Philippines Catastrophe Risk Assessment and Modeling
Component 2: Exposure Data Collection and Vulnerability Function Development

Technical Report Submitted to the World Bank

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Table of Contents

List of Figures

List of Tables

1 Introduction

The Philippines is exposed to a multitude of natural hazards such as earthquakes, typhoons (tropical cyclones[1]), and flooding (see Figure 1.1) that result in significant property damage and socio-economic impacts. The Philippines is also widely acknowledged as one of the most disaster[2]-prone countries in the world (Delica, 1994). According to Benson (1997), roughly 20 tropical disturbances enter the Philippines Area of Responsibility (PAR) on average per year, of which about 11 are classified as typhoons. According to Brown et al. (1991) it is highly likely that at least four typhoons will make landfall in any given year, while an average of eight to nine tropical cyclones would actually reach land and a further two offshore tropical cyclones would result in damage every year. While different studies may differ in their estimates of the frequency and severity of the tropical cyclones, the general consensus is that the country is severely impacted by tropical cyclones. The eastern part of the country, particularly the north east, is considered most vulnerable to typhoons.

Severe flooding is normally associated with the heavy rains accompanying typhoons. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has estimated that some 47% of average annual rainfall is due to typhoons, 14% to monsoons, and 39% to other weather systems. In December 2011, flash floods caused by typhoon Washi killed over 1,000 people and left hundreds of thousands homeless on the island of Mindanao. In September 2009, typhoon Ondoy impacted Metro Manila. Less than a week later typhoon Pepeng carved a trail of destruction in Northern Luzon for almost two weeks. Consequences of the two typhoons included casualties due to flooding and landslides brought about by continuous rain.

In addition, the Philippines is located between two major tectonic plates, the Pacific and Eurasian plates, and within the Philippine Sea plate (USGS, 2011). The Pacific plate is pushing the Philippine Sea plate beneath the eastern side of the country at a rate of about 7 cm per year (NDCC, 1990), generating regular seismic and volcanic activity. According to the Philippines Institute of Volcanology and Seismology (PHIVOLCS), the country experiences an average of five sizeable earthquakes per day, in turn resulting in ground shaking, and potentially ground rupture, liquefaction, lateral spreading, landslides, and tsunamis.

In terms of their broader economic impacts, hazards experienced in the Philippines can be divided into two distinct categories depending on their frequency of occurrence. Tropical cyclones and floods are the principal hazards falling into the category of more frequently occurring hazards. Both occur annually, although the rate of incidence and severity varies between years. Tropical cyclones alone have been estimated to cause damage equivalent to 0.6% of the GNP every year (ADB, 1994), which significantly impacts the Philippines economic recovery. The second category comprises more severe disasters with considerably longer return periods, such as major earthquakes, volcanic eruptions, or droughts (Benson, 1997).

[1] The term "tropical cyclone" is used as a generic version of the term "typhoon". Both terms are used in the report.
[2] In this report, the term "disaster" is used interchangeably with the term "catastrophe."

The Government of Philippines (GoP) has begun taking a proactive approach to disaster risk management by approving the Disaster Risk Reduction and Management (DRRM) Act in May 2010 (Republic Act No. 10121). One of the priority areas identified by the DRRM Act is the establishment of appropriate risk finance policies and instruments that will help reduce the fiscal burden of the GoP to natural disaster impacts. Furthering the work on risk finance, the GoP is implementing a technical assistance program that would lead to the formulation of a risk finance strategy. Alongside, the GoP has requested a catastrophe risk assessment study that would provide the quantitative underpinnings for the design of an ensuing catastrophe liquidity facility, especially addressing the higher layers of risk.

The World Bank, which is assisting the GoP with its disaster risk management objectives, has retained AIR Worldwide Corporation (AIR) in partnership with the Asian Disaster Preparedness Center (ADPC) for conducting the catastrophe risk modeling and assessment study.

According to the project's Terms of Reference (ToR), the natural hazards to be considered in this study are earthquake ground shaking, typhoon wind and typhoon-induced precipitation, and flooding due to non-typhoon induced precipitation (i.e., monsoonal precipitation induced flooding). The study is built over five distinct but interconnected components, which are as follows:

- **Component 1:** Hazard Data and Loss Data Collection and Management
- **Component 2:** Exposure Data Collection and Vulnerability Function Development
- **Component 3:** Catastrophe Risk Assessment at the National and Local Levels
- **Component 4:** Design of Parametric Indices for Financial Transactions
- **Component 5:** Support for Placement of Parametric Risk Transfer Products (study can be extended to include this optional component depending on the GoP's decision regarding the use of the parametric risk transfer products towards the disaster risk financing strategy)

This report serves as a summary of the results of Component 2, which focuses on collecting exposure data to estimate the population and property assets at risk to natural catastrophes in the Philippines. A population database was assembled, which can be used in the catastrophe risk assessments to estimate the potential number of injuries and fatalities in the Philippines due to the natural hazards (or perils). An Industry Exposure Database (IED) for the Philippines, i.e., a spatial database that estimates the number, the monetary value, and the characteristics of the building stock exposed to natural catastrophes was developed; this is referred to as the "private" assets database. A database of national government assets at risk to natural catastrophes was also assembled using data gathered directly from government entities and supplemented by publically accessible information and simulation techniques; this is referred to as the "Government" assets database.

The private and Government asset exposure databases were subsequently categorized into a vulnerability classification system to be used in estimating damage due to natural hazards. Damage estimation due to natural catastrophes is typically conducted by developing relationships (i.e., damage functions) between hazard intensity metrics (e.g., peak ground acceleration, maximum sustained wind speeds, etc.) to economic loss due to repair or replacement costs. AIR leveraged data from its previously developed models, supplemented with new research and analytical work conducted in this study to develop vulnerability relationships specific for the Philippines that are used as part of the catastrophe risk assessment.

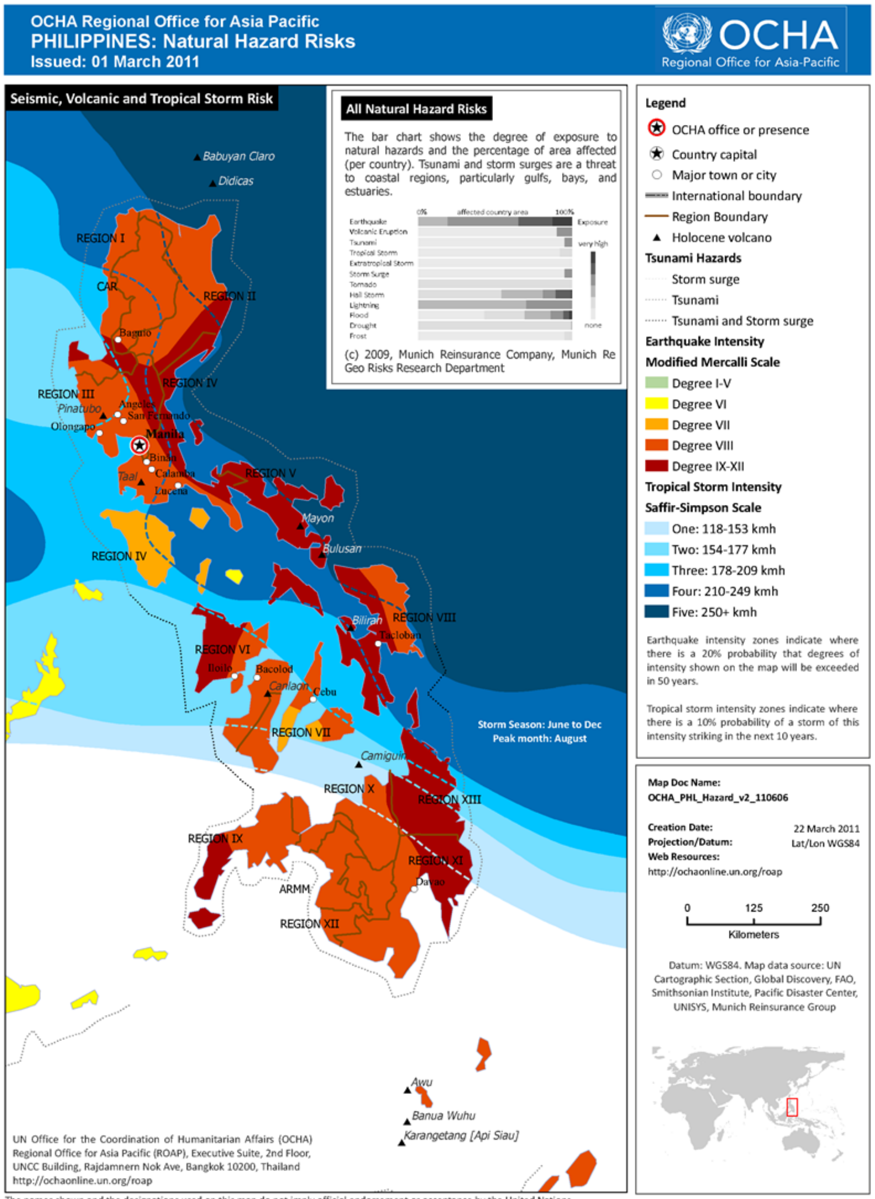

Figure 1.1. Natural Hazards Affecting the Philippines (Source: OCHA)

1.1 Limitations

The study summarized in this report is intended for use by the Government of Philippines and the World Bank to assist them with developing an understanding of the catastrophe risk associated with the population and built environment in the Philippines, and for possible development and implementation of market-ready disaster risk finance strategies. Proper application of this study requires recognition and understanding of the limitations of both the scope and methodology of the entire study.

The physical loss estimates that have been presented or will be developed for the assets[3] are neither facts nor confirmed predictions of loss that may occur either collectively or to any particular asset as a result of future events or any specific event; as such, the actual damage for a particular event may be materially different from that presented in this study. Furthermore, the assumptions adopted in determining the loss estimates do not constitute the exclusive set of reasonable assumptions, and the use of a different set of assumptions or methodology may produce materially different results. The results presented in this study simply represent our best assessment of the potential for physical losses, based on information and data available to us at the time of this study and that collected during the study. Quality of information and data available to us at the time of this study also has a large influence on the study results; improvements in data quality will improve the loss estimation process.

The scope of services performed during this assessment may not adequately address the needs of other users, and any re-use of (or failure to use) this report or the findings, conclusions, or recommendations presented herein are at the sole risk of the user. Our conclusions with respect to the loss and hazard estimates are based on our professional opinion, engineering experience and judgment, analyses conducted in the course of the study, information and data available in the literature and that provided by the World Bank and various local agencies, and are derived in accordance with current standards of professional practice.

[3] An "asset" can be a single property, a portfolio of properties, a city, a region, or an entire country and can represent physical assets or population.

2 Objectives

The primary objectives of Component 2 of the Philippines Catastrophe Risk Assessment and Modeling study are to (a) assemble a database of population at risk to natural catastrophes, (b) develop building inventory databases of private and government assets exposed to natural hazards, and (c) develop vulnerability relationships to be used for damage estimation as part of the catastrophe risk assessment of the Philippines.

This component includes three primary outputs:

1. Maps and figures of the country-specific asset and population exposure to natural catastrophes.
2. A geo-referenced database of government assets.
3. A geo-referenced database of population distribution for the Philippines.

Section 3 of this report discusses the generation of the population database along with the limitations associated with the same. Section 4 and Section 5 discuss the industry exposure database of private property and government assets, respectively. Section 6 establishes the vulnerability classification system used to categorize the property assets (i.e., construction types, age bands, and height bands) while Section 7 describes the development of the vulnerability relationships for the hazards considered in this study.

3 Population Database

3.1 Overview

A population database has been developed in order to spatially identify the population at risk in the Philippines. The database, which is provided in both table and GIS format, was compiled from official government data, including the 2010 Philippine Census of Population and Housing. The database design allows for the querying of various statistical metrics and easy superimposition with other data developed for the catastrophe risk assessment project, such as the modeled loss results (to be discussed in the Component 3 report).

3.2 Database Structure

The population database works on two levels of administrative divisions in the Philippines. The coarsest level is the Province (locally known as *Probinsya/Lalawigan*) Level, followed by the Municipality or City (*Munisipalidad/Bayan* or *Siyudad/Lungsod*) Level. The Philippines also contains two additional levels of administrative divisions: (a) the Region (*Rehiyon*) Level, which is coarser than the Province Level, and (b) the Village/Neighborhood (*Barangay*) Level, which is the finest resolution administrative division. While the Barangay Level is not considered in the population database, it has been queried during the development of the exposure datasets. For the purposes of this project, Metro Manila, which is technically a Region, is referred to as a Province. Also, both the Municipality and City Level are referred to as Municipality for simplicity. The vintage of the geographic extent of the political divisions in the administrative boundaries is between 2006 and 2008, as it includes the now-defunct province of Shariff Kabunsuan.

3.2.1 Province Level Population Database

The Province Level population database includes data for 82 Provinces in the Philippines. For each Province, the following data is provided:

1. **ProvinceID**: The Province ID as defined by the GIS shapefile (source: the National Statistical Coordination Board)
2. **ProvinceName**: The Province name (source: the National Statistical Coordination Board)
3. **RegionName**: The Region name, which is a coarser granularity than Province (source: National Statistical Coordination Board)
4. **RegionName2**: The alternative name of the Region (source: National Statistical Coordination Board)
5. **Pop2010**: The 2010 population (source: 2010 Philippine Census of Population and Housing)

6. **GrowthRate**: The annual linear population growth rate determined from population counts from 2000 to 2010 (source: Census of Population and Housing)
7. **Pop2013**: The estimated 2013 population as determined from the 2010 population and growth rate (source: Census of Population and Housing)
8. **LandAreaKM2**: The estimated land area (in km^2) as determined from the GIS shapefiles; large water bodies not included (source: National Statistical Coordination Board)
9. **(Fe)maleXXXX (various categories)**: The percentage of the population for each given gender and age range; there are 18 age ranges for each gender, every 5 years up to age 85 (source: 2010 Census of Population and Housing)
10. **Poverty**: The estimated percentage of the population in poverty (source: Family Income and Expenditure Survey)

The reader should refer to the respective data sources for additional details and definitions.

3.2.2 Municipality Level Population Database

The Municipality Level population database includes data for 1,627 Municipalities and Cities in the Philippines. In addition, 19 large water bodies are included in the database. For each Municipality (and water body), the following data is provided:

1. **MunicipalityID**: The Municipality ID as defined by the GIS shapefile (source: the National Statistical Coordination Board)
2. **MunicipalityName**: The Municipality name (source: the National Statistical Coordination Board)
3. **ProvinceID**: The Province ID as defined by the GIS shapefile (source: the National Statistical Coordination Board)
4. **ProvinceName**: The Province name (source: the National Statistical Coordination Board)
5. **RegionName**: The Region name, which is a coarser granularity than Province (source: National Statistical Coordination Board)
6. **RegionName2**: The alternative name of the Region (source: National Statistical Coordination Board)
7. **Type**: The type of Municipality, either "Municipality" or "City" (source: National Statistical Coordination Board)
8. **Pop2010**: The 2010 population (source: 2010 Philippine Census of Population and Housing)
9. **AreaKM2**: The estimated area (in km^2) as determined from the GIS shapefiles (source: National Statistical Coordination Board)

The reader should refer to the respective data sources for additional details and definitions.

3.3 Summary

According to the official government census, the population of the Philippines in 2010 was 92.3 million people. The average annual linear growth rate for the entire country is about 2.1%, which indicates that the current 2013 population would be about 98.2 million people. The average population density of the Philippines is about 330 people per km^2, but can vary quite significantly by Province, from about 30 people per km^2 in Apayao Province to 22,490 people per km^2 in Metropolitan Manila. In fact, Metropolitan Manila is the most populated Province in the country, with about 13% of the country's total population. Table 3.1 shows a summary of the Province Level population database. Figure 3.1 shows the Municipality Level 2010 population while Figure 3.2 shows the corresponding population density. This information, along with other metrics, can be extracted from the population database.

Table 3.1. Summary of Province Level Population Database

Province	Region	2010 Population	Annual Linear Growth Rate	Estimated 2013 Population	Land Area (km^2)
Abra	CAR	234,733	1.20	243,183	3,971
Agusan del Norte	Region XIII	642,196	1.62	673,407	2,923
Agusan del Sur	Region XIII	656,418	1.74	690,683	8,585
Aklan	Region VI	535,725	1.87	565,779	1,664
Albay	Region V	1,233,432	1.31	1,281,906	2,506
Antique	Region VI	546,031	1.59	572,077	2,736
Apayao	CAR	112,636	1.60	118,043	3,914
Aurora	Region III	201,233	1.58	210,771	3,041
Basilan	ARMM	391,179	1.75	411,716	1,369
Bataan	Region III	687,482	2.33	735,537	1,317
Batanes	Region II	16,604	0.08	16,644	208
Batangas	Region IV-A	2,377,395	2.48	2,554,273	2,979
Benguet	CAR	722,620	2.41	774,865	2,639
Biliran	Region VIII	161,760	1.53	169,185	534
Bohol	Region VII	1,255,128	1.04	1,294,288	3,978
Bukidnon	Region X	1,299,192	2.25	1,386,887	9,101
Bulacan	Region III	2,924,433	3.09	3,195,528	2,557
Cagayan	Region II	1,124,773	1.32	1,169,314	8,818
Camarines Norte	Region V	542,915	1.83	572,721	2,110
Camarines Sur	Region V	1,822,371	1.75	1,918,045	5,262
Camiguin	Region X	83,807	1.29	87,050	244
Capiz	Region VI	719,685	1.00	741,276	2,651
Catanduanes	Region V	246,300	1.44	256,940	1,473
Cavite	Region IV-A	3,090,691	4.98	3,552,440	1,244
Cebu	Region VII	4,167,320	2.42	4,469,867	4,876
Compostela Valley	Region XI	687,195	1.84	725,128	4,247
Davao del Norte	Region XI	945,764	2.72	1,022,938	3,488
Davao del Sur	Region XI	2,317,986	2.16	2,468,191	6,049
Davao Oriental	Region XI	517,618	1.60	542,464	5,125
Dinagat Islands	Region XIII	126,803	1.86	133,879	809
Eastern Samar	Region VIII	428,877	1.41	447,018	4,279
Guimaras	Region VI	162,943	1.52	170,373	605
Ifugao	CAR	191,078	1.82	201,511	2,503
Ilocos Norte	Region I	568,017	1.05	585,910	3,374
Ilocos Sur	Region I	658,587	1.08	679,925	2,504

Province	Region	2010 Population	Annual Linear Growth Rate	Estimated 2013 Population	Land Area (km^2)
Iloilo	Region VI	2,230,195	1.59	2,336,575	4,714
Isabela	Region II	1,489,645	1.57	1,559,807	10,282
Kalinga	CAR	201,613	1.59	211,230	2,898
La Union	Region I	741,906	1.28	770,395	1,463
Laguna	Region IV-A	2,669,847	3.58	2,956,589	1,802
Lanao del Norte	Region X	930,738	2.28	994,400	2,841
Lanao del Sur	ARMM	933,260	1.66	979,736	3,494
Leyte	Region VIII	1,789,158	1.24	1,855,715	5,561
Maguindanao	ARMM	792,668	2.61	854,734	2,461
Marinduque	Region IV-B	227,828	0.48	231,109	929
Masbate	Region V	834,650	1.79	879,471	4,005
Metropolitan Manila	NCR	11,855,975	1.94	12,545,993	558
Misamis Occidental	Region X	567,642	1.66	595,911	1,895
Misamis Oriental	Region X	1,415,944	2.57	1,525,113	3,329
Mountain Province	CAR	154,187	0.98	158,720	2,129
Negros Occidental	Region VI	2,907,859	1.33	3,023,883	7,812
Negros Oriental	Region VII	1,286,666	1.43	1,341,864	4,998
North Cotabato	Region XII	1,226,508	2.79	1,329,167	6,358
Northern Samar	Region VIII	589,013	1.77	620,290	3,394
Nueva Ecija	Region III	1,955,373	1.78	2,059,790	5,476
Nueva Vizcaya	Region II	421,355	1.48	440,063	3,923
Occidental Mindoro	Region IV-B	452,971	1.91	478,926	5,915
Oriental Mindoro	Region IV-B	785,602	1.52	821,425	4,164
Palawan	Region IV-B	994,118	3.16	1,088,360	14,537
Pampanga	Region III	2,340,355	2.43	2,510,967	2,250
Pangasinan	Region I	2,779,862	1.42	2,898,284	5,193
Quezon	Region IV-A	1,987,030	1.83	2,096,118	8,358
Quirino	Region II	176,786	1.90	186,863	3,099
Rizal	Region IV-A	2,484,840	4.55	2,824,021	1,268
Romblon	Region IV-B	283,930	0.74	290,233	1,326
Samar	Region VIII	733,377	1.44	765,059	5,442
Sarangani	Region XII	498,904	2.15	531,083	3,244
Shariff Kabunsuan	ARMM	423,836	2.61	457,022	2,292
Siquijor	Region VII	91,066	1.16	94,235	321
Sorsogon	Region V	740,743	1.39	771,632	1,992
South Cotabato	Region XII	1,365,286	2.38	1,462,767	4,348
Southern Leyte	Region VIII	399,137	1.08	412,069	1,686
Sultan Kudarat	Region XII	747,087	2.74	808,498	4,414
Sulu	ARMM	718,290	1.59	752,552	1,559
Surigao del Norte	Region XIII	442,588	1.82	466,753	2,025
Surigao del Sur	Region XIII	561,219	1.18	581,086	4,308
Tarlac	Region III	1,273,240	1.91	1,346,197	3,015
Tawi-Tawi	ARMM	366,550	1.37	381,615	1,180
Zambales	Region III	755,621	2.04	801,865	3,656
Zamboanga del Norte	Region IX	957,997	1.64	1,005,130	6,392
Zamboanga del Sur	Region IX	1,766,814	2.29	1,888,194	5,287
Zamboanga Sibugay	Region IX	584,685	1.76	615,556	2,715

