (major roads, highway bridges, transmission towers, electrical sub-stations, water & sewer infrastructure, schools and healthcare facilities). The modelling framework has built-in flexibility to test the implications of incomplete information and uncertainties in magnitudes and frequencies of future hazards. The natural hazard mapping inventory developed as part of the study is incomplete but brings together the best available information at this time. The framework could well form the basis for a national risk assessment program.

The annual average cost of rebuilding damaged infrastructure is estimated at $35.5million

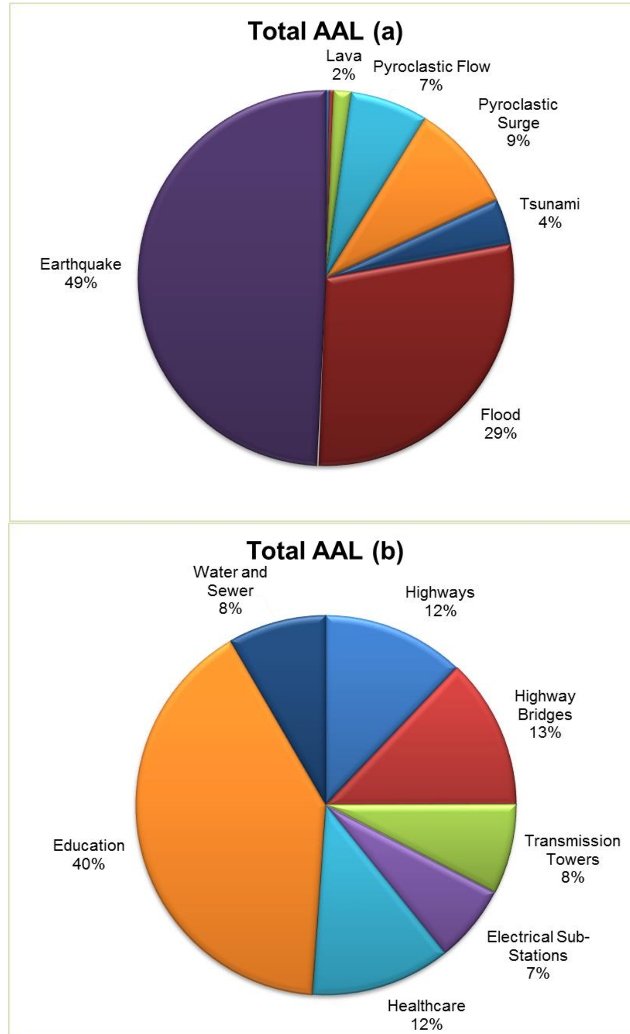
Total Average Annual Loss (AAL) for the seven infrastructure categories studied amounts to $35,528,072. For context, this represents 0.15% of annual GDP (2012).[8]

Box 1: What is Average Annual Loss?
Average Annual Loss (AAL) is a common risk metric used in disaster risk studies. It represents the expected loss per year, averaged over many years. In the context of this study, using AAL was beneficial because it:

- Provides a uniform measure
- Is comparable across hazard and infrastructure types
- Relates directly to financial implications of financial exposure
- Suits data-poor contexts
- Involves a calculation that is conceptually simple (i.e., summing expected damage to infrastructure measured in $ across hazard scenarios)

Differences in financial exposure by natural hazard and infrastructure type are worth noting (see Figure 1). Similar to other studies, losses from earthquakes and floods predominate. Earthquake losses are significant because the entire country is in a high-risk category and all infrastructure is exposed to some level of shaking. Floods occur in many parts of the country, sometimes in association with hurricanes and tropical storms. In contrast, volcanic hazards have high destructive potential but happen infrequently. Critical infrastructure construction has tended to avoid areas of highest exposure to these hazards. AAL estimates for pyroclastic flows and surges are relatively high in this analysis because of the return intervals chosen and are subject to significant uncertainty.

Figure 1. Financial exposure by hazard and infrastructure type



In (a) losses due to lahars and ash amount to 0.7% of the total AAL.

Of all infrastructure types, financial exposure of education facilities is greatest. This reflects the large numbers of buildings spread across the country, as well as their relatively low resilience to earthquake shaking. The most significant hazard varies among infrastructure types. Earthquakes are a key risk factor for highways. Floods present most pronounced risks for educational facilities.