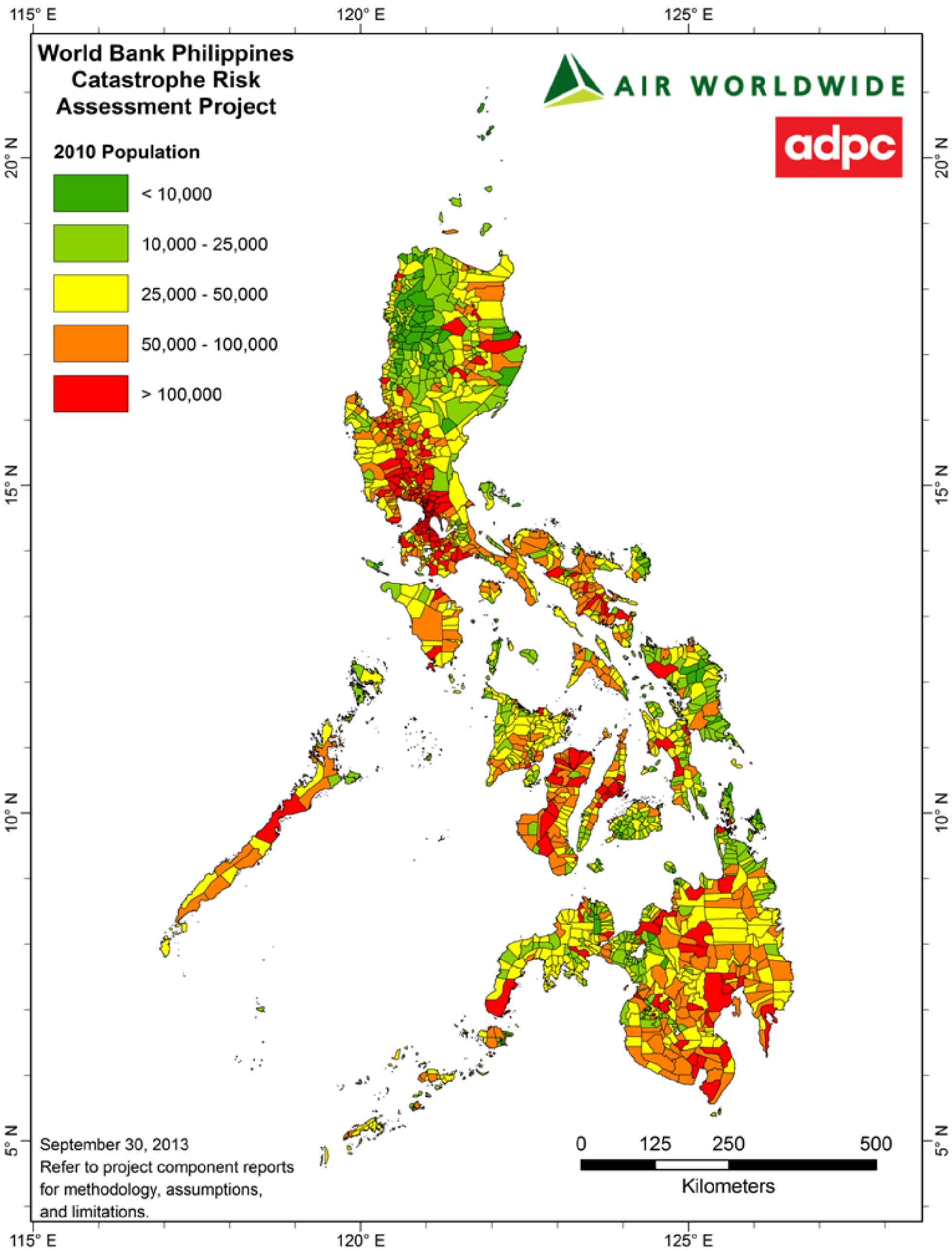

Figure 3.1. Municipality Level 2010 Population

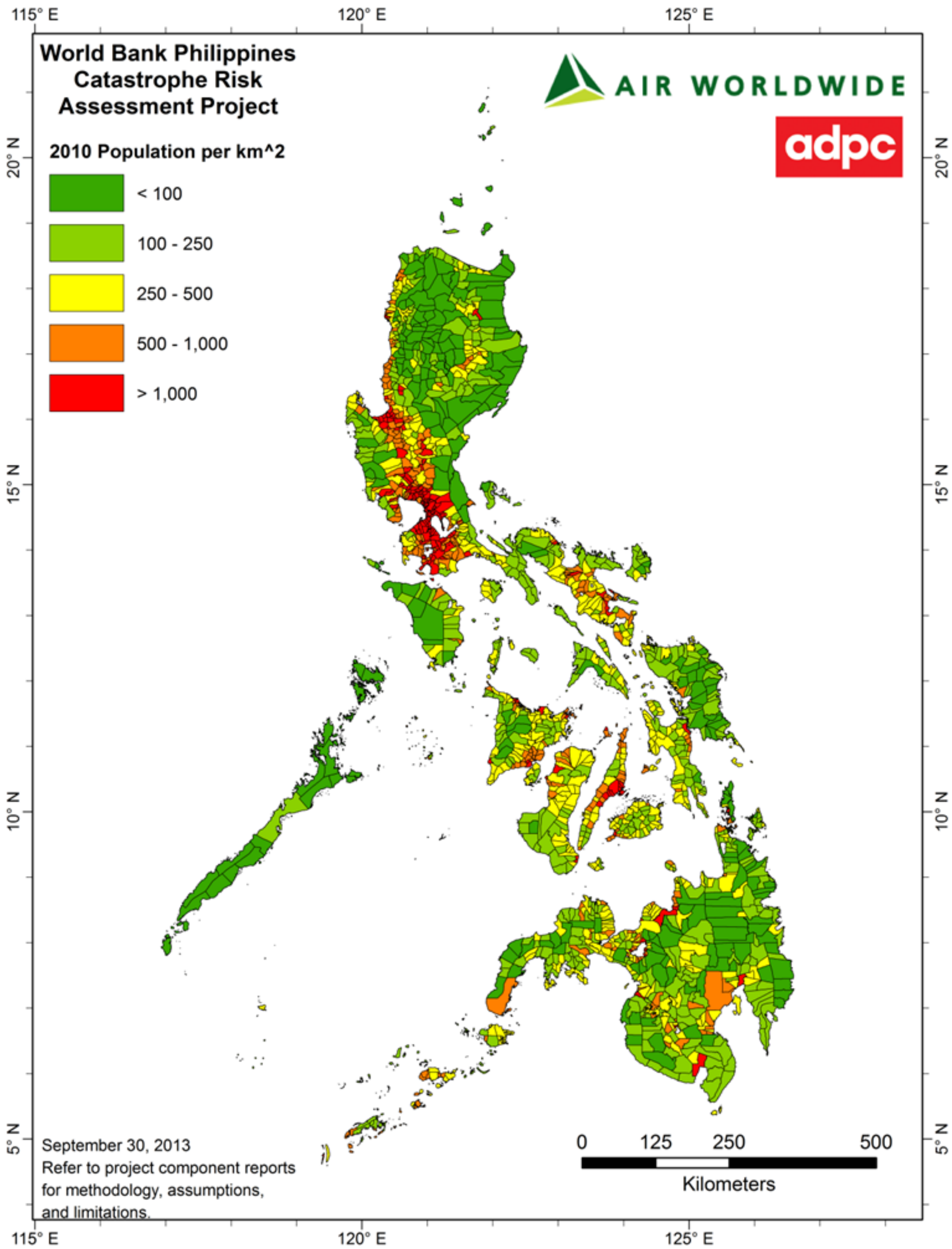

Figure 3.2. Municipality Level 2010 Population Density

3.4 Limitations

The census in the Philippines is currently enumerated every 5 years (beginning in 1960, except in 2005 where it was moved to 2007 due to budgetary constraints). Most of the data acquired in the population database has been collected from the most recently available 2010 Census of Population and Housing. The data contained in the population database, including the 2013 population estimate, may be subject to change as new data becomes available.

The geographic and political boundaries defined in the GIS database are developed by a third party. As such, these boundaries have associated limitations. AIR Worldwide and ADPC performed various spot checks to ensure the quality of the boundary data, but some errors are noted with regards to the drawn coastline and political boundaries. These are not expected to impact the data quality of the project deliverables or loss results.

As mentioned earlier, the vintage of the administrative boundaries is from 2006 to 2008. The political boundaries in the Philippines have changed in recent times. AIR Worldwide and ADPC has considered these changes and carefully mapped the 2010 data from the census to the older defined boundary layer. Since the changes in the boundaries from the different vintages of data are not mutually exclusive, it is not possible to directly map the data from some Municipalities. As such some assumptions were made for certain regions (for example the Shariff Kabunsuan Province).

The geographical area values provided in the database, which can be used to determine metrics such as population density, have been inferred from the GIS shapefiles. As such, the actual land area may be different than as obtained from other sources, such as those from more detailed survey studies.

The population database is presented at the Municipality and Province Level. Commercial and publically available gridded population databases for the Philippines are available from third parties, such as the Gridded Population of the World, LandScan, and AsiaPop. While not provided as a deliverable, these databases were leveraged and modified with the results of the population database for use during the development of other components of the project.

4 Industry Exposure Database

4.1 Overview

One of the most valuable components of all AIR's catastrophe models is the industry exposure databases (IED) that accompany them. Each IED is a country specific database containing risk counts and their respective replacement values, along with information about the occupancy and physical characteristics of the structures, such as construction types and height classifications. Developed by a dedicated team of economists, construction engineers, demographers and statisticians, these databases provide a foundation for all modeled industry loss estimates, whether for simulated events from a stochastic catalog, the re-creation of historical events, or for actual events unfolding in real time. This section provides details about the methodology used to develop the Philippines IED, as well as its composition.

4.2 Developing the Industry Exposure Database

AIR independently builds each IED from the bottom up, as shown below in Figure 4.1, using data from sources such as censuses and government reports. Information obtained from these sources is generally used to derive risk counts for each occupancy. When data for the current year is not available, as is the case with the Philippines, index factors are applied to the risk counts by occupancy to derive the current counts. Current estimates of population, housing counts or other demographic variables are used to develop these factors.

To ensure consistent modeling within and between countries, AIR has developed a method to disaggregate the risk counts for each country to a 1 km x 1 km grid.

After the risk counts are derived, a rebuild cost approach is used to calculate the replacement values for all properties. Additional information obtained from census data and other reports pertaining to the physical characteristics of the risks such as floor area, construction type, height, and year built is used in conjunction with construction cost estimates to derive the replacement values.

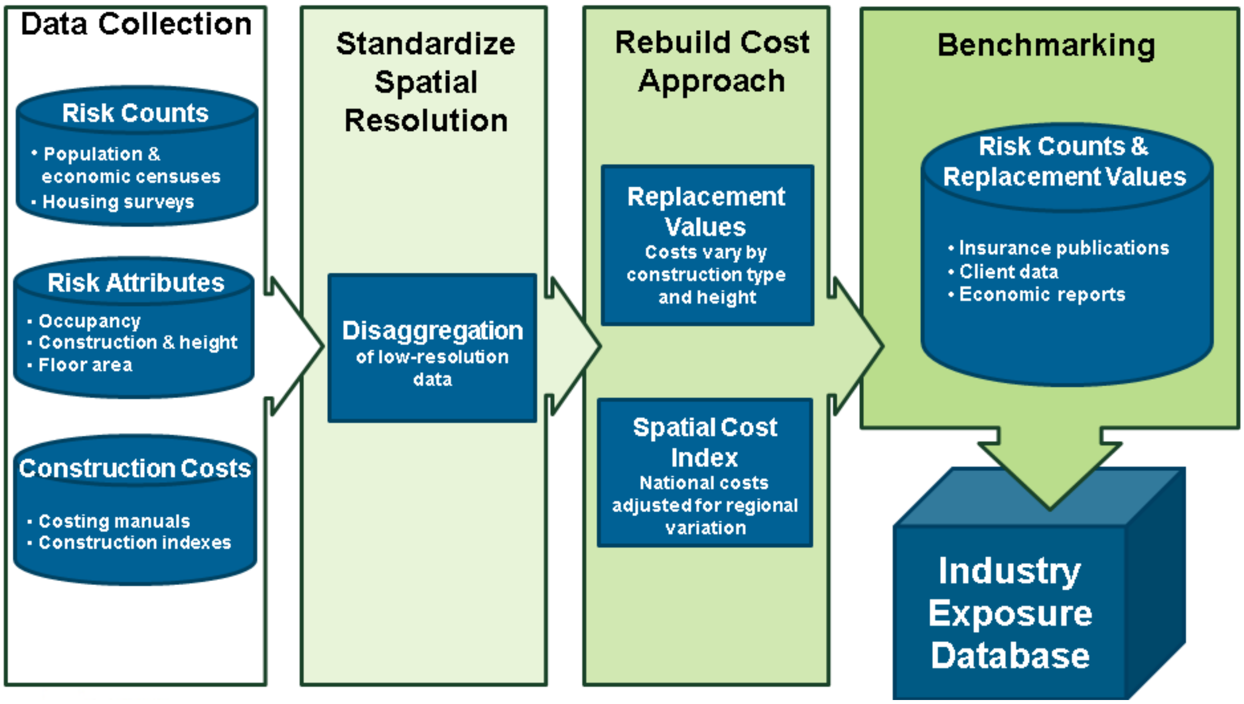

Figure 4.1. AIR approach for building industry exposure databases

4.2.1 Data Sources

A wide variety of data sources are used to develop the Philippines IED. Detailed data on risk counts, building characteristics and construction costs are obtained from the most recent available census data, construction manuals and other reports. Remotely sensed data, such as land use and elevation, are obtained from various regional and global data sets.

4.2.1.1 Risks and Attributes

- Philippines National Statistics Office
- Metropolitan Manila Earthquake Impact Reduction Study

4.2.1.2 Construction Costs

- Spon's Asia-Pacific Construction Handbook (Davis Langdon & Seah International)
- Philippines Report, Rider Levett Bucknall
- International Report, Rider Levett Bucknall
- Construction Statistics from Approved Building Permits (Philippines National Statistics Office)
- Strengthening Natural Hazard Risk in the Philippines (World Bank)

4.2.1.3 Geographical Data

- National Aeronautics and Space Administration, US
- National Geophysical Data Center
- CGIAR Consortium for Spatial Information

4.2.2 Occupancies

The AIR occupancy classes used in the Philippines IED are residential, commercial and industrial.

4.2.2.1 Residential

The residential occupancy consists of single-family houses, duplexes, and apartment units.

4.2.2.2 Commercial

The risk counts in the commercial occupancy represent establishment counts. The types of establishments that AIR classifies as commercial include the following categories: wholesale and retail trade; accommodation and food; information and communications; financial and insurance activities; real estate activities; technical activities; administrative and support services; education; human health and social work; arts, entertainment and recreation; other services.

4.2.2.3 Industrial

The risk counts in the industrial occupancy represent establishment counts. The types of risks that AIR categorizes as industrial include the following classifications: mining and quarrying; manufacturing; electricity, gas steam and air conditioning supply; water supply, sewerage, waste management and remediation activities; construction; transportation and storage. The industrial classification is not dependent on the size or value of the establishment as it is applied to both large and small scale establishments. As a result, the industrial occupancy includes a mix of low and high-value establishments.

4.2.3 Construction Types

Risk attributes such as construction type and height are key components of the IED. The classification of risks by structural type plays an important role in catastrophe modeling because differences in building materials, quality and design all have a significant impact on building vulnerability and hence modeled loss estimates. Consequently, AIR invests significant time and effort in creating a construction distribution for each IED, which captures the proportion of risks represented by various structural types—such as wood frame, masonry, concrete frame, and steel frame.

The starting point in developing the construction distribution is gathering information about the characteristics of the building stock as shown below in Figure 4.2. AIR construction engineers also collect and analyze data as they relate to construction codes and practices from sources such as censuses, published surveys, and engineering journals. Engineering expertise is used in conjunction with these data sets to derive structural type, occupancy, and height relationships.

In classifying the building stock, AIR groups buildings according to their main structural characteristics, namely construction material, the load resisting mechanism, and height. This categorizes the building stock into a sufficient number of distinct classes that each is unique in terms of its structural response to the dynamic loads imposed by different hazards.

Leveraging additional sources such as land use plans (GIS layers) and building code requirements enables a more realistic characterization of each structure, such as its location relative to other buildings and a particular hazard. Thus the correlation between structural type, hazard, construction practice and location is captured.

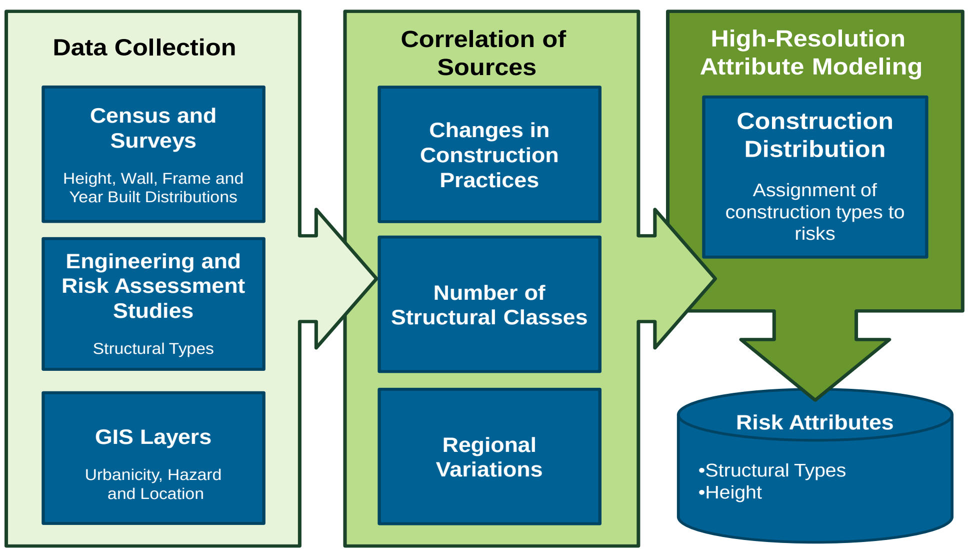

Figure 4.2. AIR approach for building construction distributions[4]

[4] For additional details on developing the construction distributions within AIR IEDs, see the AIR Current *Construction Distributions: An Essential Element of Robust Industry Loss Estimates* available at this link: http://www.air-worldwide.com/PublicationsItem.aspx?id=20203.

The following construction classes, shown in the table below, are used in the IED.

Table 4.1. AIR Construction Classes in the IED

Construction Class	Structural Material Type
Non-Engineered	Makeshift/Assembled/Local Materials
Wood Frame	Wood
Unreinforced Masonry, load bearing wall	Masonry
Reinforced Masonry	
Reinforced Concrete, shear wall w/MRF	Concrete
Reinforced Concrete Shear Wall (Without MRF)	
Reinforced Concrete MRF	
Steel MRF	Steel
Light Metal	Light Metal

Single-family home and industrial risks are classified as "low-rise." Apartment buildings and commercial risks are further categorized by height as provided in Table 4.2 below.

Table 4.2. AIR Height Categories for Apartment and Commercial Risks

Height Class	Stories
Low-rise	1-3
Mid-rise	4-7
High-rise	8 +

4.2.4 Exposure Disaggregation

When the exposures team at AIR builds an IED for a country, it starts by collecting data on risks at the highest geographic resolutions available. For many regions, however, even the highest resolutions are still too low to generate reliable estimates of industry losses. To address this, AIR has developed an innovative method to disaggregate risks from coarse resolutions to a resolution of 1 km x 1 km by incorporating data sets that are closely correlated to risk data, but with one important distinction – the additional data already exists at a resolution of at least 1 km x 1 km. These data sets serve as reliable proxies for risk data, thereby creating an effective model to improve both the resolution and accuracy of each IED as a whole.

Thus, disaggregation is the process of distributing data from coarse geographic resolutions to higher resolutions with the aid of auxiliary information, such as land-use data sets. At AIR, disaggregation leverages both the latest demographic techniques and AIR's own innovative approach to achieve a final resolution of 1 km x 1 km.

Through disaggregation, AIR is able to improve the accuracy of the spatial distribution of all affected exposures and their associated values, ultimately improving the reliability of industry loss estimates generated by the catastrophe models.

The sections that follow outline the disaggregation process.

4.2.4.1 Land Use

Land use data sets—such as NASA's MODIS data set, which is available at 500 m resolution worldwide—group areas of similar land types into categories such as forests, beaches, agriculture, parks, and urban areas, to name just a few. Although some categories are generalized—"urban" may not distinguish suburb from city center, for example—there is sufficient differentiation to classify the land use types into two categories: buildable and unbuildable.

Unbuildable areas are those that are so unlikely to contain property risks that they are excluded from the risk distribution. For example, it would be highly improbable to find an apartment complex atop an alpine glacier, or an industrial plant in the middle of a lake. Land use types such as these are deemed unbuildable, while all other types are considered buildable, and are included when distributing, or disaggregating, risks.

In Figure 4.3 below, land use categories have been aggregated for demonstration purposes into buildable land types such as urban and agriculture, as well as unbuildable land types such as water and perpetual snow or glacier.

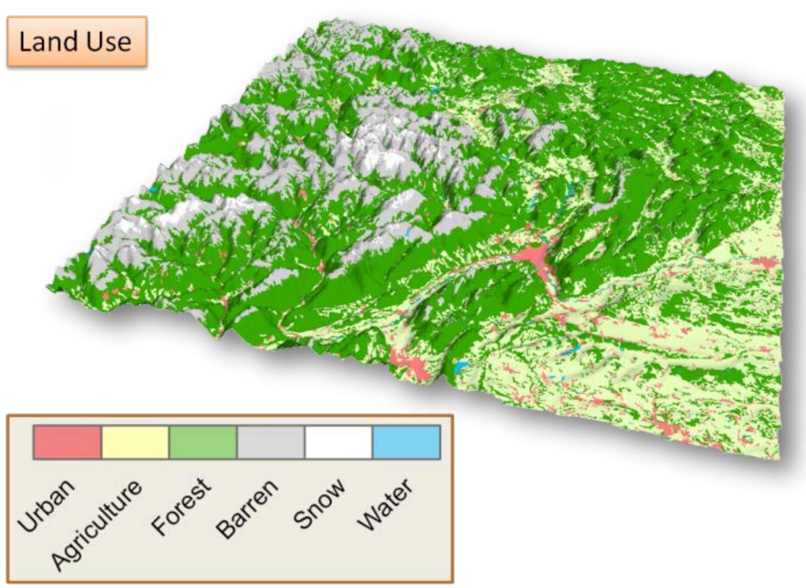

Figure 4.3. Example of Aggregated Land Use Categories

4.2.4.2 Elevation and Slope

Elevation data at a resolution of 90 meters worldwide is available from the CGIAR Consortium for Spatial Information. Elevation also provides valuable insight into identifying unbuildable areas. As an example, considering land use alone, a mountaintop meadow might be classified as buildable while, in reality, the likelihood of finding buildings there is very small due to the fact that its elevation isolates it from roads and other populated places.

Slope is calculated directly from elevation, and is also used to exclude unbuildable areas. An area that has a buildable land-use type and is at relatively low elevation can simply be too steep to build on.

4.2.4.3 Land Use, Elevation, and Slope Masks

When all of the unbuildable areas have been identified based on land use, elevation, and slope values, the three data sets are used to generate a set of three masks—maps that mask the unbuildable land so that only the buildable land areas are visible. The process is illustrated in Figure 4.4.

The three masks are then combined into a single, total mask in which only those areas that are classified as buildable land by all three criteria are included. Risks are not allowed to distribute to any of the unbuildable (masked) areas during disaggregation.

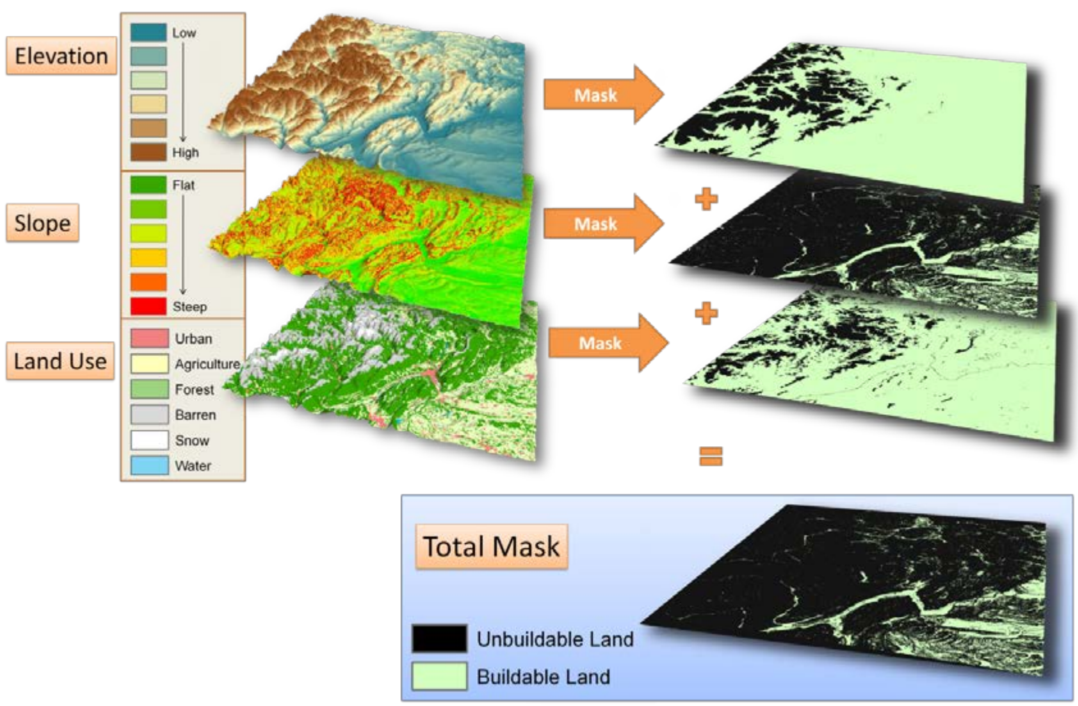

Figure 4.4. Combining the Unbuildable Areas from Land Use, Elevation, and Slope Generates a Total Mask of Unbuildable Areas.

4.2.4.4 Impervious Surface Areas (ISA)

The Impervious Surface Areas (ISA) data set from the National Geophysical Data Center (NGDC) approximates the density of manmade materials—i.e. buildings, roads, parking lots, and the like— at a resolution of 1 km x 1 km (Figure 4.5). The ISA was developed based on nighttime lights and population counts.

The highest ISA values (shown in red) correspond to areas covered by manmade materials—primarily city centers—and the lowest values correspond to more natural areas, such as rural plains and water bodies. ISA is used to locate relative hotspots, placing more buildings where there are more manmade materials, and fewer in less populated places. To determine the probability of locating a certain number of buildings per 1 km x 1 km at a particular ISA value, a relationship between the ISA and building density is derived. This relationship is not linear—overall, building density tends to increase more steeply as ISA values get higher—and is therefore carefully calibrated based on available data, including purchased high-resolution building counts for certain countries. Calibrating in this way not only ensures the accuracy of the risk distribution for a region as a whole, but increases the reliability of the values in each 1 km x 1 km grid cell.

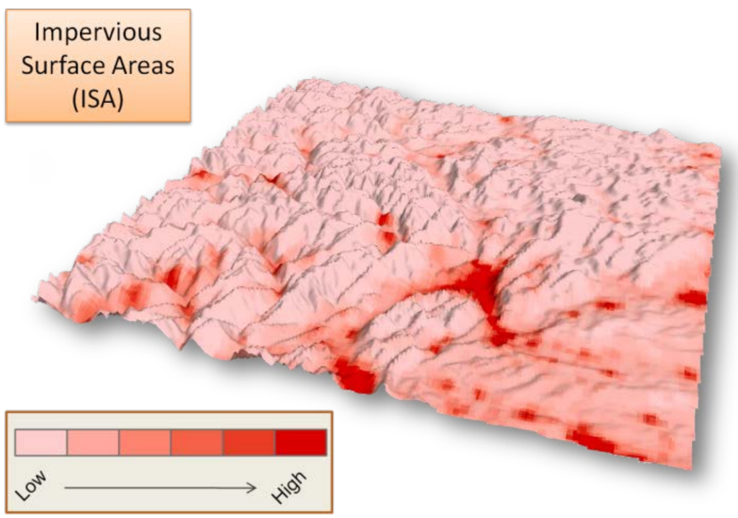

Figure 4.5. The Impervious Surface Areas (ISA) from USGS. Higher Values (dark red) Indicate Higher Densities of Manmade Materials, which are Correlated to Higher Population Densities.

Not all occupancies relate to ISA in the same way, a fact that is taken into account when developing the relationship between building counts and ISA values. While apartments and commercial buildings tend to populate city centers, which are areas with relatively high ISA values, single-family homes can be prominent in areas with lower ISA values, such as the suburbs and outskirts of cities. For this reason, each occupancy is assigned a unique probability distribution in relation to ISA.

4.2.4.5 Regional Data Sets

In addition to land use, elevation, slope, and ISA data, which are available worldwide, a variety of local data sets are used to fine-tune disaggregation to the characteristics of a specific region. In the Philippines, a high resolution gridded population data called AsiaPop is available[5]. Population data increases the accuracy of disaggregation because population density is highly correlated with building density.

4.2.4.6 Deriving the Probability Density Function

Using land use, elevation, slope, ISA, and any additional regional data, a probability density function is generated that determines the pattern of disaggregated risks for each region and occupancy (Figure 4.6). A preliminary density distribution is developed by combining the distribution derived from ISA, with additional distributions derived from regional data sets. The total mask derived from the individual land use, elevation and slope masks is added to the preliminary distribution to create the "Final Risk Distribution"—the probability distribution with all unbuildable areas excluded. In Figure 4.6, this distribution is shown in 3-D to emphasize the areas with the highest values. The highest peak is the center of the most prominent urban area on the map, and corresponds to the area with the largest number of disaggregated risks.

Depending on the occupancy, the highest peak in the distribution does not always fall in the middle of a city, but instead reflects the area with the highest concentration of risks in that occupancy.

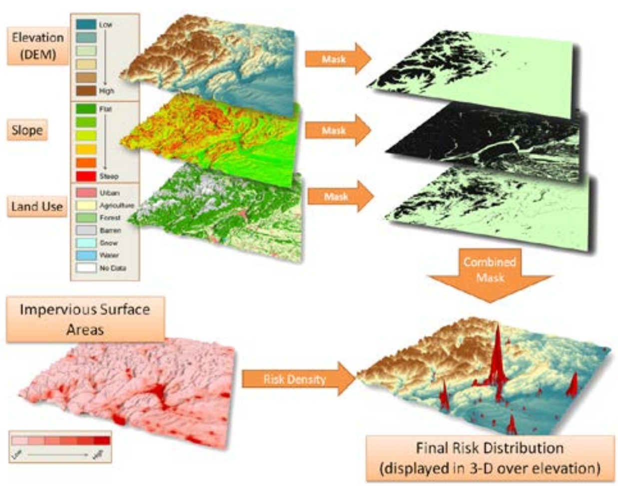

Figure 4.6. A Probability Density Function Determines the Pattern of Disaggregated Risks for Each Region and Occupancy at a Resolution of 1 km x 1 km.

[5] More information about AsiaPop can be found at http://www.asiapop.org/

4.2.4.7 Validating Disaggregation

Throughout the disaggregation process, the employment of numerous validation techniques ensures the highest level of accuracy possible. Comparison against satellite imagery, for example, helps ensure the accuracy of disaggregated risks. Figure 4.7 shows the final distribution of risks overlaid on satellite imagery. The darker pink areas contain the densest risks. Areas that contain no color received no risks. The areas with no risks in the two upper corners contain a river, while the area in the lower right corner contains a mix of forest and unpopulated fields. Where there are risks (the pink areas), numerous buildings can be seen beneath the distribution.

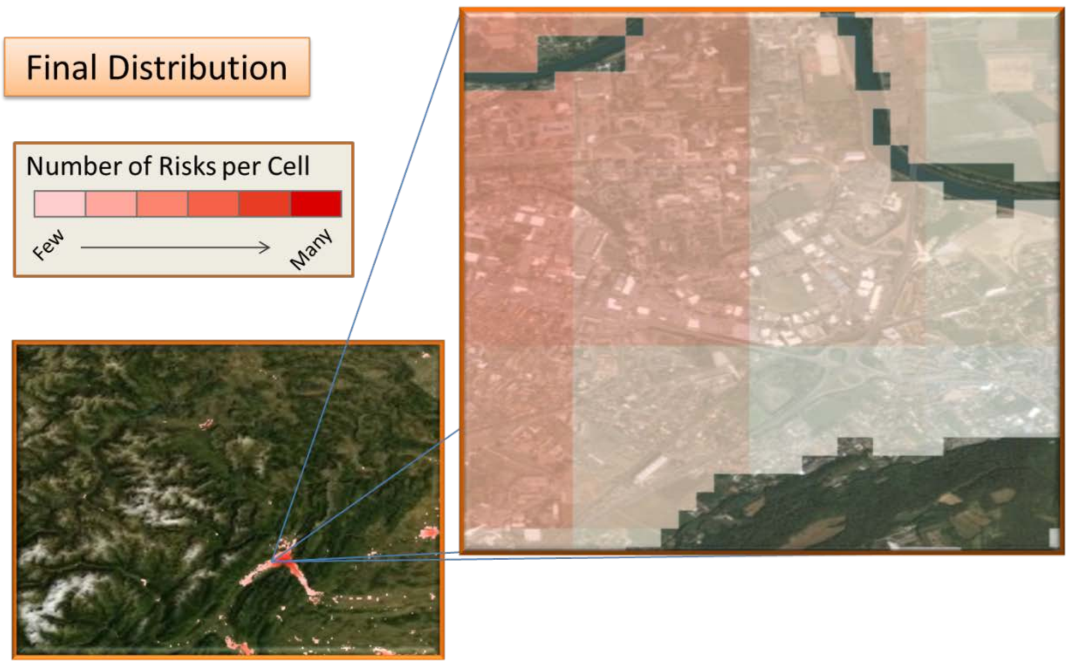

Figure 4.7. Example: Final Distribution of Disaggregated Risks, Overlaid on Satellite Imagery

In addition to satellite imagery, statistical reports, known risk locations and, where available, high-resolution risk data all help in calibrating the disaggregation process to particular regions and in validating the disaggregation methodology overall.

4.2.5 Replacement Values

After the risks and attributes are derived, AIR uses a rebuild cost approach to generate building exposure values by occupancy. The rebuild cost approach calculates replacement values by multiplying floor area estimates by construction costs, which are usually expressed in terms of a unit cost per square foot or square meter. Various data sources have been used to obtain estimates of rebuild cost per unit area for buildings of various occupancies, heights, and construction types.

Figure 4.8 shows how the unit cost per square meter for various occupancies and construction materials can vary considerably. This figure doesn't include mid-rise and high-rise buildings, whose costs are typically much higher than low-rise buildings.

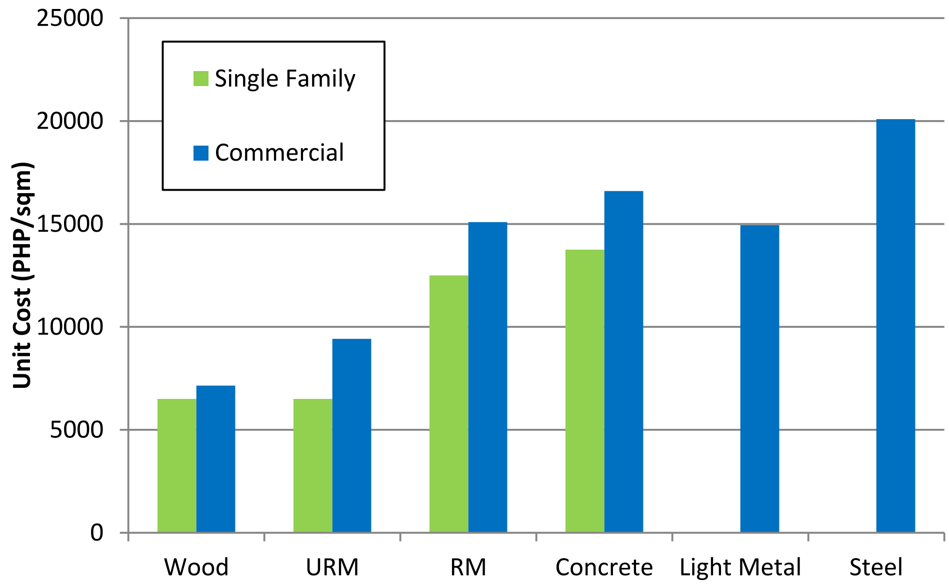

Figure 4.8. Sample Rebuild Cost Estimates, per Square Meter, for Low-rise Construction

AIR's construction costs are combined with building sizes to calculate building replacement values that represent building exposure in the IED. These estimates are refined spatially to account for local and regional variation in construction costs. After reasonability checks, additional coverage values for contents are calculated using standard industry coverage splits derived from an extensive review of industry reports and client data for each occupancy classification.

4.2.6 Validating the Industry Exposure Databases

4.2.6.1 Data Validation

AIR corroborates its raw data sets against alternative regional and global data sets containing reported building and economic attributes. When anomalies are discovered, additional research is conducted to verify any questionable data. In the Philippines, several independent reports containing building inventory data were available, which allowed for direct comparisons with the IED building attributes. One example is a study by a collaboration of the Institute to the Protection and Security of the Citizen (IPSC), Joint Research Centre (JRC) of the European Commission in Ispra, Italy, and the World Bank's Development Research Group with funding from the Global Facility for Disaster Risk and Recovery (GFDRR) and JRC (Uwe Deichmann et al. 2011). This study was conducted in the City of Legazpi, the capital of Albay province in the Bicol region of Luzon island. This study utilized high resolution satellite imagery, as well as a ground survey to generate information on hazard, exposure (mostly the building stock) and vulnerability. Figure 4.9 shows the proportion of the building stock replacement value in the study against the AIR Philippines IED by different construction types.

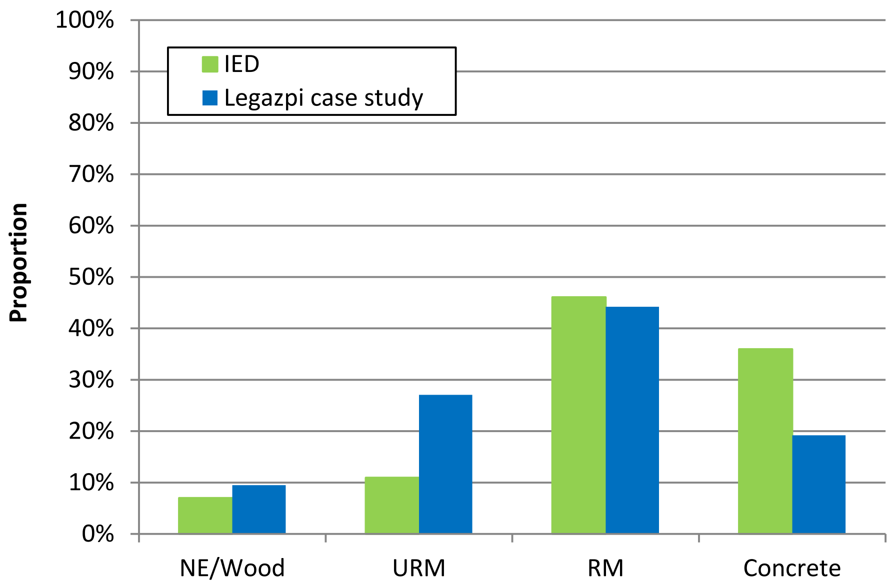

Figure 4.9. Construction Distribution by Replacement Cost

Overall, there is good correlation between these two studies:

- The construction types in the IED are in line with the Legazpi study which include non-engineered/wood frame (assembled material/ timber and bamboo or assembled material in the study), unreinforced masonry (brick traditional in the study), reinforced masonry (brick traditional with reinforced concrete columns in the study), and concrete (reinforced concrete frame with brick in fill walls in the study).
- The proportion of the non-engineered/wood frame and the reinforced masonry in the building stock in the IED agrees well with the study.

- Some differences would be expected because the IED accounts for the entire city of Legazpi whereas the Legazpi case study was only conducted in a 1km x 1km specific area.
- The Legazpi case study may overestimate the proportion of the unreinforced masonry and underestimate the proportion of concrete building types since the study includes a large overpopulated area which has a large percentage of the traditional unreinforced masonry buildings.

A similar comparison was conducted with data collected from a study performed by Bautista et al. (2012), which focused on developing exposure and vulnerability modules for an earthquake damage study of Iloilo city. The study involved conducting a detailed ground level survey of more than a thousand buildings of various occupancy types to develop building exposure models. Figure 4.10 below shows a comparison of the floor area by material type in Iloilo city from the AIR Philippines IED with the information collected in this survey.

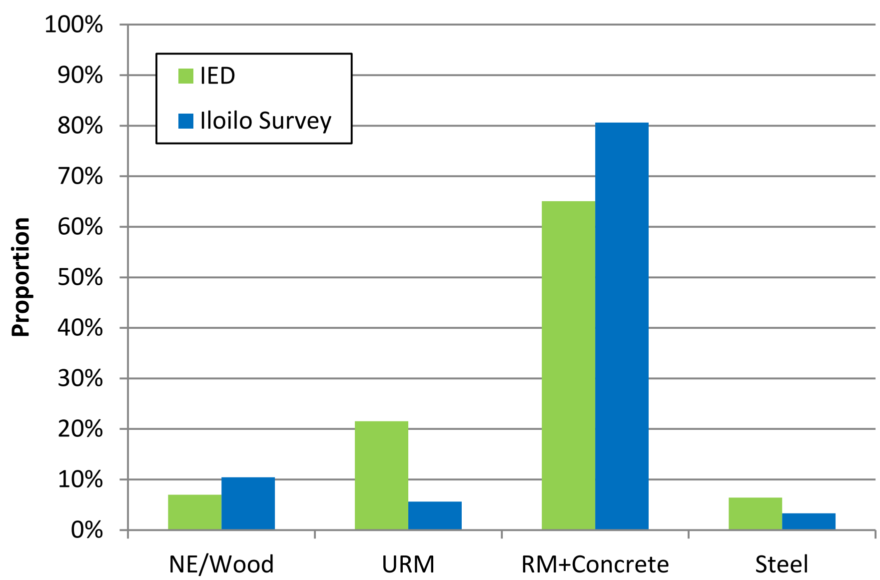

Figure 4.10. Construction Distribution by Floor Area

Overall, the IED results are in line with the Iloilo city building survey.

- The classification of the construction types in the unreinforced masonry, reinforced masonry and concrete in the study is slightly different with the IED. Some of the reinforced masonry and the concrete buildings defined in the study were classified as unreinforced masonry and reinforced masonry buildings in the IED considering the local construction practice and quality control.

- Therefore, the total percentage of the unreinforced masonry, reinforced masonry and concrete in the IED agrees well with the study. In addition, the proportion of the non-engineered/wood frame and the steel in the building stock in IED agrees well.
- Some differences would be expected since the study is a relatively small sample of buildings (1077 in a city of almost 90,000 buildings) and the IED refers to the entire building inventory of the Iloilo City.

4.2.6.2 Aggregate Benchmarking (Gross Capital Stock)

In addition to checking the input data sets, AIR benchmarks its national total values against various independent sources, such as gross capital stock and client data aggregates. Independent valuations of building stock, called gross capital stock, are available from statistics offices for many countries around the world. Gross capital stock (GCS) comprises of several components, including commercial and residential buildings, roads and bridges, and transportation like ships and trains. For each of these components, it contains estimates of the replacement cost in today's currency. The values for residential and commercial building stock are directly comparable to the aggregate residential and commercial building values. The countries that produce a measure of GCS do it as part of the annual reporting of gross domestic product in their National Accounts. For the countries that do not create estimates of GCS, like the Philippines, AIR creates its own estimate using economic modeling and the same standard accumulation methodology used by other countries. The UN Statistics Division is used as the data source for all of our time series data for capital stock calculations. It provides a consistent series starting from 1970 that is available in nominal and constant 2005 national currency units.

The methodology starts with the annual changes in GCS called gross fixed capital investment, or GFCI. This contains new additions to the capital stock as well as subtractions when something is taken out of service or demolished. Every country collects this data, even the ones that do not estimate gross capital stock. After modeling a starting value for each component of GCS for a fixed point in time, for example 1970, the annual GFCI up to the current year is summed and added to the initial capital stock. Then the GCS is inflated to get current value in today's currency.

4.3 IED Summary

This section provides summary statistics, as well as plots showing the spatial distribution of exposure values in the Philippines IED. The replacement values presented below include both Coverage A (structure value) and Coverage C (building contents value). The total exposure value is approximately 31.1 trillion PHP, of which 24.8 trillion is Coverage A and 6.3 trillion is Coverage C.