Some spatial patterns in risk exposure are evident

Is financial exposure regionally concentrated? Summarizing results by municipality and displaying them as maps helps identify patterns across the country. In this case, spatial patterns are not obvious if combining hazard and infrastructure types. Exploring results by infrastructure type and hazard does reveal risk “hotspots”. For example, Figure 2 shows AAL for healthcare facilities by municipality as a proportion of total stock. Expected losses are significant across the country but tend to be higher in coastal areas (up to 4% of the value of total stock). These areas are subject to more flooding, tsunami impacts and earthquakes, which unconsolidated soils amplify.

This study is an initial step to improve assessment and ultimately management of natural hazard risks to infrastructure of economic and social importance in El Salvador.

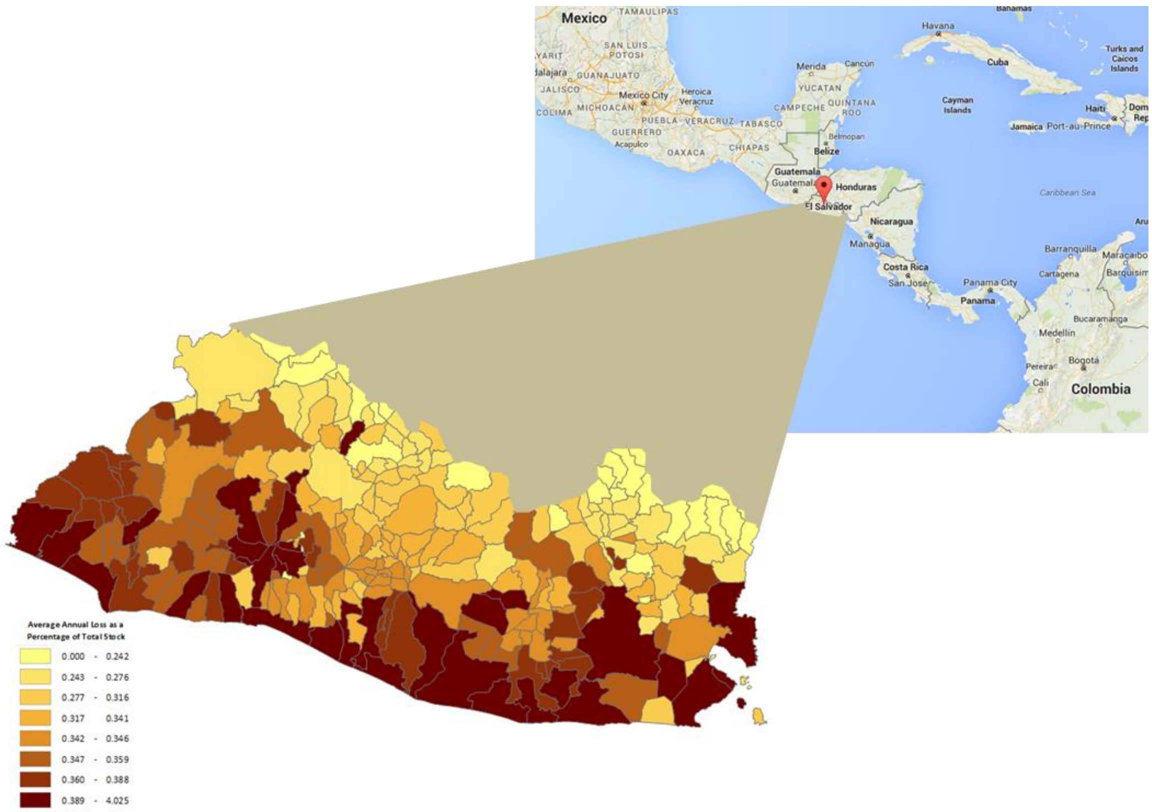


Figure 2. Expected losses to healthcare facilities, by municipality. Deep red denotes highest vulnerability, as measured by AAL as a proportion of total proportion of total stock.

The following recommendations aim at augmenting government capacity to increase the resilience to disaster risks of existing infrastructure and to take natural hazard risk into account in future development.