4.3.1 Country Summary -- Philippines

Capital:	Manila
Local Currency:	PHP
Exchange Rate to USD:	0.023
IED Vintage:	End 2013
IED Native Resolution:	1km x 1km grid

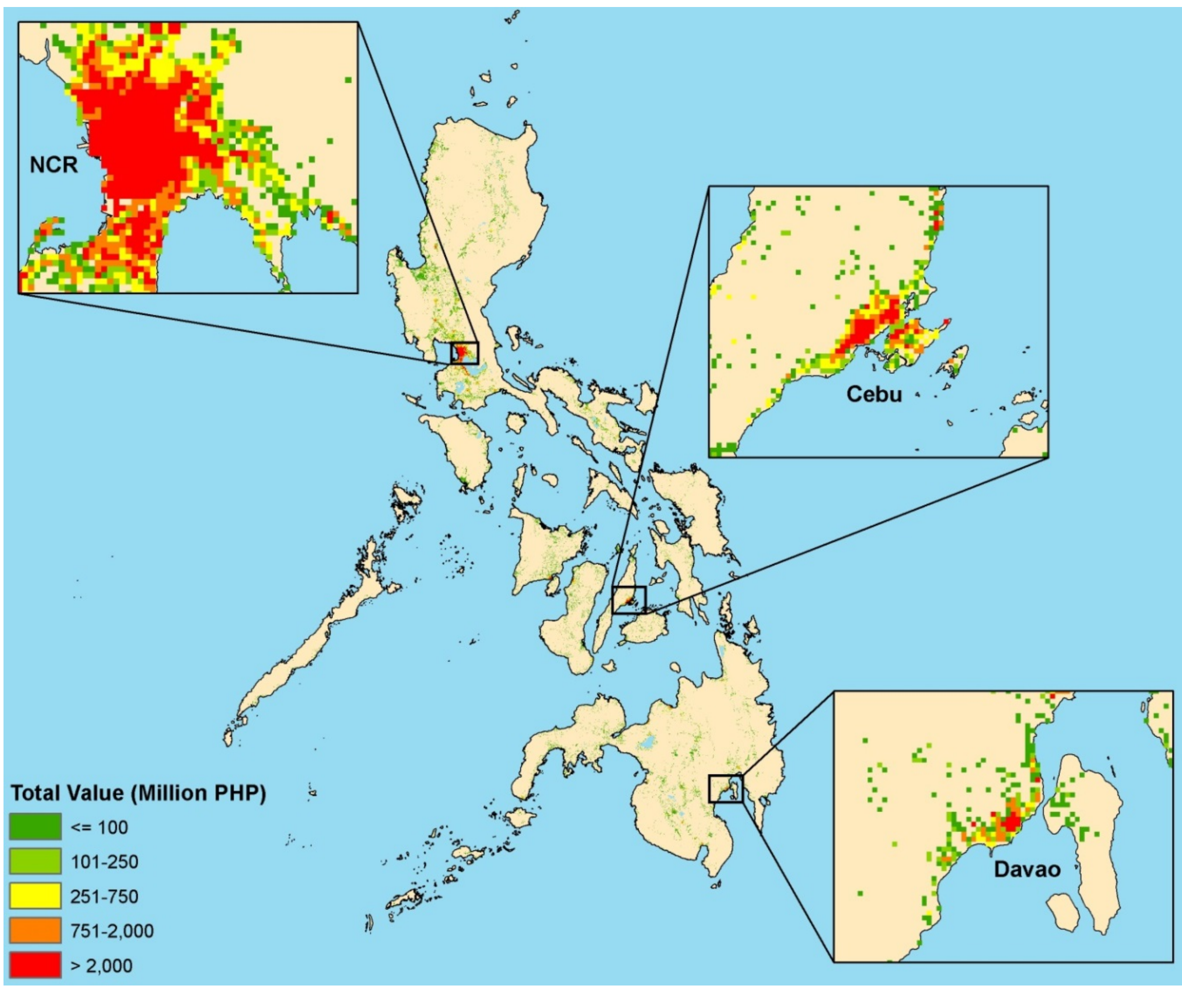

Figure 4.11. Combined Commercial/Industrial Value per 1km x 1km

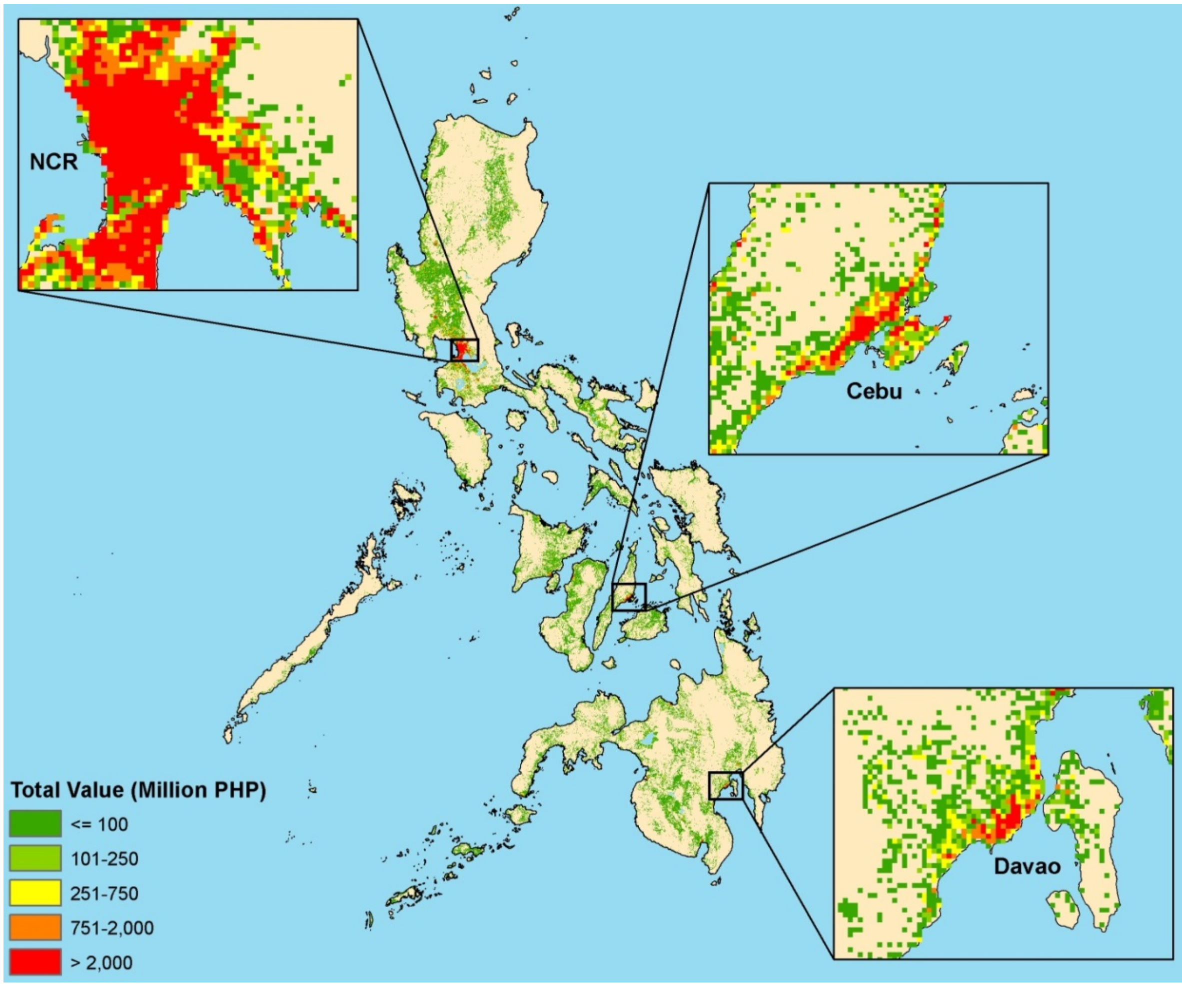

Figure 4.12. Residential Value per 1km x 1km

4.3.2 Summary Statistics[6]

Table 4.3. Estimated Total Value by Occupancy (Million PHP)

Country	Currency	Residential	Commercial	**Industrial**	Total
Philippines	PHP	17,772,049	7,370,024	5,908,787	31,050,859

Table 4.4. Estimated Total Risks by Occupancy

Country	Residential[7]	Commercial[8]	Industrial[5]
Philippines	23,084,724	886,447	199,818

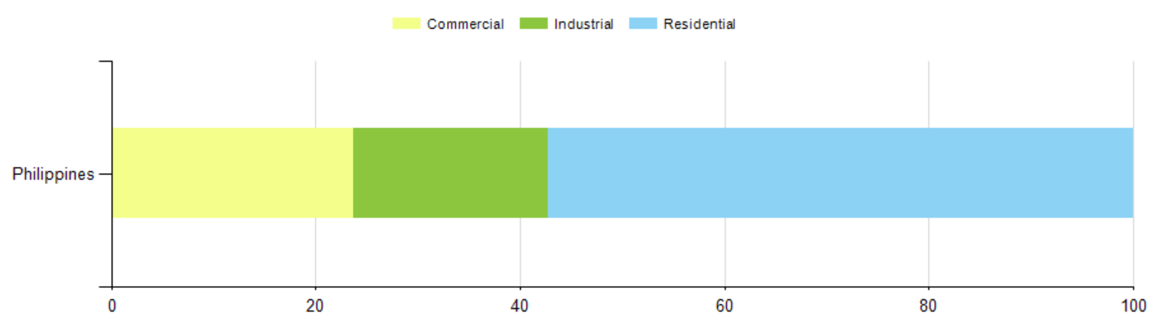

Figure 4.13. Share of Industry Exposure by Occupancy

[6] Due to rounding, percentages may not total 100%.
[7] Dwelling counts
[8] Establishment counts

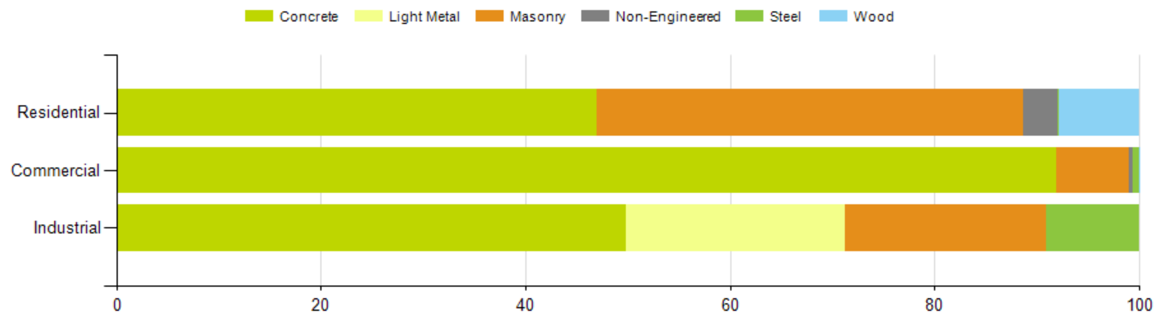

Figure 4.14. Share of Industry Exposure by Construction

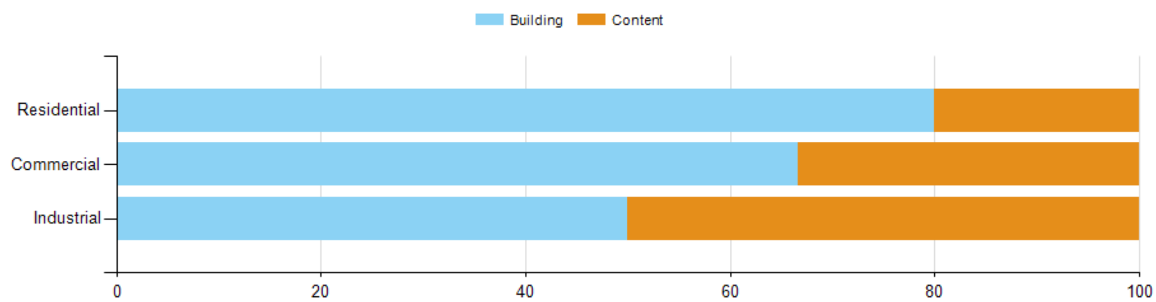

Figure 4.15. Share of Industry Exposure by Coverage

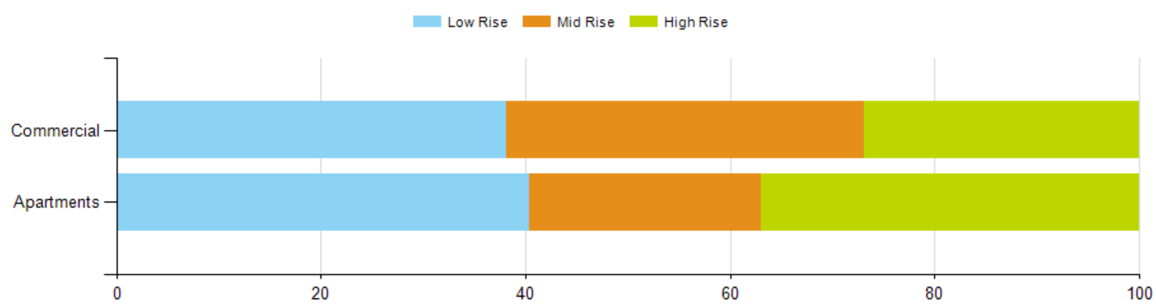

Figure 4.16. Share of Industry Exposure by Height

5 Government Asset Exposure Database

5.1 Overview

A detailed inventory of national government assets including state-owned enterprises and specific infrastructure assets has been assembled, which comprises their location, structural and non-structural characteristics, and replacement cost. The information on such assets has been collected from a wide variety of data sources. In particular, several local government agencies were contacted directly by ADPC and requests for information were issued (e.g., see Table 5.1). While it was initially perceived that data was available and easily accessible in the Philippines, the data, in general, was difficult to obtain, incomplete, and, in most cases, not at the level that can be used for catastrophe risk modeling (e.g., Table 5.2 lists the final data obtained from the local agencies). As such, AIR Worldwide and ADPC supplemented and conditioned the raw data to improve its quality and format it for use with the catastrophe risk models. An extensive data search was performed to leverage additional data available in the public domain. When data was not available (or partially available), modeling techniques and/or expert judgment was used to simulate or estimate the asset characteristics. For example, when the exact location (latitude/longitude) of an asset was not provided, the asset was aggregated to the population centroid of the given administrative division. Furthermore, when attributes and replacement costs were not available, these were simulated, estimated, or assumed using supplementary data. In addition to the final government asset database, the raw data obtained from the local agencies is provided as part of the project deliverables. The details of the raw data are not discussed comprehensively.

Table 5.1. Primary Government Agencies Contacted for Data Requests

Agency	Abbreviation
Bureau of Corrections	BOC
Civil Aviation Authority of the Philippines	CAAP
Commission of Higher Education	CHED
Department of Education	DepEd
Department of Interior and Local Government	DILG
Department of Health	DOH
Department of Public Works and Highways	DPWH
Government Service Insurance System	GSIS
Light Rail Transit Authority	LRTA
National Power Corporation	NPC
National Statistics Office	NSO
Philippine National Railway	PNR
Philippine Ports Authority	PPA
National Transmission Corporation	TransCo

Table 5.2. Final List of Usable Raw Data Obtained from the Local Agencies

Dataset	Agency	Raw Data Quality Grade[9]		
		Location	Attributes	Replacement Value
Roads	DPWH	A	A	A
Bridges	DPWH	A	A	A
Prisons	BOC	A	A	A
Light Rail	LRTA	A	N/A	N/A
Airports	CAAP	A	N/A	N/A
Schools	DepEd	C	B	B
Public Administration Buildings	DPWH	C	B	B
Hospitals	DOH	C	N/A	N/A
Seaports	GSIS	C	N/A	B
Flood Control & Drainage[10]	DPWH	C	C	C

5.2 Database Structure

The government asset exposure database consists of almost 200,000 entries, and is provided in table and GIS format. For each entry, the following data is provided:

1. **GlobalID**: The unique ID number for each entry in the database
2. **ID**: The unique ID number for each asset type. For some cases, the ID number can be used to map the entry to the raw data obtained by the government agencies. Official ID numbers are used for bridges, medical facilities, hospitals, and schools.
3. **Name**: The name of the asset
4. **Note**: Supplementary information for the asset, which varies by asset type:
    a. ***Airport***: Airport class as defined by CAAP; also, an indication of if the entry is explicitly the modeled runway
    b. ***Government Hospital***: Hospital category by service capability as defined by the DOH; also, an indication if the hospital is managed by the DOH
    c. ***Government Medical Facility***: Facility type
    d. ***Light Rail***: Indication of station or track
    e. ***Rail***: Indication of station or track
    f. ***Port***: Indication of the corresponding port management office (PMO)

[9] Definitions of the Raw Data Quality Grade: "A" = Data can, in general, be used directly; "B"= Data has issues and needed to be fully or partially simulated; "C" = Data has significant issues and needed to be supplemented with other data; "N/A" = Data not provided by local agencies

[10] Due to lack of data quality, Flood Control & Drainage data was not used

   g. ***Power Plant***: Indication of "NPC" (government owned) or "NPC-IPP" (private/government owned)
   h. ***Prison***: Prison name
   i. ***Public Administration Building***: Name of corresponding government department
   j. ***Public School***: Indication of elementary or secondary school

5. **X**: Location of asset - longitude in decimal degrees
6. **Y**: Location of asset - latitude in decimal degrees
7. **LocationNote**: Level of location accuracy:
   a. ***Aggregate*** = Aggregated to a ≈1km grid (for Road, Rail, and Light Rail)
   b. ***Exact*** = The site-level location as given by the raw data, or deduced from remote sensing; for some datasets (such as schools), this may not be the accurate position for some assets
   c. ***Municipality_Population_Center*** = The approximate center of population (i.e., the grid cell with the largest population) within the given Municipality (as deduced from AsiaPop and the population database)
   d. ***Settlement_Centroid*** = The centroid of the given settlement location (as deduced from ADPC)
   e. ***Province_Population_Center*** = The approximate center of population (i.e., the grid cell with the largest population) within the given Province (as deduced from AsiaPop and the population database)
   f. ***Admin_Centroid*** = The centroid of the given administrative division (as deduced from ADPC)
   g. ***Approximate*** = The approximate location, typically based on judgment when data is not available
   h. ***AsiaPop*** = Aggregated to a ≈1km grid as per AsiaPop and the population database
8. **EstimatedValuePHP**: The estimated replacement value of the structure (i.e., Coverage A) in 2013 Philippine Pesos
9. **Construction**: The construction class assigned as per UNICEDE[11]:
   a. ***100*** = General/Unknown
   b. ***101*** = Wood Frame
   c. ***111*** = Masonry
   d. ***131*** = Reinforced Concrete
   e. ***151*** = Steel
   f. ***201*** = Conventional - Multiple Span Bridges
   g. ***203*** = Major Bridges

[11] Refer to www.unicede.com for more information

   h. ***204*** = Railroads
   i. ***205*** = Highways
   j. ***206*** = Runways
10. **Occupancy**: The occupancy class assigned as per UNICEDE:
   a. ***300*** = Unknown
   b. ***316*** = Health Care Services
   c. ***343*** = Government - General Services
   d. ***344*** = Government - Emergency Services
   e. ***345*** = Universities, Colleges and Technical Schools
   f. ***346*** = Primary and Secondary Schools
   g. ***351*** = Highway
   h. ***352*** = Railroad
   i. ***353*** = Air
   j. ***354*** = Sea and Inland Waterways
   k. ***476*** = Hydro-Electric Power Systems – General
   l. ***477*** = Thermo-Electric Power Systems – General
11. ***Height***: The height class associated with the asset:
   a. ***1*** = Low-Rise (1-3 stories)
   b. ***4*** = Mid-rise (4-7 stories)
   c. ***8*** = High-rise (8+ stories)
12. **Year**: The age band assigned estimating the year in which the building was built:
   a. Unk = Unknown
   b. ≤ 1971
   c. 1972 – 1991
   d. ≥ 1992
13. **Type**: The main type or class of the asset:
   a. ***Airport*** = CAAP managed airport
   b. ***Bridge*** = Bridge maintained by the national government (DPWH)
   c. ***Government Hospital*** = Government owned hospital
   d. ***Government Medical Facility*** = Government owned medical facility
   e. ***Light Rail*** = Light Rail (LRTA) in Metro Manila
   f. ***Port*** = Large government owned sea port
   g. ***Power Plant*** = Large government owned and partial government owned power plant
   h. ***Prison*** = Large government owned prison
   i. ***Public Administration Building*** = Public administration building from the DPWH database

j. ***Public School*** = Elementary/secondary public school
k. ***Public University*** = State owned college/university
l. ***Rail*** = Operational rail system maintained by the PNR
m. ***Residual Institutions*** = Additional institutional assets
n. ***Road*** = National primary and secondary roads maintained by the DPWH

14. ***DataSource***: The main source of the raw, unconditioned, data:
    a. ***AIR*** = Data collected by AIR Worldwide from the public domain
    b. ***BOC/ADPC*** = Data obtained directly from the Bureau of Corrections by ADPC
    c. ***CAAP/ADPC*** = Data obtained directly from the Civil Aviation Authority of the Philippines by ADPC
    d. ***DepEd*** = Data obtained online from the Department of Education
    e. ***DepEd/ADPC*** = School-level data obtained directly from the Department of Education by ADPC
    f. ***DepEd_Buildings/ADPC*** = Building-level data obtained directly from the Department of Education by ADPC
    g. ***DIVA/PNR*** = Data obtained from DIVA-GIS and the Philippines National Railways website
    h. ***DOH/ADPC/AIR*** = Data obtained directly from the Department of Health by ADPC and modified by AIR
    i. ***DOH/AIR*** = Data obtained online from the Department of Health by AIR
    j. ***DPWH/ADPC*** = Data obtained directly from the Department of Public Works and Highways by ADPC
    k. ***LRTA/ADPC*** = Data obtained directly from the Light Rail Transit Authority by ADPC
    l. ***MMEIRS*** = Data collected from the Metro Manila Earthquake Impact Reduction Study
    m. ***PPA/ADPC/AIR*** = Data obtained directly from the Philippine Port Authority by ADPC and modified by AIR
15. **ProvinceID**: The ID of the Province where the asset is located (refer to the population database)
16. **ProvinceName**: The name of the Province where the asset is located
17. **MunicipalityID**: The ID of the Municipality where the asset is located (refer to the population database)
18. **MunicipalityName**: The name of the Municipality where the asset is located

5.3 Methodology

A brief overview of the source data, methodology, assumptions, limitations, and final results for each modeled asset type is presented in the subsections below. Refer to the References section for a select list of data sources.

5.3.1 Roads

A comprehensive GIS database of roads was obtained directly from the Department of Public Works and Highways (DPWH). The raw data includes about 31,341 km of national primary and secondary roads in polyline form. This number is validated against 31,597 km of national primary and secondary roads indicated in aggregate tables from the DPWH website. The raw data attributes include road length, surface type (asphalt, concrete, gravel, earth), and condition (good, fair, bad, or poor). Unit replacement cost data was also acquired from the DPWH. The replacement cost was estimated as a function of road length, surface type, and condition. The road exposure is aggregated to a ≈1km grid for modeling purposes. Only paved national primary and secondary roads (about 30,673 km) are included in the final database.

5.3.2 Public Schools

A SQL database of public schools was obtained directly from the Department of Education (DepEd), which includes two levels of data: (a) a database of 43,647 school facilities, and (b) a database of 177,325 buildings aggregated at 34,296 school facilities. The raw building attribute data includes the school ID, location (lat/long, Province, Municipality, etc.), building type (97 non-structural categories such as "Bagong Lipunan" and "Marcos Type"), year of construction, number of stories, building length, and building width. Unit replacement costs were also obtained directly from DepEd, and are a function of the floor area and location. The final replacement value of each school is determined using a rebuild approach, which calculates the replacement value from the floor area, number of stories, and unit cost.

The latitude and longitude locations given in the raw data are occasionally not accurate. Based on spot checks of satellite imagery, many schools in the raw data are geo-referenced far from populated areas. The exact location (lat/longs) of over 75% of the school facilities is not provided in the raw data. Schools with unknown lat/longs are aggregated to the centroids and population centroids of Municipalities, Barangays, or known settlements based on the given data. In addition, not every public school is included in the raw database. Some heavily populated Municipalities are completely devoid of schools in the raw database, including in the Manila area. The attribute data in the raw database is also incomplete and has several errors. For example, the given length of the buildings ranges from zero meters to eleven kilometers in the raw database. Obvious errors are corrected in the final database based on data deemed reasonable within the raw data.

Due to data quality issues in the DepEd SQL database, other data sources are leveraged to supplement and improve the data, including data from the Metro Manila Earthquake Impact Reduction Study (MMEIRS) and tables obtained from the DepEd website. Furthermore, recent field surveys carried out by the World Bank and ADPC in the Manila area are used to inform the attribute characteristics.

The final database includes 46,606 public elementary and secondary schools; 43,646 from the DepEd SQL data; 103 from the MMEIRS data; and 2,857 from data obtained from the DepEd website. The number of schools is validated against the 45,973 public elementary and secondary schools in 2011-2012 indicated in the aggregate table provided in the DepEd website. Note that school facilities are indexed in the final database, rather than school buildings. The location, attributes, and replacement value of the buildings are aggregated to the school facility location. It is noted that the official school ID and name is provided in the final database, which can be used in the future to update or improve the data quality.

5.3.3 Government Hospitals

A GIS database of medical facilities was obtained directly from the Department of Health (DOH), which includes 679 hospitals, 2,390 regional health units, and 172 Barangay heath stations. The given locations of facilities in the raw data are occasionally not accurate. Based on spot checks of satellite imagery, many facilities in the raw data are geo-referenced far from populated areas (e.g., the middle of a forest, in the ocean, etc.), apparently in part due to an indexing error in the raw dataset. In addition, not all facilities are represented in the raw data. For example, Barangay heath stations are indexed in only in a few of the countries' more than 40,000 Barangays. Very limited attribute data is provided in the raw data, such as the hospital name and an older version of the facility ID. Due to the lack of quality of the DOH GIS data, other data sources are leveraged to supplement and improve the data, including data from MMEIRS, the DOH website, the National Health Facility Registry, and other public sources.

No replacement cost information was obtained directly from the DOH. Unit replacement values and attributes are inferred from industry reports, construction cost data, and other public sources. The replacement value for each facility is estimated using several metrics including facility footprint area, facility type, and number of beds. The construction class and height band is simulated based on the category, type, and size of the hospital. The final database includes 774 government hospitals, all of which have been manually verified via satellite imagery. It is noted that the official hospital ID and name are provided in the final database, which can be used in the future to update or improve the data quality.

5.3.4 Government Medical Facilities

Government medical facilities include public medical facilities that are not classified as public hospitals. Due to the lack of quality of the DOH GIS data (recall the subsection above), several public data sources are leveraged to supplement and improve the medical facilities data, including MMEIRS, the DOH website, the National Health Facility Registry, and other public sources. Nominal replacement costs are estimated for each facility based on facility type. The cost estimates are based on information obtained from public sources. The locations (lat/longs) of the facilities are aggregated to the approximate population centroid of the Municipality or Province, depending on what is provided in the given raw data. The construction class and height band is simulated based on the type of the facility. A total of 17,969 government health facilities are included in the final database: 14,951 Barangay Health Stations, 92 City Health Offices, 15 District Health Offices, 14 Drug Abuse Treatment and Rehabilitation Centers, 76 Main Health Centers, 175 Municipal Health Offices, 6 Provincial Health Offices, and 2,640 Rural Health Units. It is noted that the official facility ID and name are provided in the database, which can be used in the future to improve the data quality.

5.3.5 Large Power Plants

No useful data on power plants was obtained from the local agencies. Several public sources are leveraged to obtain data on power plants, including the Philippine Department of Energy (DOE) website, the Philippines National Power Corporation (NPC) website, the Carbon Monitoring for Action (CARMA) database, industry reports, and other sources. Attributes collected include construction year, plant type (coal, gas, geothermal, etc.), and power capacity, among others. Replacement costs are estimated from industry data, construction data, publically available reports, and other sources. For facilities without direct costing data, the replacement value is simulated from several metrics including plant type, size, and total power capacity. The final database includes 24 power plants, most of which are verified via satellite imagery. Note that only large NPC (National Power Corporation) and NPC/IPP (joint NPC and independent power producer) facilities are indexed in the final database.

5.3.6 Seaports

A GIS database of seaports was obtained directly from the Philippine Port Authority (PPA), which includes the location of 24 base ports. Supplementary public data (including the PPA website and other public databases) is used to geo-reference 190 government ports, for which the location is manually verified via satellite imagery. The raw data from the PPA contains limited attribute data, mainly aggregate replacement values given for each PMO (port management office) jurisdiction. The replacement value is disaggregated to every port within the PMO jurisdiction through metrics such as shipping calls, cargo traffic, number of passengers, and port size. The Port of Cebu, which is not managed by the PPA but rather the Cebu Ports Authority, is included in the final database. Public sources are used to estimate the attributes of the Port of Cebu.

5.3.7 Airports

A GIS database of airports was obtained directly from the Civil Aviation Authority of the Philippines (CAAP), which includes all 85 CAAP managed airports. The location of every airport in the database is manually verified via satellite imagery. Limited attribute data is provided in the CAAP database, such as the airport name and airport class. Supplementary information is collected from public sources, including the runway length, runway material, number of passengers, number of aircraft movements, and the approximate footprint size of the airport buildings. Replacement costs are estimated from public data, construction reports, news articles, and global industry data. For airports with no replacement value data, the value is simulated using several metrics such as building footprint, airport class, runway length, runway type, aircraft movements, and number of passengers. The airport construction class is simulated based on the airport size and airport class.

5.3.8 Rail

No data on national railroad assets was obtained from the local agencies. GIS data on rail networks is leveraged from several public sources, such as OpenStreetMap and Digital Chart of the World. The final database includes about 530 kilometers of main track and 32 stations. The rail system data is verified with the Bicol Trains Route Map issued in the Philippine National Railways (PNR) website. Unit replacement costs are estimated from global industry data. The rail track exposure is aggregated to a ≈1km grid for modeling purposes.

5.3.9 Public Universities

No data on public universities was obtained from the local agencies. Data is leveraged from several public sources, including the Philippine Association of State Universities and Colleges (PASUC) website. The final database includes 113 state school, college and university institutions, the locations of which are manually verified using satellite imagery. The unit replacement costs are estimated from construction cost data and industry reports. The replacement cost for each facility is simulated using the campus size, building footprint area, and building density. The construction class is estimated based publically available data.

5.3.10 Public Administration Building

A database of public administration buildings in table format was obtained directly from the Department of Public Works and Highways (DPWH), which includes data on 4,417 buildings. The lat/longs are not given, but rather the corresponding administrative division. The given administrative level varies for the different entries, and at minimum the Region Level is provided. As such, assets are aggregated in the final database to the approximate population center of the given administrative division. The raw building attribute data includes floor area, number of stories, type of construction, date of construction, book value, assessed value, and condition. The raw attribute data is occasionally inaccurate and incomplete; unreasonable and missing data is corrected and simulated for the final database based on the remaining good quality data. The database includes buildings for dozens of departments. For example, 45% of the entries are from the Department of Public Works and Highways, 14% are from the Department of Agriculture, and other departments consist of 5% or less of the remaining entries each. It is not possible to assess the scope and completeness of this dataset.

5.3.11 Prisons

A GIS database of regional prisons was obtained directly from the Bureau of Corrections (BOC), which includes 122 buildings aggregated in 7 regional prison facilities. Detailed attribute data is provided in the BOC data for each building, including the year built, number of stories, floor area, construction type (concrete or mixed construction), range of construction cost, and building condition. The raw data, with some minor formatting, is used directly for the final database.

5.3.12 Light Rail

A GIS database of the light rail transportation network was obtained directly from the Light Rail Transit Authority (LRTA), which includes about 49 km of track and 45 stations. This data is verified with the LRT-1 (Red) Line, the MRT-2 (Green) Line, and the MRT-3 (Blue) Line maps from the LRT and MRT websites. No attribute data is provided in raw database. Unit replacement costs are estimated from local official estimates and global industry reports. The light rail track exposure is aggregated to a ≈1km grid for modeling purposes

5.3.13 Bridges

A GIS database of bridges was obtained directly from the Department of Public Works and Highways (DPWH), which includes 7,935 bridges maintained by the national government under the Bridge Management System. This number is verified against the 7,949 bridges indexed in aggregate tables from the DPWH website. It is noted that 78 bridges are not geo-referenced in the DPWH GIS database, but rather included in the GIS table without lat/long information. As such, three additional large bridges are manually geo-referenced with satellite imagery. The remaining 75 bridges are not geo-referenced and thus not included in the final database. However, these are typically small bridges with a relatively low replacement cost. Attributes in the raw GIS database include bridge length, bridge type (arch, box, girder, etc.), and bridge material (bailey, concrete, steel, timber). Unit replacement costs are estimated from data obtained directly from the DPWH. The replacement value of each bridge is determined as a function of the bridge length and bridge material. It is noted that the official bridge ID and name are provided in the database, which can be used in the future to update or improve the data quality.

5.3.14 Residual Institutions

Data from several pertinent government agencies was not obtained, including but not limited to data on emergency services, city halls, and other public buildings. A comprehensive public data search was queried, but no good quality and complete datasets were found for such assets in general. In an attempt to not underrepresent public assets for which data was not directly obtained, an alternative approach is used to index and account for government assets not explicitly included in the exposure database. The total value of the structures modeled in the industry exposure database (see Section 4), as well as the value of the government buildings explicitly accounted for in the database, is compared to official construction statistics and census data, which can be used to estimate the value of institutional (public) buildings. It is noted that a residual value remains, which is attributed to government buildings not explicitly accounted for. This residual value, which represents the residual government institutions, is disaggregated on a ≈1-km grid based on population data.

5.4 Summary

Table 5.3 provides a summary of the government asset exposure database. Also shown in the table is the representative unit replacement cost per asset. The representative unit cost is shown for informative purposes; the actual methodology to estimate the total replacement value involves several metrics not detailed in the table (refer to the Sections above). The database includes assets with a total estimated Coverage A (structures only) value of approximately 2.7 trillion PHP. Roads account for about 25% of the total value (Figure 5.1). By province, the National Capital Region (Manila) accounts for about 14% of the total value (Figure 5.2). Maps of the replacement value by Province are shown in Figure 5.3. Maps showing the location of the assets for each asset type are provided in the Appendix.

Table 5.3. Summary of the Government Asset Exposure Database

Asset Type	Representative Unit Replacement Cost	Number	Estimated Replacement Value (PHP)*
Road	25 to 36 million PHP per km	≈30,673 km of paved national primary and secondary roads	680,566,613,326
Residual Institutions	5,000 PHP per person	n/a	461,674,455,000
Bridge	0.5 to 1.0 million PHP per meter	7,860 bridges maintained by the national government under the Bridge Management System	326,790,678,987
Power Plant	40 to 90 million PHP per MW of installed capacity	24 large NPC and NPC/IPP power plant facilities	295,667,261,120
Public School	7,000 to 12,000 PHP per square meter	46,606 public elementary and secondary school facilities	294,944,436,274
Airport	Runway: 40,000 to 100,000 PHP per meter Buildings: 65,000 to 115,000 PHP per square meter	85 CAAP airports	232,017,926,000
Public University	12,000 PHP per square meter	113 state school, college and university institutions	123,874,249,854
Port	Data given in the raw datasets	190 government ports	111,280,700,659
Light Rail	Track: 650 million PHP per km Station: 730 million PHP per station	≈49 km of track & 45 stations	65,470,607,012
Government Hospital	17,500 PHP per square meter	774 government hospitals	49,986,422,951
Public Administration Building	Data given in the raw datasets	4,417 buildings	28,750,872,283
Government Medical Facility	Small Facility: 0.65 million PHP Medium Facility: 4.38 million PHP Large Facility: 12.13 million PHP	17,969 government medical facilities	25,867,915,868
Rail	Track: 6 million PHP per km Station: 370 million PHP per station	≈530 km of track & 32 stations	14,829,614,040
Prison	Data given in the raw datasets	122 buildings in 7 prisons	509,850,000
Total	**-**	**-**	**2,712,231,603,374**

*All values listed are for Coverage A only (structure value)

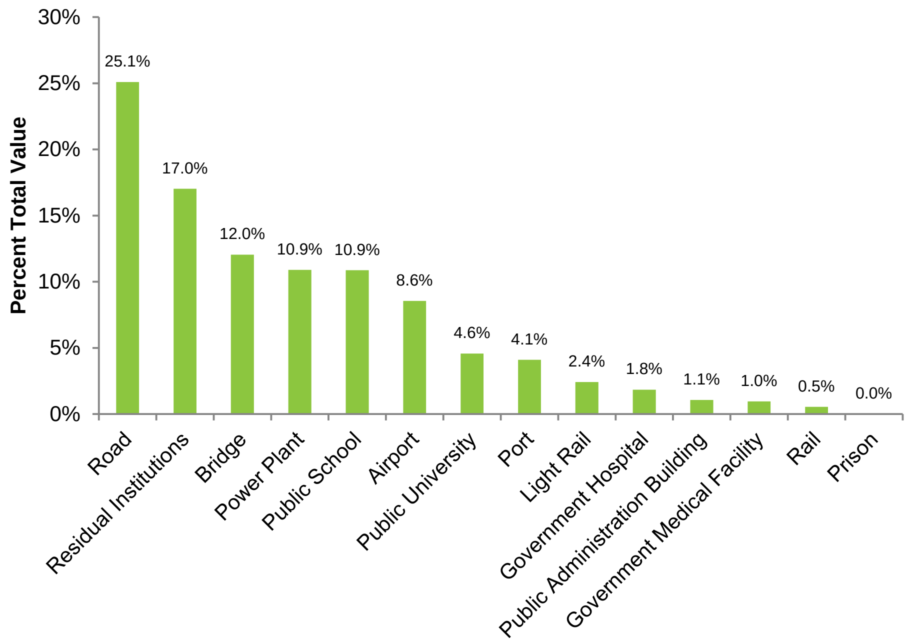

Figure 5.1. Government Asset Database Value by Type

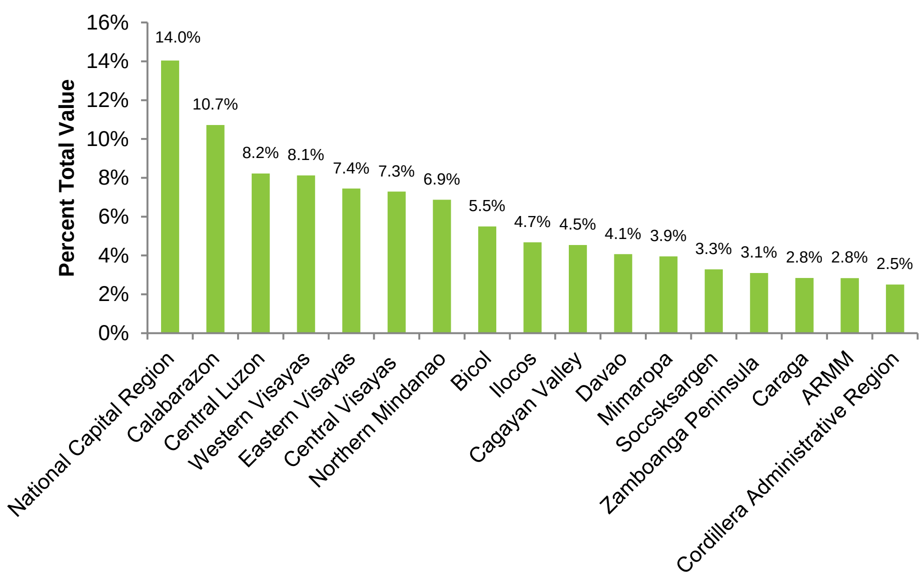

Figure 5.2. Government Asset Database Value by Region

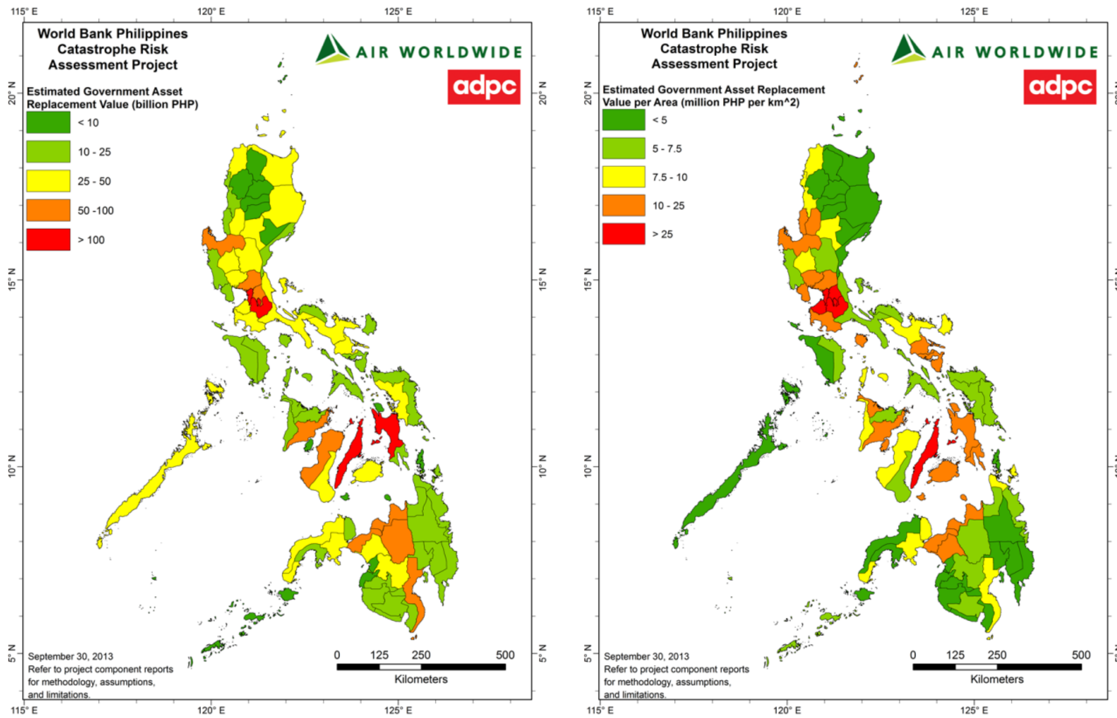

Figure 5.3. Government Asset Database – Estimated Replacement Value by Province (Left Panel) and Estimate Replacement Value Density by Province (Right Panel)

5.5 Limitations

Primarily due to the limitations in the raw data, some uncertainty and potential for error is expected for the government asset database. Data users are cautioned to consider carefully the provisional nature of the information before use. The database of government assets provides a view of the assets at risk that is used for the purpose of catastrophe risk modeling within the project scope. The database should not be considered, in general, a true account of the location and characteristics of all government assets. For example, no systematic field survey was completed to verify the entries in the database. The raw data itself used in the development of the database has limitations, errors, and may be incomplete. Many of the entries in the final database are estimated, simulated, or assumed based on ancillary data, industry practices, and expert judgment.

6 Vulnerability Asset Classes

6.1 Overview

A classification system dividing building assets by their vulnerability to natural catastrophes was established to facilitate the risk assessment of private and government assets. Buildings are classified according to a set of primary structural characteristics that influence the asset vulnerability with respect to the natural hazards being considered in this study. The characteristics used to define vulnerability classes in the Philippines are based on the type of occupancy, type of construction, year of construction and number of stories of the building because these attributes have a substantial influence on the performance of structures during natural catastrophes. This section discusses the various vulnerability classes considered for the Philippines.

6.2 Type of Occupancy

The occupancy type of an asset is defined by what the building is primarily used for. The various occupancy types considered for the Philippines are as follows:

- **Residential - Permanent dwelling single family**
  - Residential houses and dwellings (e.g., single-unit houses)
- **Residential - Permanent dwelling multi-family**
  - Residential flats and apartments (e.g., multi-unit houses)
- **Residential - Out building**
  - Residential out-buildings (e.g., garages, out-houses, toilets, kitchens, sheds, workshops)
- **Commercial - General commercial**
  - General commercial buildings (e.g., supermarkets, stores, offices), market stalls, pharmacies
- **Commercial – Health care services**
  - Hospitals and medical clinics
- **Industrial – General industrial**
  - General industrial and manufacturing facility buildings, mining buildings, oil/gas processing buildings
- **Industrial - Power Systems**
  - Hydro and Thermo-Electric and power systems
- **Public – Education**
  - Education buildings (e.g. preschools, primary schools, secondary schools, tertiary education, colleges/universities)
- **Public - Emergency services**
  - Firefighting and police station buildings

- **Public - General public facility**
  - Community facility buildings (e.g., community halls, sports facilities), public services facility buildings, NGO (non-governmental organization) facility buildings
- **Public – Government**
  - General government buildings (e.g., governmental offices), defense buildings (e.g., barracks)
- **Public - Health care services**
  - Clinic, hospital, other health facility buildings
- **Infrastructure**
  - Utility buildings, highways, railroads, airport buildings and runways, sea and inland waterway assets.

6.3 Type of Construction

The type of construction is defined by a building's construction material and the associated structural characteristics of its lateral force resisting system. The various construction classes considered for the Philippines are as follows:

- **Wood** – In the Philippines, wood is primarily used for residential buildings (about 20% of residential buildings are made of wood) such as single family and multiple family dwellings. These are wooden frame structures built mostly with components such as wooden roof joists and stud walls.
- **Masonry** – Masonry constitutes over 30% of residential and 15% of commercial and industrial buildings in Philippines. These buildings are constructed using masonry blocks and are typically used for low-rise buildings. They can be of the following types:
  - ***Unreinforced masonry (URM) buildings*** include structures that do not have any (or negligible) reinforcement steel within the load-bearing masonry walls. As a result, these structures have limited lateral load-resistance capacity and are very vulnerable to the lateral loads generated by earthquakes. This poor performance of URM structures has been observed in all past earthquakes.
  - ***Reinforced masonry (RM) buildings*** contain load-bearing walls of brick or concrete block masonry reinforced by steel rods. The reinforced brick, or reinforced hollow concrete block shear walls, which extend from the foundation to the roof, provide lateral load-resistance to the structure.
- **Concrete** – Reinforced concrete is widely used in Philippines. It constitutes over 30% of residential and over 45% of commercial and industrial buildings. These structures consist of typical reinforced concrete elements (e.g., beams, columns, and shear walls), which make up the primary lateral load-resisting system. The concrete building types considered for the Philippines are:

  - Reinforced concrete shear wall with moment resisting frames (MRFs)
  - Reinforced concrete shear wall without MRFs
  - Reinforced concrete MRFs
  - Reinforced concrete MRFs with URM
- **Steel Frame** – Steel is rarely used in Philippines for buildings. It constitutes only about 5% of commercial and industrial buildings and mostly for high rise structures. Typical steel buildings consist of steel columns and beams. The beam-column connection is typically the most critical part of a steel frame. The types of steel buildings considered for Philippines are:
  - Steel light frame
  - Braced steel frame

6.4 Age Bands

Age bands divide the building stock by the year of construction of an asset. It is important to account for the year of construction because building codes in a region are often revised with advancement in research and development which greatly influence the performance of the buildings, especially under seismic loading. An in-depth building code review was conducted by AIR to evaluate the implementation and changes of seismic and wind design criteria throughout the history of the Philippines and is summarized in Sections 7.3.1 and 7.3.2. In order to capture the influence of major code revisions, Philippine buildings are classified into three age bands: Pre 1972, 1972 to 1992 and Post 1992.

6.5 Height Bands

Height bands represent the height of buildings. Height is one of the defining features of a structure that influences its vulnerability with respect to natural hazards. In order to capture the dependence of the performance of a building on its height, buildings are classified into three groups; low-rise (less than 4 stories), mid-rise (4 – 7 stories) and high rise (greater than 7 stories).

7 Damage Estimation

7.1 Overview

AIR has developed vulnerability relationships for property assets in the Philippines that estimate damage caused by ground shaking from earthquake events (earthquake ground shaking), wind and precipitation associated with tropical cyclone events and flooding associated with non-tropical cyclone precipitation. The severity of the physical damage experienced by buildings and infrastructure assets from the above-mentioned perils is represented by damage functions (DFs). These functions are statistical relationships that estimate the expected loss to an asset when subject to different levels of intensity (or intensities) induced by a natural catastrophe event. The degree of loss is represented by the so-called damage ratio (DR), which is defined as the ratio of the cost to repair the asset to the total replacement value of the asset.

7.2 Intensity Measures

Three types of natural hazards are considered in this risk analysis: earthquake ground shaking, tropical cyclone wind, and precipitation flooding (due to both tropical cyclones and non-tropical cyclone events). The effects of these events are measured by the intensity measures (IMs) described below. These IMs are used as input to the damage functions discussed herein.

- **Wind speed** (for tropical cyclones)
  - Wind speeds are defined as the maximum one-minute sustained wind speed at 10 meters above the ground surface at the exposure location
- **Water height** (for flooding induced by tropical cyclones and non-tropical cyclone precipitation)
  - The height of the standing water at the exposure location
- **Ground motion intensity** (for earthquakes)
  - The intensity of the ground motion is gauged by the horizontal peak ground acceleration (PGA) or by the 5%-damped elastic spectral acceleration (S_a) at oscillator periods of 0.3, 1.0 and 3.0 seconds at the exposure location

Note that other effects of these events, such as landslides, liquefaction, and fire-following earthquake were not explicitly considered. Their effects, however, are somewhat implicitly included in these analyses to the extent that the losses induced by such phenomena were included in the empirical data from historical events used to calibrate the damage functions adopted herein.

7.3 Damage Function Development

There are three types of methodologies commonly adopted in catastrophe risk assessment to develop damage functions: *analytical*, *empirical* and *hybrid*. Analytical methods are primarily based on computer modeling of structures and the loading process; empirical methods are primarily based on observed damage data; and hybrid methods are a combination of analytical and empirical methods. Typically, hybrid methodologies are commonly adopted due to the lack of sufficient information for computer modeling of structures and the loads as well as insufficient empirical data to develop complete damage functions.