Five strategies to reduce disaster risks, building on results of this study, stand out

1. **Use initial risk estimates to set priorities for infrastructure reinforcements and retrofits.** Study results can already inform investments in corrective measures – repairs, retrofits and tactics to reduce risk of specific infrastructure facilities. Infrastructure managers can identify the source of the AAL for their facilities and set priorities according to different hazard types. A portfolio of measures to reduce risk includes measures to reduce a facility's vulnerability (e.g., structural improvement to reduce seismic impacts, flood impacts), reduce a facility's exposure (e.g., moving the facility upland, constructing berms to intercept landslide paths), decrease the potential for service disruptions from a facility (e.g., changing operational plans) and decrease recovery times and costs should infrastructure fail (e.g., rapid response tactics). Study results can also help identify infrastructure components that show a high potential for loss but that require further study to determine cost-effective measures to reduce risk.

2. **Ensure national-level results inform local planning.** Local governments play a key role in disaster risk reduction. Information from national-level risk assessments such as this one can complement local-level analysis. The recently-completed *Proyecto de Fortalecimiento de Gobiernos Locales (PFGL)* (an initiative funded the World Bank Group to strengthen local governance[9]) invested $8 million in building the capacity of El Salvador's 262 municipalities in disaster risk management. Developing a municipal disaster risk management plan was a part of this. Not all municipalities completed their plans within the initiative's timelines and the plans developed vary in depth and quality.[10] Nevertheless, sharing information from analyses undertaken at different scales is important. The national-level study identified infrastructure most exposed to a range of natural

hazards. The hazard scenarios and maps developed as part of it can be an input to new municipal plans and their updates. Information flows can and should occur in both directions. For example, the national-level risk assessment can refine its analysis of facilities' vulnerability based on municipalities' assessment of the impact of past disasters related to infrastructure failure.

3. **Broaden risk metrics beyond infrastructure replacement costs.** This study represents risk in the form of Average Annual Loss estimated from direct impacts on infrastructure. We chose this approach for the reasons mentioned in Box 1. Clearly, this is a partial view of values at risk. Future work should incorporate aspects of risk beyond direct repair or replacement cost of infrastructure. An expanded view of risk can include, for example, damage to and loss of building contents (e.g., hospital facilities containing expensive equipment), network impacts (e.g., loss of power to a water treatment plant can result in the failure of the water supply to a hospital which then severely impairs the functioning of that hospital), recovery time and its impact (e.g., if a bridge is easily bypassed or a new temporary bridge can be put in place rapidly then damage to that bridge is less significant than if it will take years to replace) and other indirect costs (e.g., loss of jobs and economic activity due to infrastructure loss and the impact of that loss on other infrastructure).

4. **Analyze the influence of climate change on vulnerability to flooding, landslide risk, and tsunamis.** Global climate change is shifting weather patterns; the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events are changing as a result.[11] El Salvador has witnessed the damaging effects of the increased intensity of extreme weather and climate events over the last five years. Risk assessments should take into account the influence of changing climate conditions on vulnerability profiles.

   This study included hazards and their disaster impacts that are independent of climate change (e.g., volcanic hazards and related impacts). It also includes hazards and impacts with clear links to climate change. In particular, we can expect:

   - Increasing intensity and/or frequency of tropical storms and hurricanes leading to higher frequencies of flooding and possibly greater extents;
   - Increased probability of intense rainfall leading to higher potential for landslides and lahars;
   - Rising sea levels and loss of mangroves increasing vulnerability to tsunami.

   Explicit modelling of future climate and related impacts was beyond the scope of this study, but we did undertake sensitivity analysis. For flooding, which is an important source of AAL, results of climate modelling are of limited use in confidently predicting how floods may change in response to changing climate. However, modelling results do suggest that peak flood events could be twice as frequent in El Salvador in future.[12] Doubling flood frequency in our analysis would make flood risk at least as high as the level of earthquake risk. Increased peak flows could also expand the extent of areas inundated. Analysis in our modelling framework indicates that a relatively small increase in flood extent could have a large impact on the number of buildings exposed.

   Future risk assessment studies should investigate the three dimensions of climate change listed above. We recommend starting with flood hazards and enhancing the flood scenarios represented in our current modelling framework to enable examination of the impacts of shifts in flood extents and probabilities that are likely with climate change.