AIR used hybrid methods to develop damage functions for the perils considered in this study. For vulnerability to earthquake ground shaking, AIR conducted an in-depth literature review of current research and Philippines building design codes, executed engineering analyses to create base damage function specific to the Philippines, and leveraged data and analysis from countries with similar design standards to extend the base damage functions to a comprehensive suite of vulnerability relationships. Initially, AIR was planning on using previously developed typhoon wind damage functions for this assessment given the restrictive time constraints of the project; however, an approach similar to the earthquake damage function development was ultimately used because it was determined that the existing relationships could be enhanced using currently available data and research. AIR did leverage previously developed damage functions for precipitation induced damage to be consistent with the existing hazard models being used in the catastrophe risk assessment. The details of the damage function development are summarized in the following sections.

7.3.1 Vulnerability to Earthquake Ground Shaking

To develop earthquake damage functions, AIR first evaluated the building codes in the Philippines to understand the seismic design standards that have been implemented throughout the years. Figure 7.1 shows the evolution of building codes in Philippines. The figure also shows the major earthquakes that preceded and likely prompted the revisions of the building codes. The first National Building Code of Philippines (NBCP) was officially implemented in 1972 following the disastrous 7.3 magnitude earthquake in Casiguran in 1968. The NBCP was primarily based on the Unified Building Code (UBC) 1970 and the ACI 318-71. After few minor revisions, the NBCP was eventually superseded by the National Structural Code of Philippines (NSCP) in 1992 following the disastrous 7.7 magnitude earthquake in Luzon in 1990. The NSCP was a major revision over NBCP and was based on the UBC 1988 and ACI 318-89. Since 1992, NSCP has been revised twice in 2001 and 2010 but their degree of implementation has largely been indeterminable. One of the primary conclusions from this review is that Philippine seismic requirements are based on similar, if not the same, building codes used for the U.S.; therefore, data and analyses developed for the U.S. can be leveraged as long as they are adjusted to capture any differences in performance that are specific to the Philippines (e.g. in terms of construction practices, material quality, etc.).

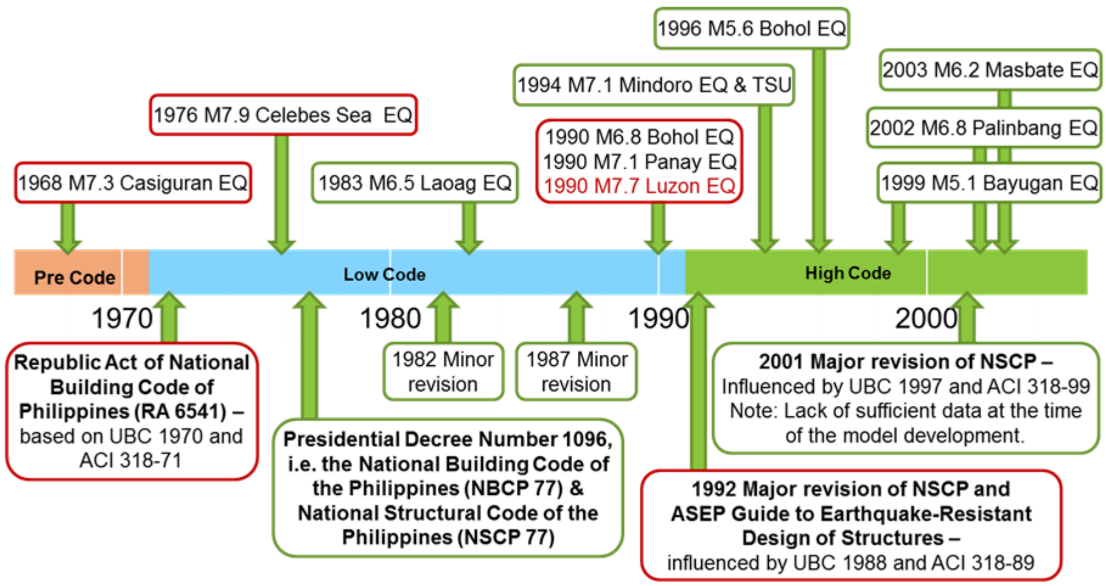

Figure 7.1. Evolution of Seismic Design in Philippine Building Codes

Once the code review was completed, the following methodology was used to develop earthquake damage functions for the Philippines. This method consists of first developing *base* damage functions for the most prevalent building types in the Philippines and then developing damage functions for other building types by estimating their vulnerabilities relative to the base types. The developed damage functions are then validated using damage observations from past events as contained in existing literature.

Based on their prevalence in the Philippines, the low-rise concrete and masonry buildings are selected to develop the base damage functions. These damage functions are developed using incremental dynamic analysis (IDA) using single degree of freedom (SDOF) system representations of the buildings. The steps to develop the base damage functions are as follows:

SDOF Representation: An SDOF model of a structure is essentially a point mass connected to a fixed point through a spring that emulates the pushover curve and the hysteretic behavior of the structure. An SDOF model is well suited to model structures whose dynamic behavior is typically dominated by the first-mode (i.e. fundamental period of vibration). Most low-rise buildings' structural response to earthquake loading is first-mode dominated and, therefore, these types of structures can be modeled well with SDOF systems. For modeling the base building types, SDOF systems are developed using the OpenSees software.

The pushover curves for the SDOF models are developed using capacity curves for Philippines buildings developed in the Earthquake and Tsunami Disaster Mitigation for the Asia Pacific project (EQTAP). This study was conducted from 2000 to 2004 by the Earthquake Disaster Mitigation Research Centre, Japan. In the EQTAP project, the Metro Manila Case Study (MMCS) was undertaken to investigate the seismic vulnerability of buildings in Metro Manila. In MMCS, the capacity curves for the buildings were estimated based on the judgment of local experts obtained using a statistical method of surveying called the Delphi method.

A typical capacity curve is bilinear and is primarily intended to be used in static analysis procedures such as the Capacity Spectrum Method. However, bilinear capacity curves do not include the negative stiffness region of a pushover curve which is usually critical for dynamic analysis. Therefore, as shown in Figure 7.2, the negative stiffness region was added to the pushover curves using the methodology developed by Ryu et al (2008). The methodology recommends the use of the median of the collapse fragility curve as the spectral displacement at collapse. The shear force at the collapse point is typically considered as 20% of the shear force at the ultimate point.

Incremental Dynamic Analysis: A suite of 20 ground motions developed in the SAC Project (2000) were used for the IDA by scaling the ground motions to various intensity levels. Figure 7.3 shows the results from the IDA analysis for 5 ground motions from the suite of 20. As is typically observed in an IDA analysis, Figure 7.3 shows that there is a significant amount of uncertainty in the prediction of displacement for a given intensity.

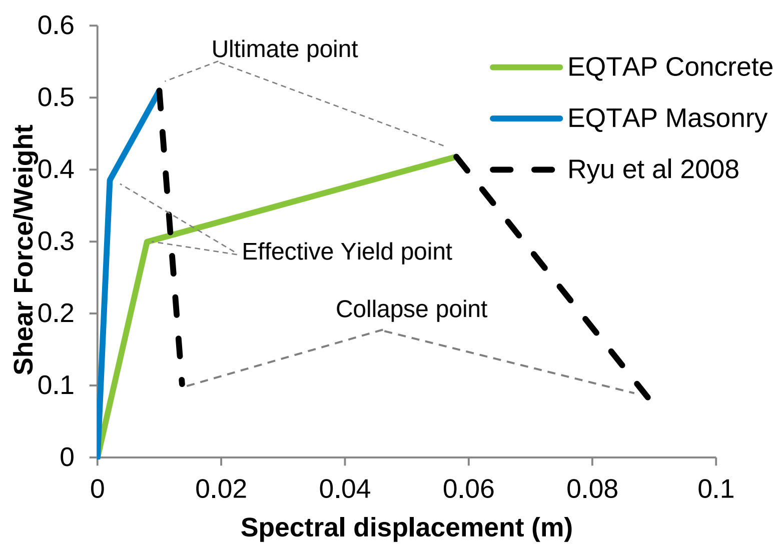

Figure 7.2. Capacity Curves Used for IDA Analysis

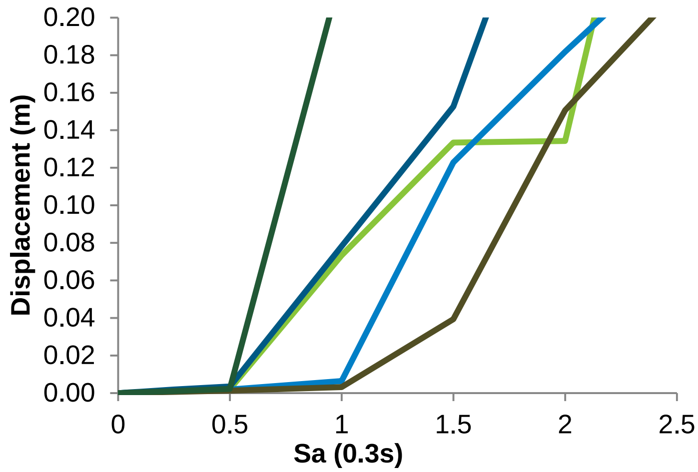

Figure 7.3. IDA Analysis Results for Selected Ground Motions

Developing Fragility Curves: A fragility curve provides the probability of exceeding a damage level, conditioned on the value of an intensity measure or a demand parameter. In this project, the fragility curves are developed for discrete damage states: Slight damage, Moderate damage, Extensive damage and Complete damage as defined by HAZUS (a loss estimation methodology commonly used in the U.S.). These fragility curves are developed conditioned on spectral displacement so as to allow their integration with the IDA results. Fragility functions are developed based on those provided by HAZUS for U.S. buildings. However, HAZUS fragility functions were adapted for the Philippines to capture the difference in structural characteristics between U.S. and Philippine buildings. A comparison of representative capacity curves demonstrated that, in general, the ductility of U.S. buildings was significantly higher than Philippine buildings. To account for this difference in ductility, the HAZUS fragility functions were transformed by multiplying the X axis values by the ratio between the spectral displacement at the ultimate point of the EQTAP capacity curve (see Figure 7.2) and the spectral displacement at the ultimate point of the HAZUS capacity curve. Figure 7.4 shows an example of the resulting transformed fragility curves developed for the Philippines as compared to the original HAZUS fragility functions.

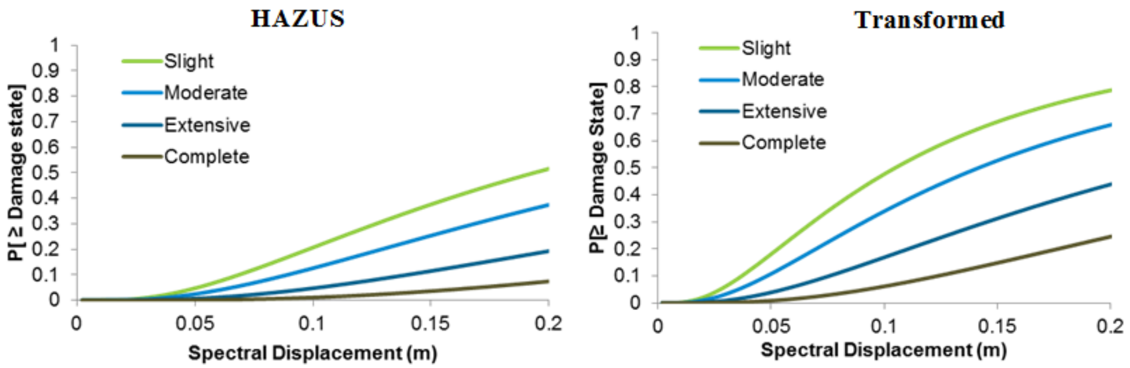

Figure 7.4. Development of Fragility Functions Using HAZUS

Developing Damage Functions: Using the developed fragility curves, the IDA result from each ground motion can be used to generate a damage function as follows:

$$MDR(Sa) = [P_S(Sa) - P_M(Sa)] \times DR_S + [P_M(Sa) - P_E(Sa)] \times DR_M + [P_E(Sa) - P_C(Sa)] \times DR_E + P_C(Sa) \times DR_C$$

where $MDR(Sa)$ is the mean damage ratio corresponding to Sa, and $P_S(Sa)$, $P_M(Sa)$, $P_E(Sa)$ and $P_C(Sa)$ are the fragility values corresponding to Sa for slight, moderate, extensive and complete damage states. The variables DR_S, DR_M, DR_E and DR_C are the damage ratios corresponding to the various damage states. The final damage function is computed as the arithmetic mean of all the damage functions generated using the ground motions.

Estimating Relative Vulnerability: In order to develop the earthquake damage functions for the remaining vulnerability asset classes for Philippines outside the base damage functions, AIR leveraged its suite of previously developed damage functions to develop relative vulnerability relationships for other types of buildings. The base damage functions were mapped to an existing set of U.S. damage functions, where more data and analysis is available. This set of functions was used to compute the relative vulnerability between low-rise, reinforced concrete/masonry buildings and buildings with other primary structural characteristics (e.g. construction type, year built, number of stories). These relative ratios were then used to scale the Philippine base damage functions to derive functions of other construction types, age bands and heights to provide a full suite of functions for the Philippines.

The base damage functions were mapped to the U.S functions because the building codes in Philippines have traditionally been based on U.S. codes and it is fairly reasonable to expect that, all else being equal, the buildings from the two countries corresponding to the same design code will have similar performance. The AIR damage functions for the U.S. are based on engineering analyses, damage data collected after historical earthquakes, claims data at both property and aggregated levels, loss estimates for past earthquakes, and a careful evaluation of the prescription in the building codes.

Different regions within the U.S. are designed to varying levels seismic requirements; thus, the vulnerability of U.S. will also vary across the country. The country can be roughly divided into three regions of seismic design – Central Eastern (CE), Pacific North-West (PNW) and California (CA) – and AIR has developed complete sets of damage functions for each region. Comparing the Philippines base damage functions to those of U.S., it is found that the seismic vulnerability of Philippines buildings is closer to that of the Pacific North-West region, as shown in Figure 7.5. This suggests that the expected seismic performance of Philippines buildings is more vulnerable than their intended design, as the NSCP 1992 seismic requirements for the majority of the country are more comparable to those found in California. This difference may be due to the prevailing construction practices.

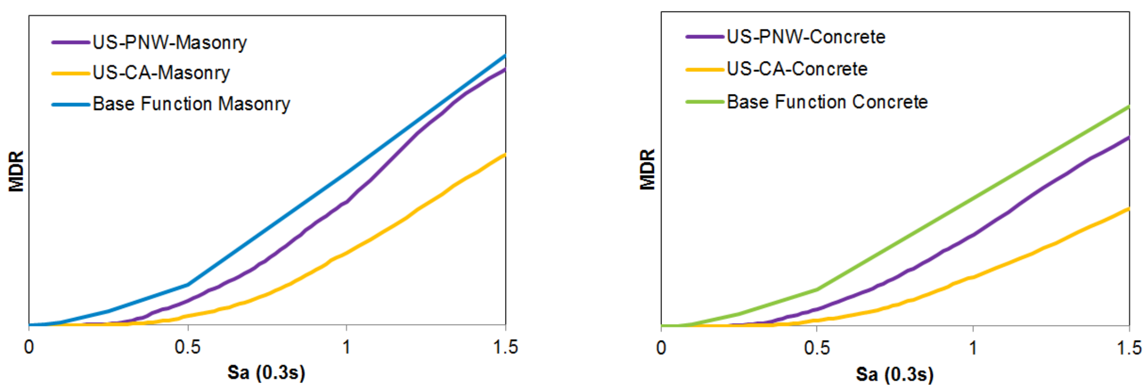

Figure 7.5. Comparison of Base Damage Functions with AIR's U.S. Damage Functions

Although the actual earthquake damage functions developed for this study cannot be distributed due to the proprietary nature of these relationships, Table 7.1 provides the relative vulnerability between low-rise reinforced concrete buildings (one of the base damage functions) and structures with different characteristics at a peak ground acceleration of 0.4g.

Table 7.1. Summary of Relative Earthquake Vulnerability Relationships.

Construction	Height (stories)	Relative Vulnerability
Wood	less than 4	0.7
Masonry	less than 4	1.3
Reinforced Concrete	**less than 4**	**1.0***
	Between 4-7	0.8
	more than 7	0.5
Steel	more than 7	0.8

*Base damage function

Validation of Damage Functions: The damage functions developed are validated by evaluating against laboratory tests and post-earthquake reports available in the literature.

- Shake table test: Imai et al (2012) performed shake table tests for two full scale models of masonry buildings – one built as per NSCP 2010 and the other built as per locally prevailing practices. Table 7.2 shows the levels of damage observed for the two models for different intensity levels. Figure 7.6 shows that the base damage function for masonry agrees fairly well with the observed damage to the model built as per locally prevailing construction practices. This also reinforces the observation made earlier that the performance of existing buildings in the Philippines is expected to be lower than that would be deduced assuming perfect application of the design codes.
  - 1990 Luzon earthquake damage data: Table 7.3 shows the damage data from Luzon 1990 earthquake provided by Cambridge earthquake impact database (CEID). The table also shows the prediction of percentage of buildings in various damage states as estimated by the model using the developed damage functions. It is found that the damage data agrees well with model predictions.

Table 7.2. Shake table test data from Imai et al (2012)

PGA (g)	As per NSCP 2010	Locally Prevailing Practices
0.17	No damage	No damage
0.40	No damage	Moderate damage
0.85	Heavy Damage	Collapse

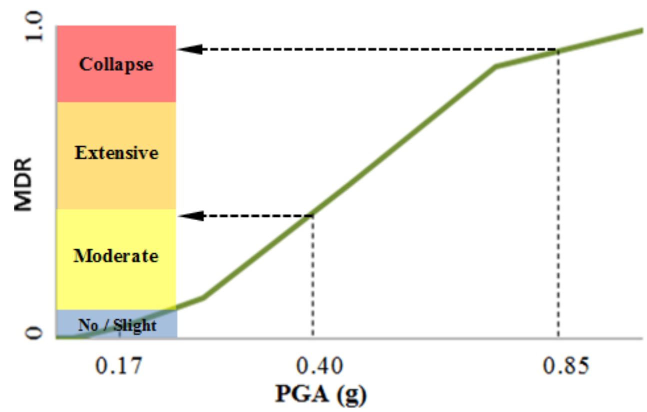

Figure 7.6. Validation of Base Damage Function for Masonry Using Shake Table Test Results in Imai et al (2012)

Table 7.3. Luzon 1990 Earthquake Damage Data by Cambridge Earthquake Impact Database

Province	Number of buildings in a damage state		
	No damage	Partial damage	Complete damage
Benguet	72293	14618	7970
La Union	82722	16066	3583
Nueva Ecija	223839	14339	1679
Nueva Vizcaya	50250	5352	2620
Pangasinan	360692	16764	3044
Tarlac	147582	10736	3396
Total	**937378**	**77875**	**22292**
Percentage	**90.4%**	**7.5%**	**2.2%**
Model Predictions	**91.9%**	**7.8%**	**0.34%**

7.3.2 Vulnerability to Typhoon Wind

Buildings respond differently to wind loads depending on their characteristics such as construction type, occupancy, height and year built. The wind vulnerability functions for the Philippines are based on engineering analyses of different types of buildings subjected to wind loads. These base vulnerability curves are additionally adjusted to account for labor and material costs, building construction practices, and claims adjustment practices in the Philippines.

The model captures the differences in vulnerability of buildings of different construction and occupancy types. For example, apartment buildings usually receive a degree of engineering attention similar to commercial construction. However, apartments have some building components that make them more susceptible to wind damage than commercial construction, including balconies and sliding glass doors. Based on this, apartment buildings are expected to have higher vulnerability than commercial buildings. There are separate damage functions for building and contents, where contents damage due to wind is closely related to the damage sustained by the building.

Wind speed profiles are characterized by increasing wind speeds with height. For a given storm at a given location, a low-rise building may experience Category 1 wind speeds, while the upper floors of a 20-story building may experience winds corresponding to a Category 3 typhoon. On the other hand, while the wind hazard increases with height, vulnerability typically decreases. High-rise buildings are less vulnerable since they are generally well-engineered and built to strict building code requirements. These important vulnerability aspects are reflected in the model by separate damage functions for each building height band (low-, medium- and high-rise).

Good resolution and quality data on damage and losses from wind is scarce for the country. In such instances, AIR engineers leverage extensively validated damage functions from other regions. A review of the building codes in the Philippines indicates that they have traditionally been based on the ones used in the U.S. as shown in Table 7.4. Thus, the AIR suite of vulnerability functions for a particular area in the U.S. was used for a more in-depth assessment of the wind vulnerability of the building stock in the Philippines.

Table 7.4. Historical basis of the NSCP wind loading provisions for buildings

Philippine Code	U.S. Code Basis
NSCP-2010	ASCE 7-05 / IRC
NSCP-2001	ASCE 7-95
NSCP-1992	ANSI A58.1-72
NSCP-1972,1977,1982	ANSI A58.1-55

The year of construction is a building characteristic typically used as a proxy for changes in the building code. Figure 7.7 shows that the wind zone maps in the Philippines have remained relatively consistent although the basic design wind speeds vary by code revision. The available year of construction statistics data for the Philippines is very limited and indicates that buildings in the Philippines are predominantly 1992 or older year built. The lack of data, coupled with the unknown extent of local code enforcement of the wind provisions, is the reason for a vulnerability module which does not support different age bands or specific regional modifiers.

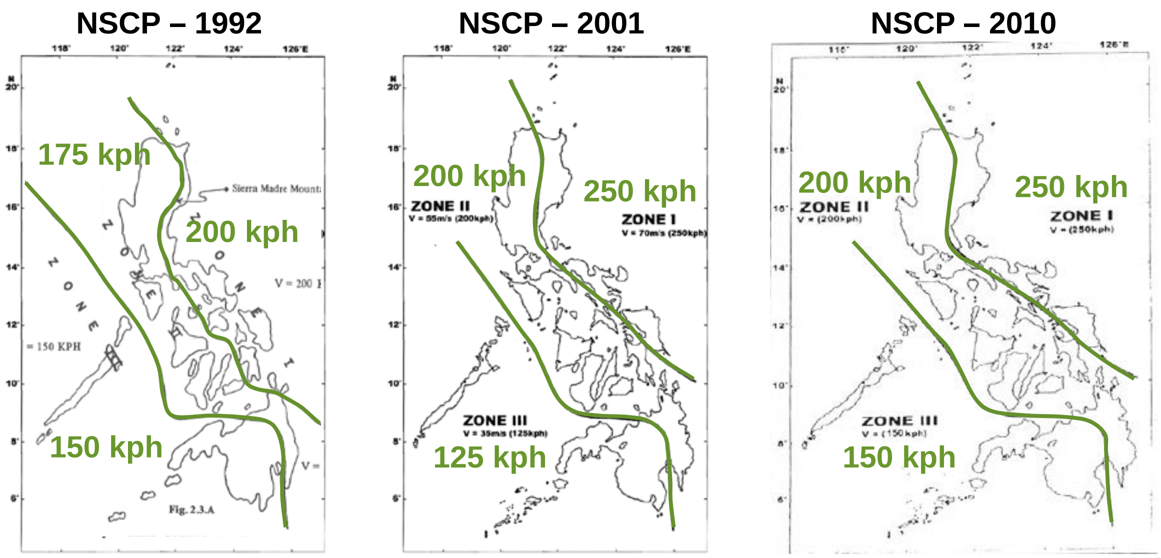

Figure 7.7. Evolution of the wind zone maps for the Philippines

Wind hazard levels and building codes in the Philippines suggest vulnerability similar to that of buildings in the following U.S. regions:

- Key West, FL for NSCP Zone I
- New Orleans, FL for NCSP Zone II
- Houston, TX for NSCP Zone III

However, construction in the Philippines often lacks characteristics typical for the hurricane prone regions of the U.S. such as stringent code enforcement and the use of engineered window shutters, strong building-foundation connections, impact resistant glass, etc. Thus, it can be expected that the wind vulnerability of Philippine buildings, on average, is more comparable to that of buildings in the Houston, TX region.

To further investigate the effect that these characteristics have on the expected vulnerability of buildings in the Philippines, AIR leveraged additional regional information based on the recently completed Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) study for the World Bank. The PCRAFI study included the development of state-of-the-art catastrophe risk models for 15 Pacific Island Countries (PIC) where construction practices can be considered similar to those in the Philippines, especially for residential construction. AIR developed and validated the PCRAFI vulnerability module based on engineering analyses, in-depth study of the regional building characteristics and available damage and loss data from past events including reconnaissance reports. Figure 7.8 shows example comparisons of U.S. and PCRAFI based damage functions corresponding to the wind vulnerability characteristics of Philippine buildings.

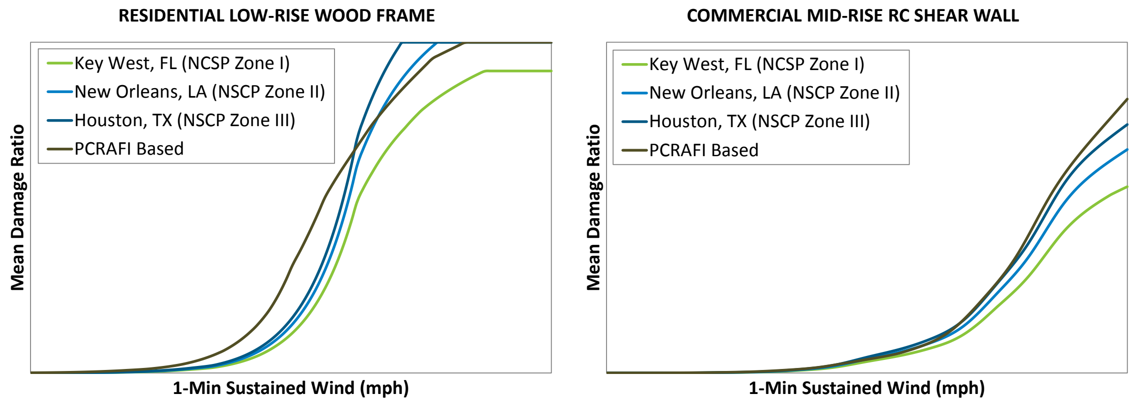

Figure 7.8. Wind vulnerability comparisons

Although a subject of similar wind design provisions as buildings in the U.S., the wind vulnerability of buildings in the Philippines may be higher due to prevailing construction practices and code enforcement. For example, Figure 7.8, left, illustrates that the U.S. damage functions for residential low-rise wood frame construction underestimate, especially in the low wind range, the vulnerability of the same type of buildings in the region as represented by the PCRAFI based damage function. On the other hand, commercial buildings are better engineered and constructed. This results in similar wind vulnerability of commercial buildings in the region and these in the U.S. as shown in Figure 7.8, right.

In summary, PCRAFI based damage functions were determined to better approximate the expected vulnerability of certain building types in the Philippines. The PCRAFI damage functions were appropriately adjusted to reflect the different combinations of construction, occupancy and height of the building stock in the Philippines. The existing AIR model was updated with these PCRAFI based and, in some instances, with the appropriate Houston, TX damage functions.

Although the actual wind damage functions developed for this study cannot be distributed due to the proprietary nature of these relationships, Table 7.5 provides the relative vulnerability between low-rise reinforced concrete buildings (one of the base damage functions) and structures with different characteristics at a wind speed intensity of 100 mph.

Table 7.5. Summary of Relative Wind Vulnerability Relationships.

Construction	Height (stories)	Relative Vulnerability
Wood	less than 4	6.2
Unreinforced Masonry	less than 4	2.5
Reinforced Masonry	less than 4	1.3
	4 to 7	1.1
Reinforced Concrete	**less than 4**	**1.0***
	4 to 7	0.7
	more than 7	0.5
Steel	less than 4	1.1
	4 to 7	0.6
	more than 7	0.5

*Base damage function

7.3.3 Vulnerability to Typhoon and Non-typhoon Induced Precipitation

Philippines building code provisions for flood are much more limited than those for wind and their implementation in design and construction is uncertain. Additionally, observation data of good resolution and quality is very scarce; this holds true not only for the Philippines but worldwide, in general, for this hazard. The available claims data for the Philippines contained information on the primary building characteristics pertinent for flood vulnerability modeling. Of these, the occupancy class was more reliably documented than the buildings' height and construction type characteristics. Thus, the flood damage functions are based on a building's occupancy and the total amount of precipitation at its location.

Figure 7.9 shows the relative mean flood damage functions for buildings of different occupancy types in the Philippines. For instance, typical construction types used for single-family homes such as wood frame or masonry are generally more vulnerable to flood when compared to other occupancy types for which concrete and steel are more common. Masonry and wood frame are generally characterized by weak connections between building elements; the material itself is more permeable and therefore more vulnerable to water damage. On the other hand, commercial and apartment buildings usually have stronger foundations than residential buildings, and these foundations provide a stronger resistance to flood loads. However, many multi-story apartment buildings in the Philippines have commercial establishments on the first floor, which is most susceptible to flood damage. Therefore, the flood damage functions for commercial establishments show less flood resistance than those for apartments. The design of industrial facilities in flood prone areas typically includes measures such as the selection of a flood safe elevation for the site and the critical equipment. Thus, industrial occupancy exposure is expected to be least vulnerable to flooding.

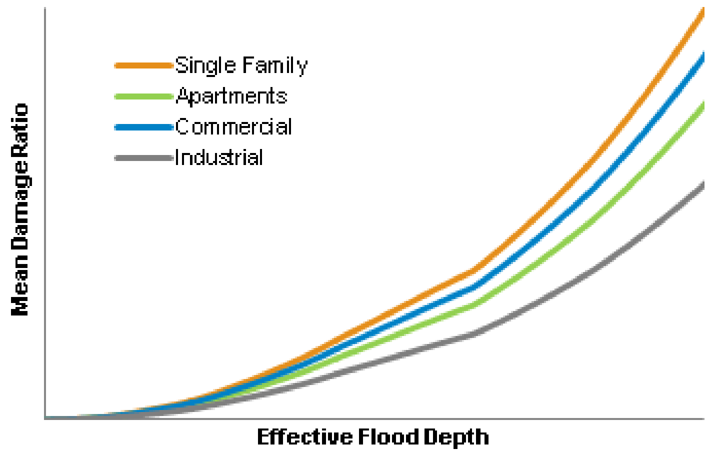

Figure 7.9. Representation of Flood Damage Functions for Different Occupancy Types

The precipitation based damage functions in the AIR Typhoon Model for Southeast Asia relate effective precipitation depth to the amount of damage sustained expressed in terms of mean damage ratio. The effective depth is total event rainfall at the location minus a flood threshold for the country. The flood threshold is a critical hazard value below which the building is assumed undamaged. Its value is based on the degree of sophistication and efficiency of the flood defense systems in the country. For example, in Hong Kong, the government is heavily invested in flood reduction measures, whereas the flood defense systems are not as sophisticated in the Philippines. Thus, the flood threshold would be higher for Hong Kong than that for the Philippines.

The damage functions are calibrated to the hazard resolution of the existing model, i.e. the total event rainfall at a location is the average amount of total precipitation over a larger area in which the location is situated. Accordingly, the “effective flood depth” measure is not an “actual” flood depth that a building observes in real life; rather, it is an indication of flood or a flood index for the larger area.

The model includes separate damage functions for building and contents. While contents damage from wind is directly related to the amount of wind damage to the building, the amount of contents damage from flood is more closely related to actual hazard rather than to building damage.

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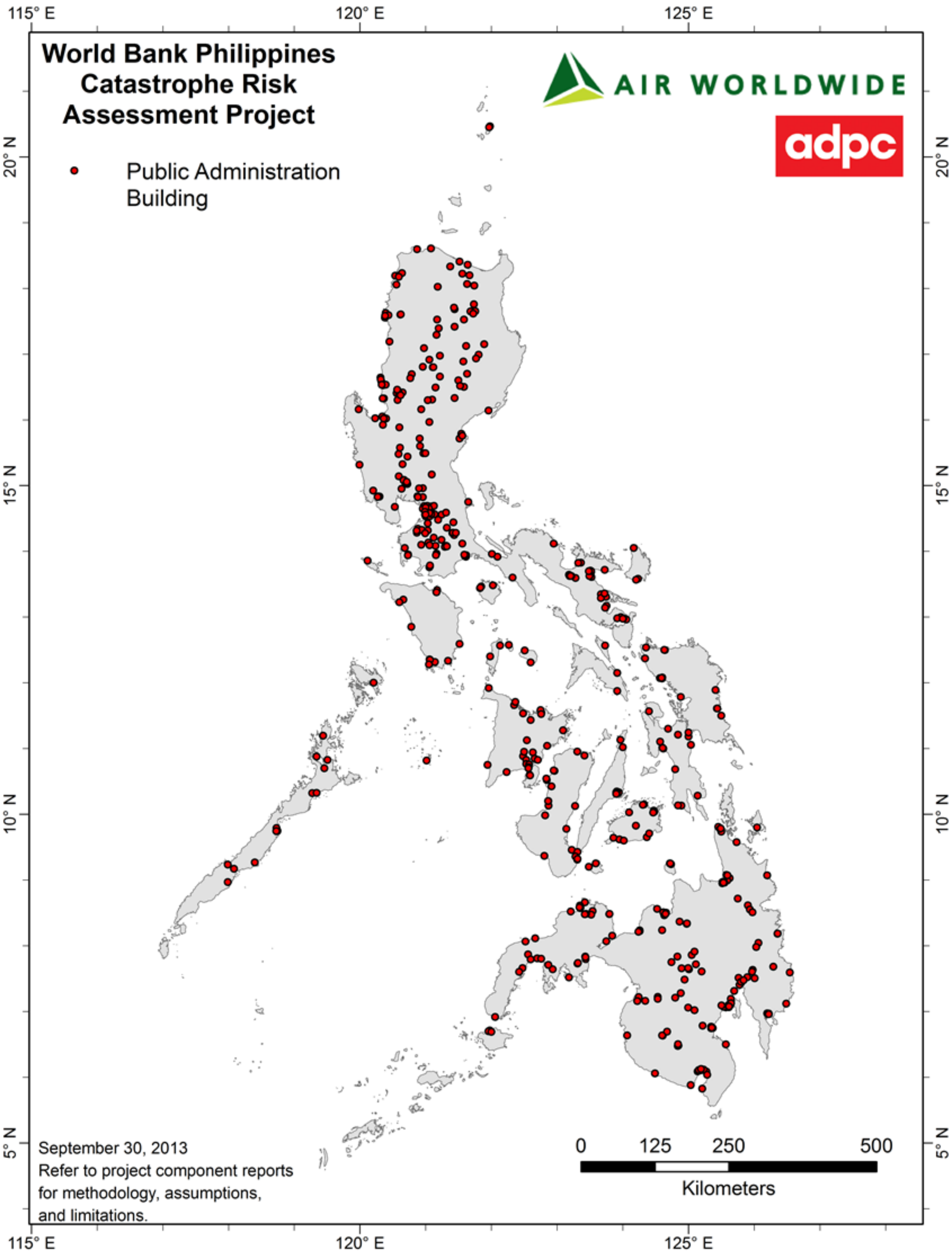
About AIR Worldwide Corporation

AIR Worldwide Corporation (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 50 countries. More than 400 insurance, reinsurance, financial, corporate and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, detailed site-specific wind and seismic engineering analyses, agricultural risk management, and property replacement cost valuation. AIR is a member of the ISO family of companies and is headquartered in Boston with additional offices in North America, Europe and Asia. For more information, please visit www.air-worldwide.com.

About Asian Disaster Preparedness Center (ADPC)

As a leading regional resource center, Asian Disaster Preparedness Center (ADPC) works towards the realization of disaster reduction for safer communities and sustainable development in Asia and the Pacific. Since its inception in 1986, ADPC has been recognized as the major independent center in the region for promoting disaster awareness and the development of local capabilities to foster institutionalized disaster management and mitigation policies. ADPC was originally established as an outreach center of the Asian Institute of Technology after a feasibility study conducted jointly by two agencies of the United Nations, the Office of the United Nations Disaster Relief Coordinator (current the UN Office for the Coordination of Humanitarian Affairs) and the World Meteorological Organization in January 1986. Funding for the study was provided by the United Nations Development Program in response to requests from countries in the region for international assistance to strengthen their national disaster management systems. Thus, the initial role conceived for the center was mandated by an expressed need to assist countries of the Asia and the Pacific region in formulating their policies and developing their capabilities in all aspects of disaster management.