5. **Nurture and sustain collaboration across ministries responsible for infrastructure.** To date, risk assessments for disaster management planning in El Salvador have taken place sporadically with project funding. The results of this study and the process behind it offer an opportunity to build a sustainable approach to national-level risk assessment based on ongoing collaboration among government ministries and other agencies responsible for infrastructure. In developing the study we identified a network of actors who share an interest in infrastructure risk assessment and support the need to build on the momentum created by this CDKN-funded study. Suggested next steps fall in two main areas: (a) establishing a sustainable organizational structure for national risk assessment and (b) improving data availability and quality now and over time.

   Resources are scarce and key technical staff are in high demand. Several actions can be taken to continue to make progress. These include fostering data and information sharing among agencies backed by appropriate high-level agreements; identifying and empowering key staff; and promoting regular communications and interaction across agencies. Designating a government focal point to lead coordination efforts is critical. One option is for the Ministry of Environment and Natural Resources to assume that coordination role.

   This study used the best available data accessible to the team during project timelines. However, work remains to ensure that the most up to date and accurate infrastructure data has been collected. This involves working closely with representatives of the different ministries and agencies involved and can take considerable time. A cost-effective approach to augmenting the inventories compiled may be to engage graduate students and researchers from local Universities. Filling data gaps (e.g., on factors that make infrastructure vulnerable) is also important. Routine activities, such as national censuses for schools, hospitals, and transportation infrastructure, are key entry points to collect new data of relevance to risk assessment.

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Endnotes

[1] UNISDR, Global Assessment Report 2015, El Salvador Country Risk Profile

[2] Disaster Risk Management in Central America: GFDRR Country Notes – El Salvador http://www.gfdrr.org/sites/gfdrr.org/files/El_Salvador_DRM.pdf

[3] UN Disaster Assessment and Coordination, 2010. Also, CDKN & ODI (2014). The Future Framework for Disaster Risk Reduction - based on Global Hotspots data, World Bank (2005).

[4] According to the Program of Indicators of Disaster Risk and Risk Management for the Americas of the Inter-American Development Bank Nicaragua, Jamaica, Guatemala, El Salvador and Honduras are most vulnerable among 19 Latin American countries. This assessment is based on an aggregate measure that considers exposure and susceptibility, socioeconomic fragilities and lack of resilience (IPCC 2012, page 92).

[5] C. Kattan, Personal communication; Informe Nacional Sobre la Gestión Integral del Riesgo De Desastres de El Salvador (2013)

[6] See *Ley de Protección Civil, Prevención y Mitigación de Desastres* http://www.preventionweb.net/files/21406_15530leydeproteccincivil1.pdf

[7] Agencies include the Ministries of Education, Health and Public Works, the Water Agency (ANDA), the Hydropwer Commission for the Lempa (CEL), the authority overseeing electrical transmission and distribution (ETESAL) and the port and airport authority (CEPA).

[8] http://databank.worldbank.org/data/reports.aspx?Code=NY.GDP.MKTP.CD&id=af3ce82b&report_name=Popular_indicators&populartype=series&ispopular=y

[9] See: http://www.pfgl.gob.sv/Site/index.php/pfgl/antecedentes.html

[10] PFGL Unidad Ejecutora del Proyecto "La experiencia del PFGL en la Planificación Municipal del Riesgo de Desastres desde una metodología participativa", presentación 20 de marzo, 2015. Ryna Avila, personal communication.

[11] IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

[12] E. Aguilar, T. Peterson, P. Obando, R. Frutos, J. Retana, M. Solera, J. Soley, I. Garcıa, R. Araujo, A. Santos, V. Valle, M. Brunet, L. Aguilar, L. Alvarez, M. Bautista, C. Castanon, L. Herrera, E. Ruano, J. Sinay, E. Sanchez and G. Oviedo, "Changes in precipitation and temperature extremes in Central America and northern South America, 1961–2003," Journal of Geophysical Research, vol. 110, p. 15, 2005.

The Intergovernmental Panel on Climate Change (IPCC) suggests that in the Central America/Mexico region 1-in-20 year annual maximum 24-hour precipitation rates will become a 1-in-5 to -15 year events by the end of 21st century.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.