Appendix:
Government Assets Sector Maps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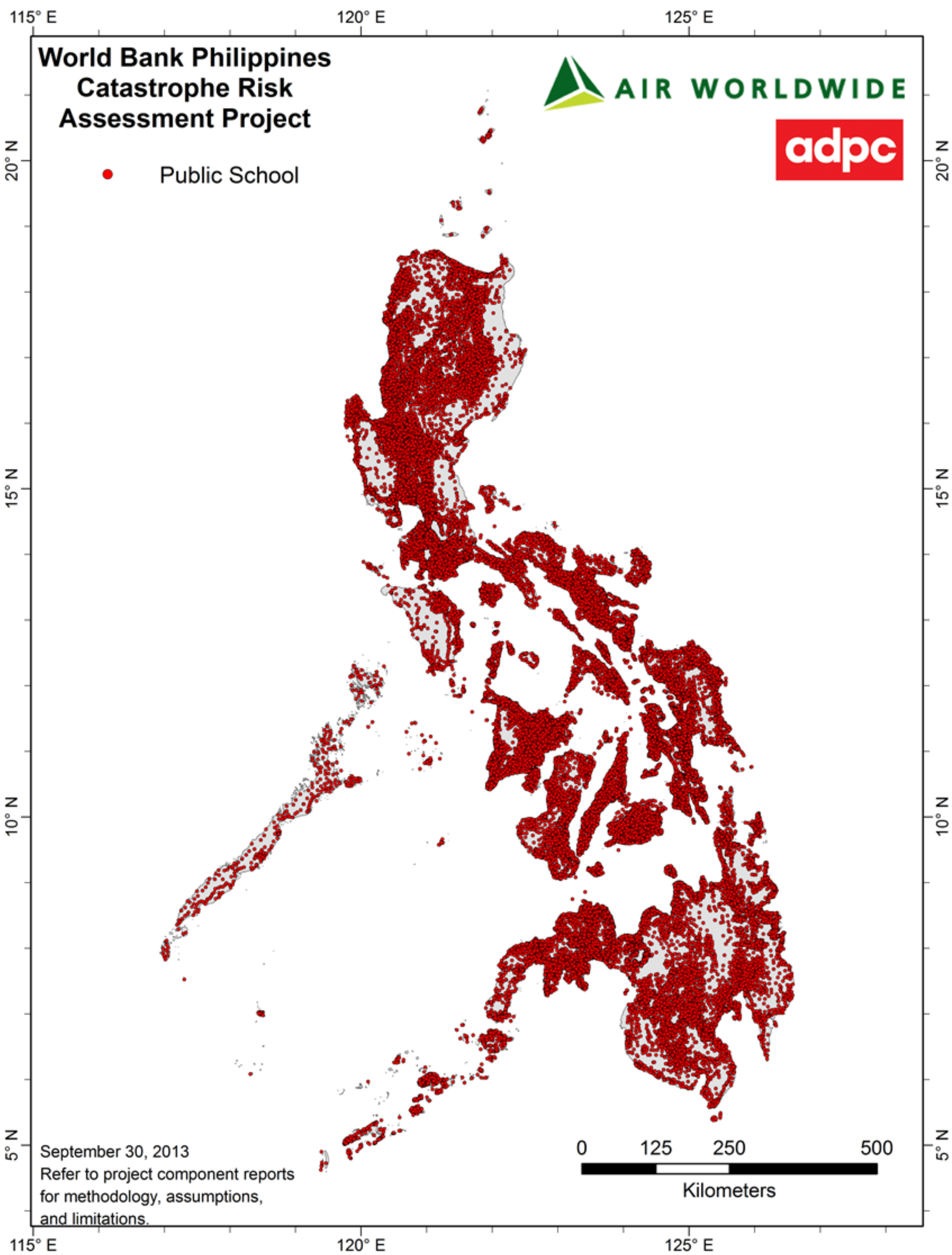
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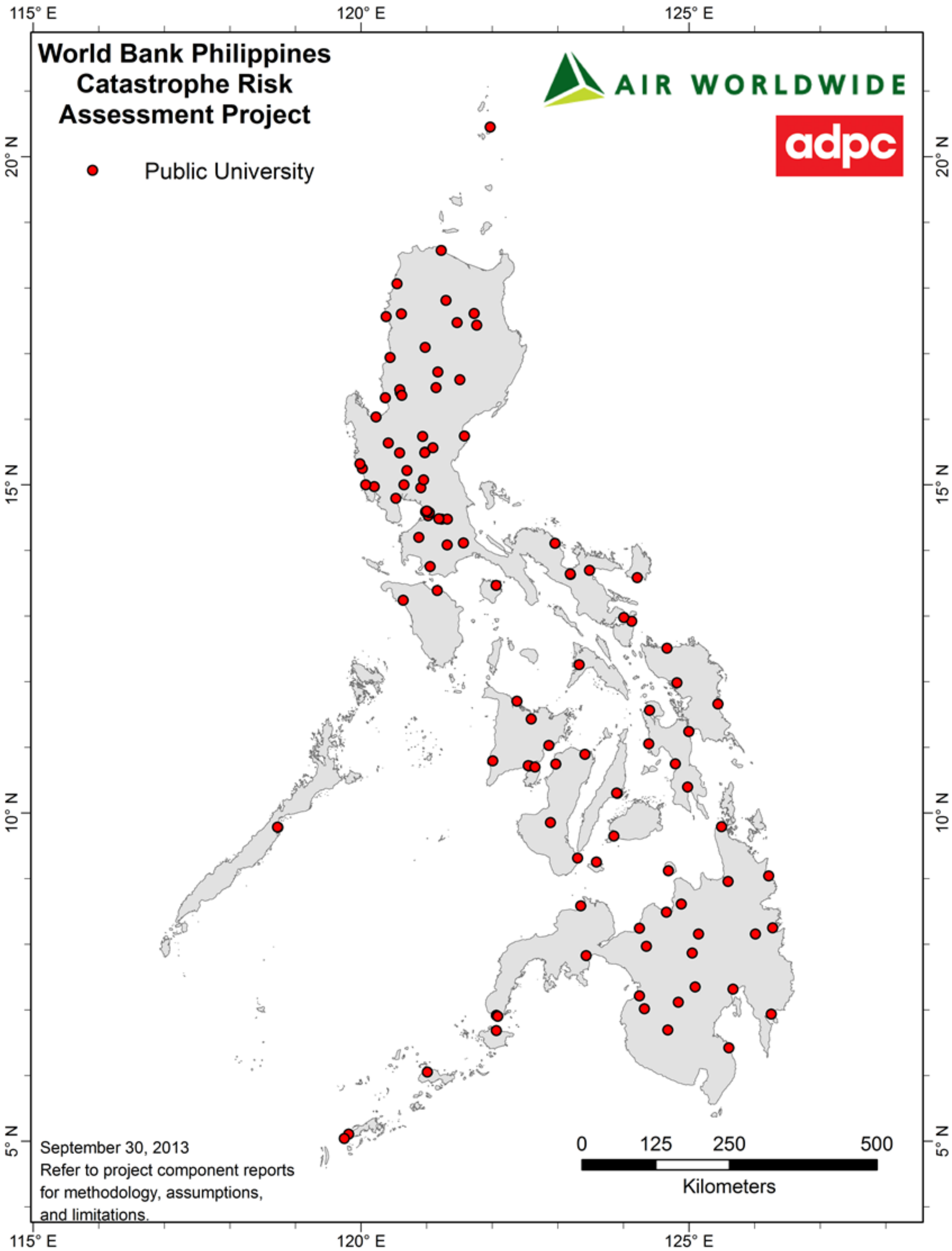
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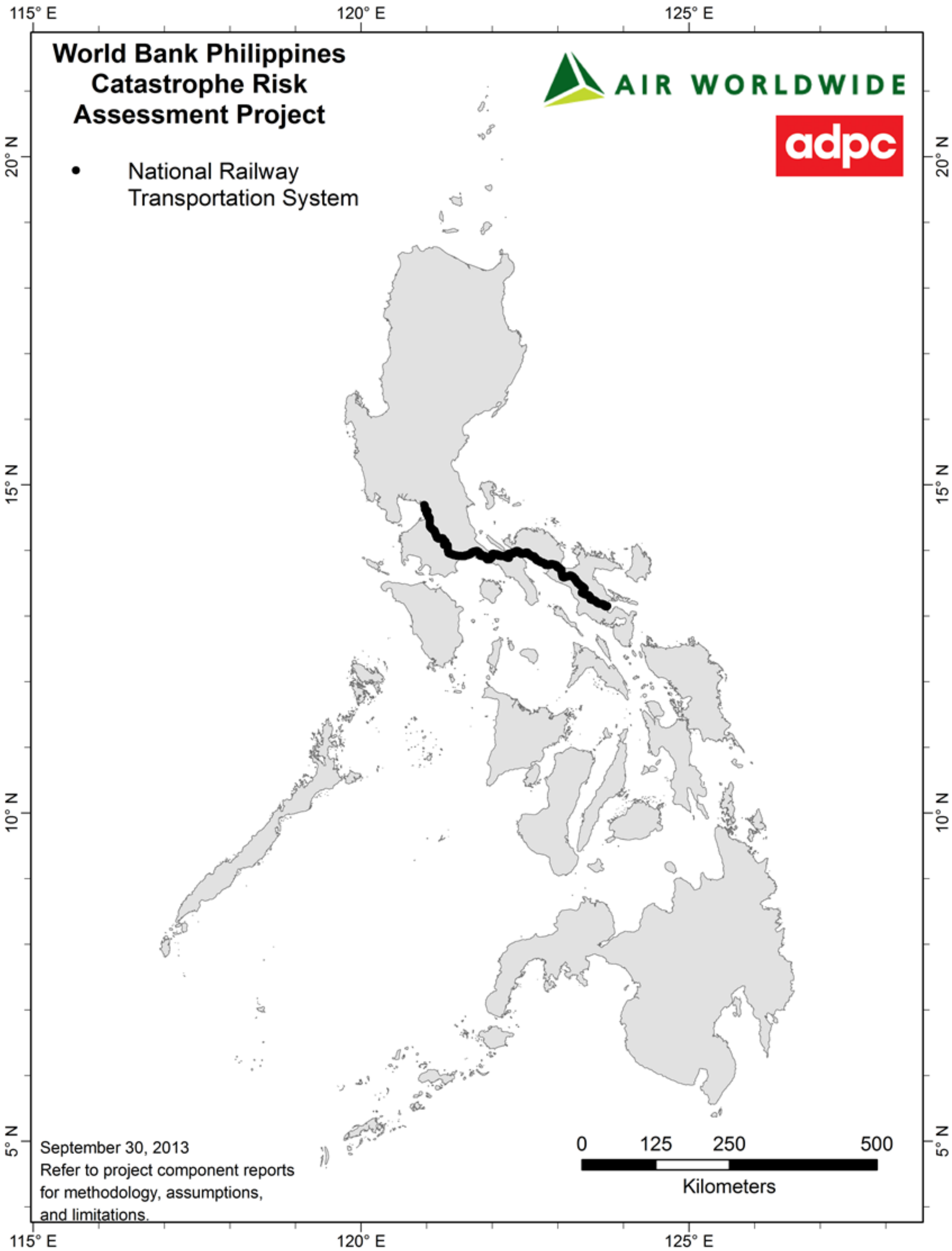
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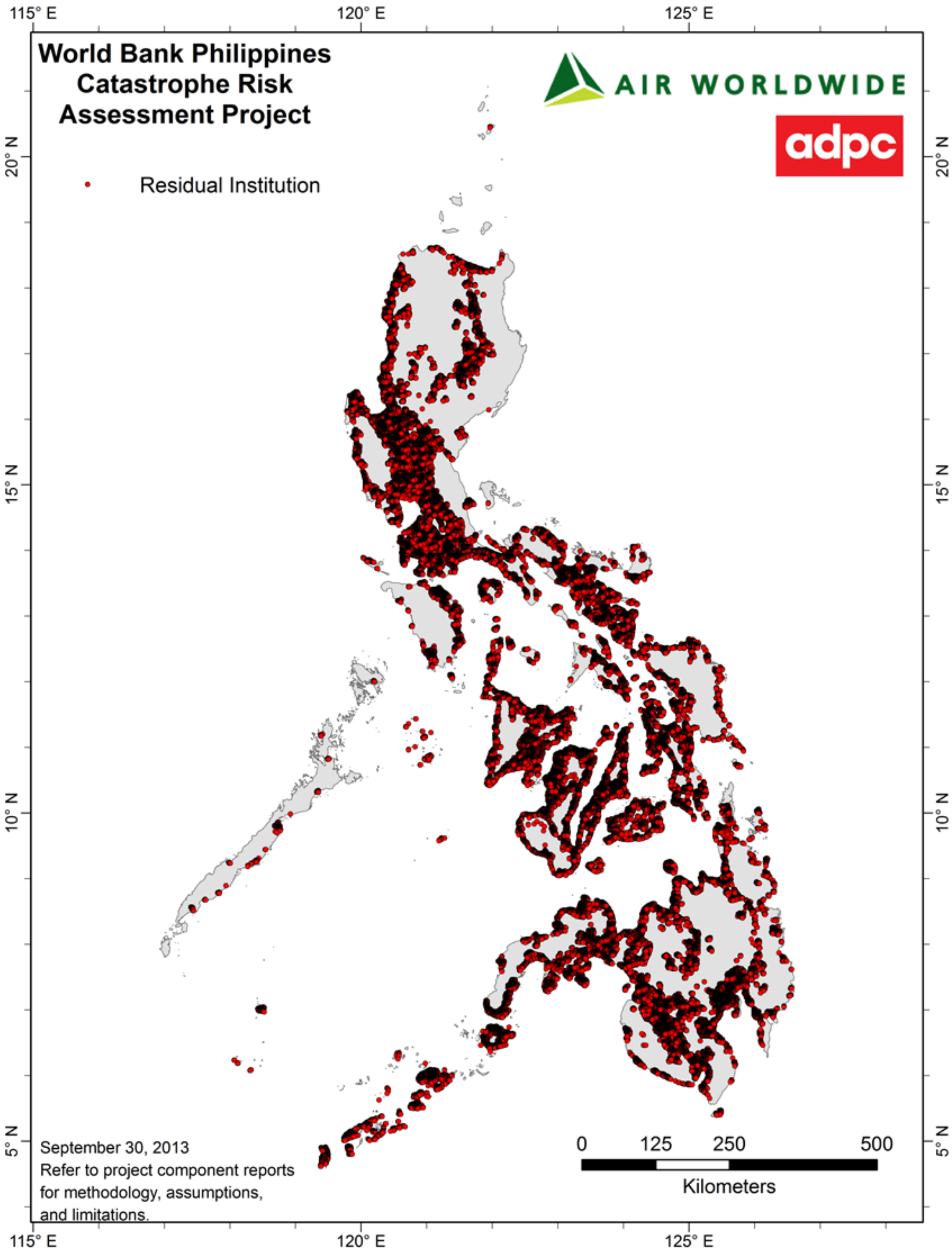
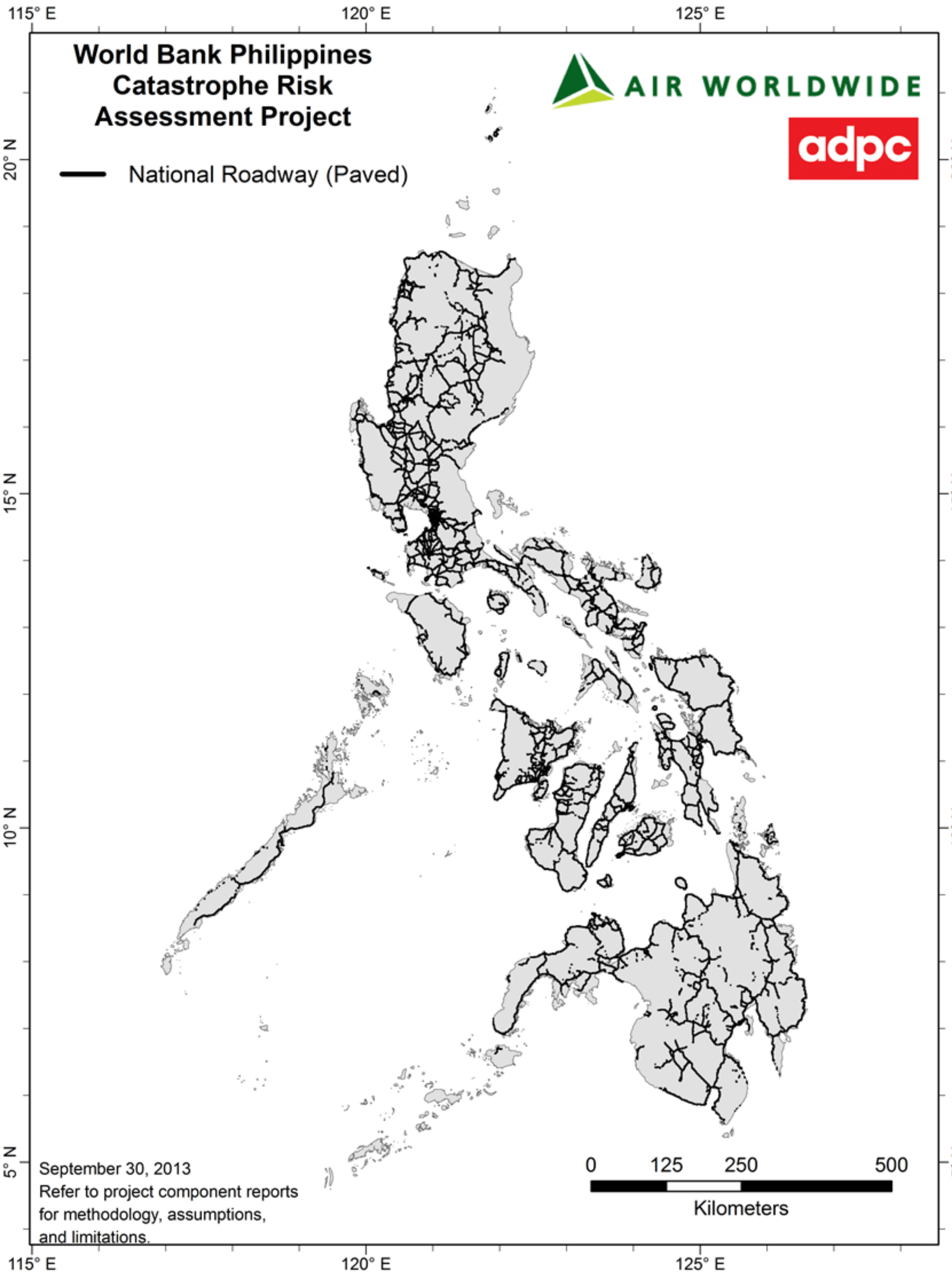
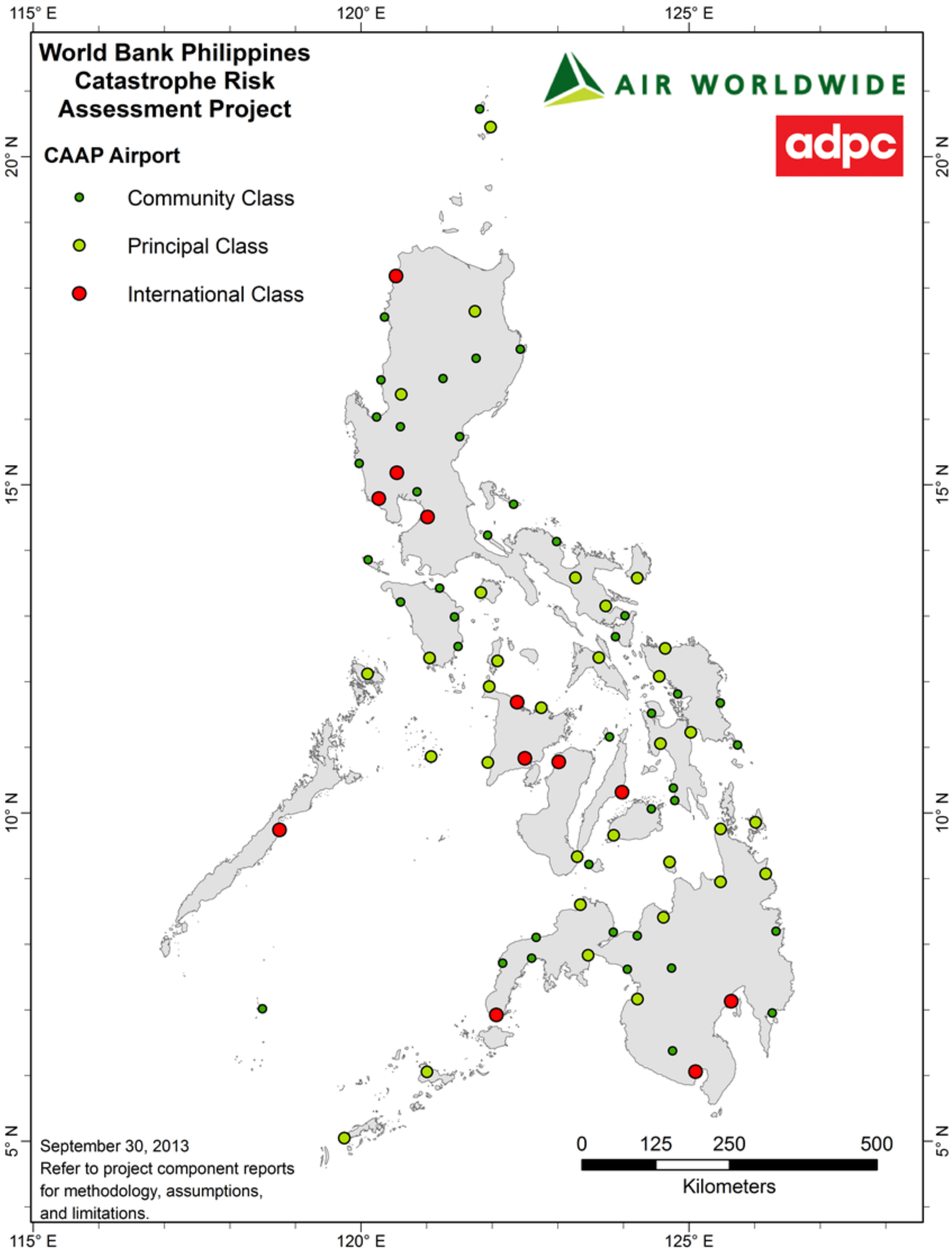
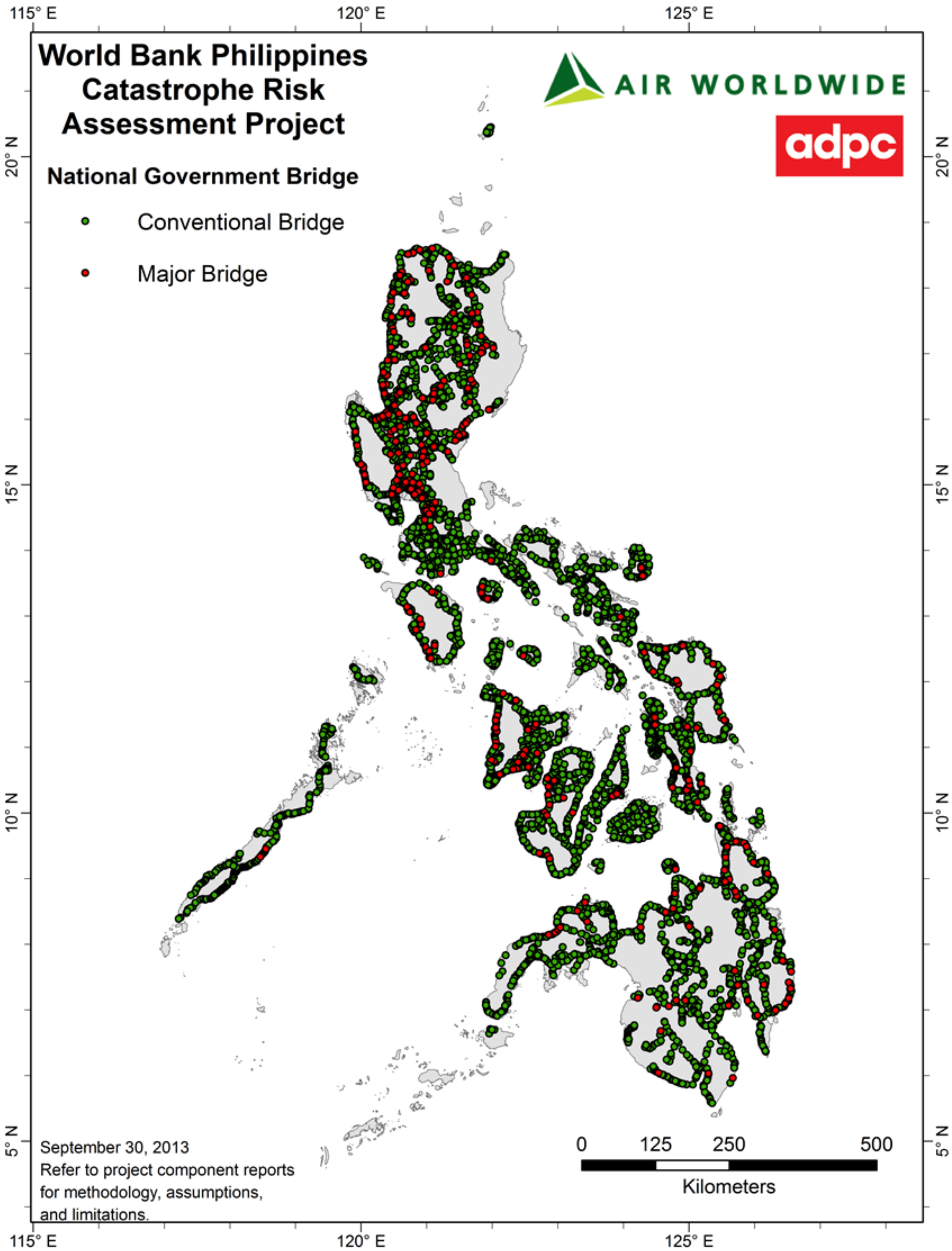
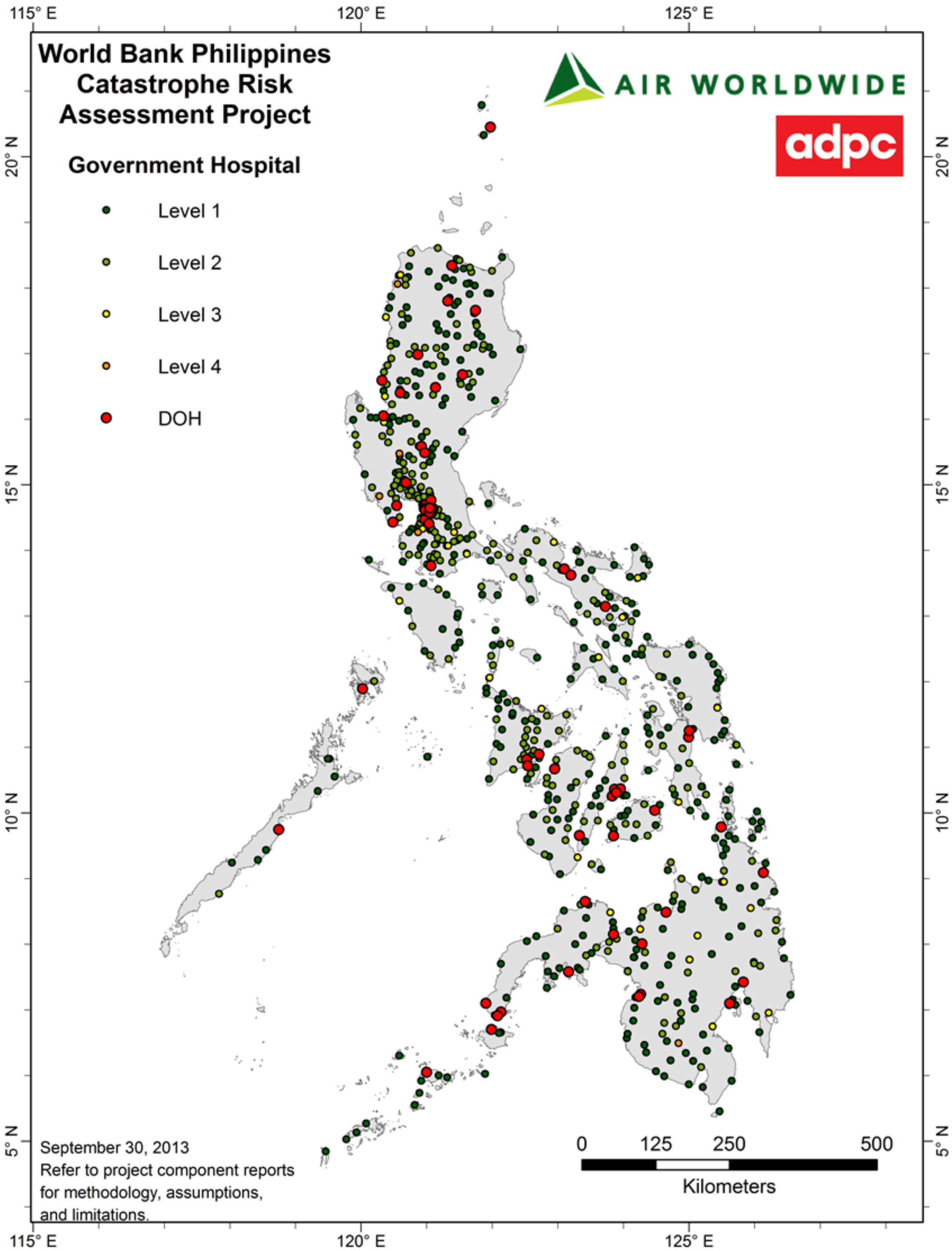
500
Kilometers

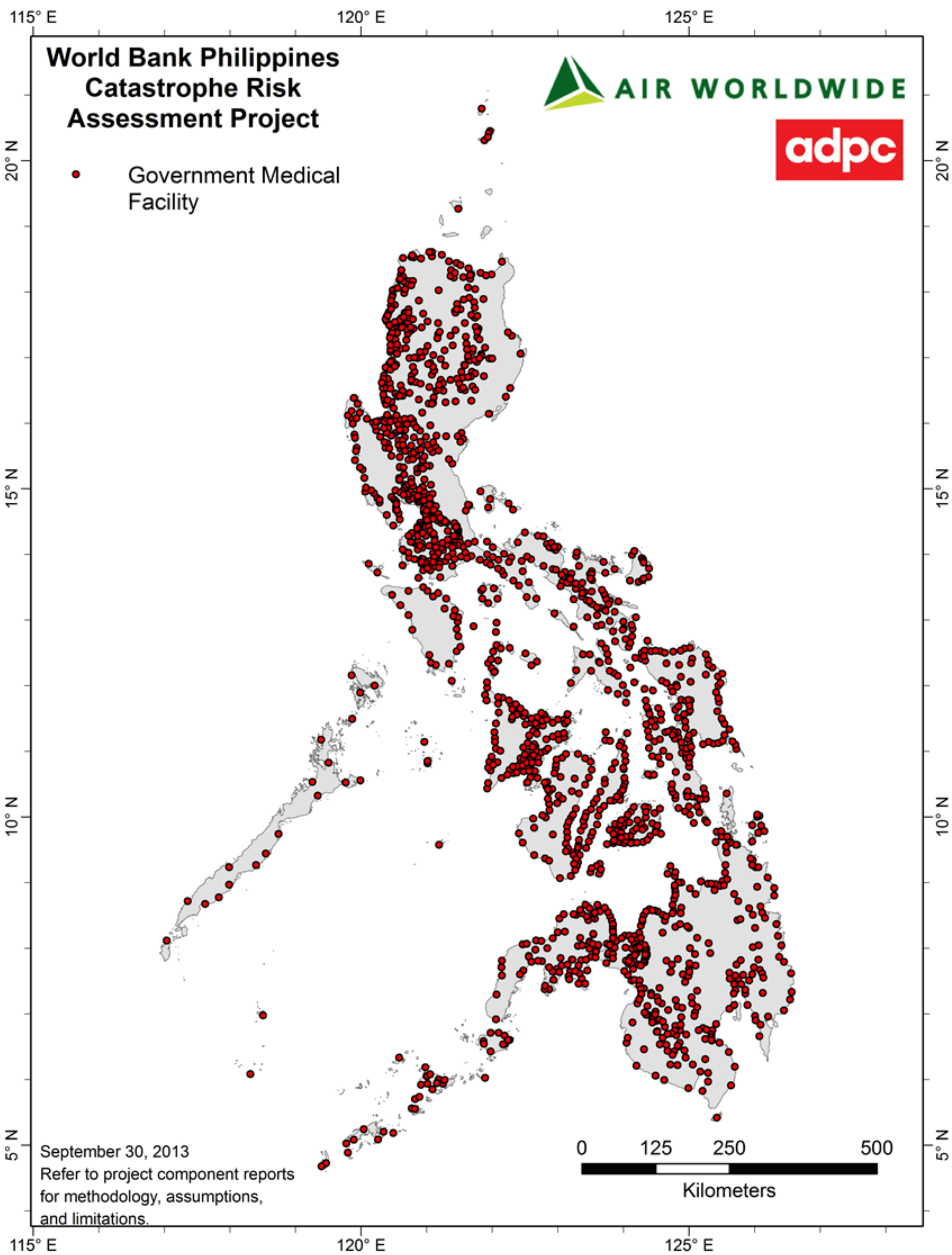

115° E
120° E
125° E
World Bank Philippines
Catastrophe Risk
Assessment Project
AIR WORLDWIDE
adpc
Residual Institution
20° N
15° N
10° N
5° N
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.
0 125 250 500
Kilometers

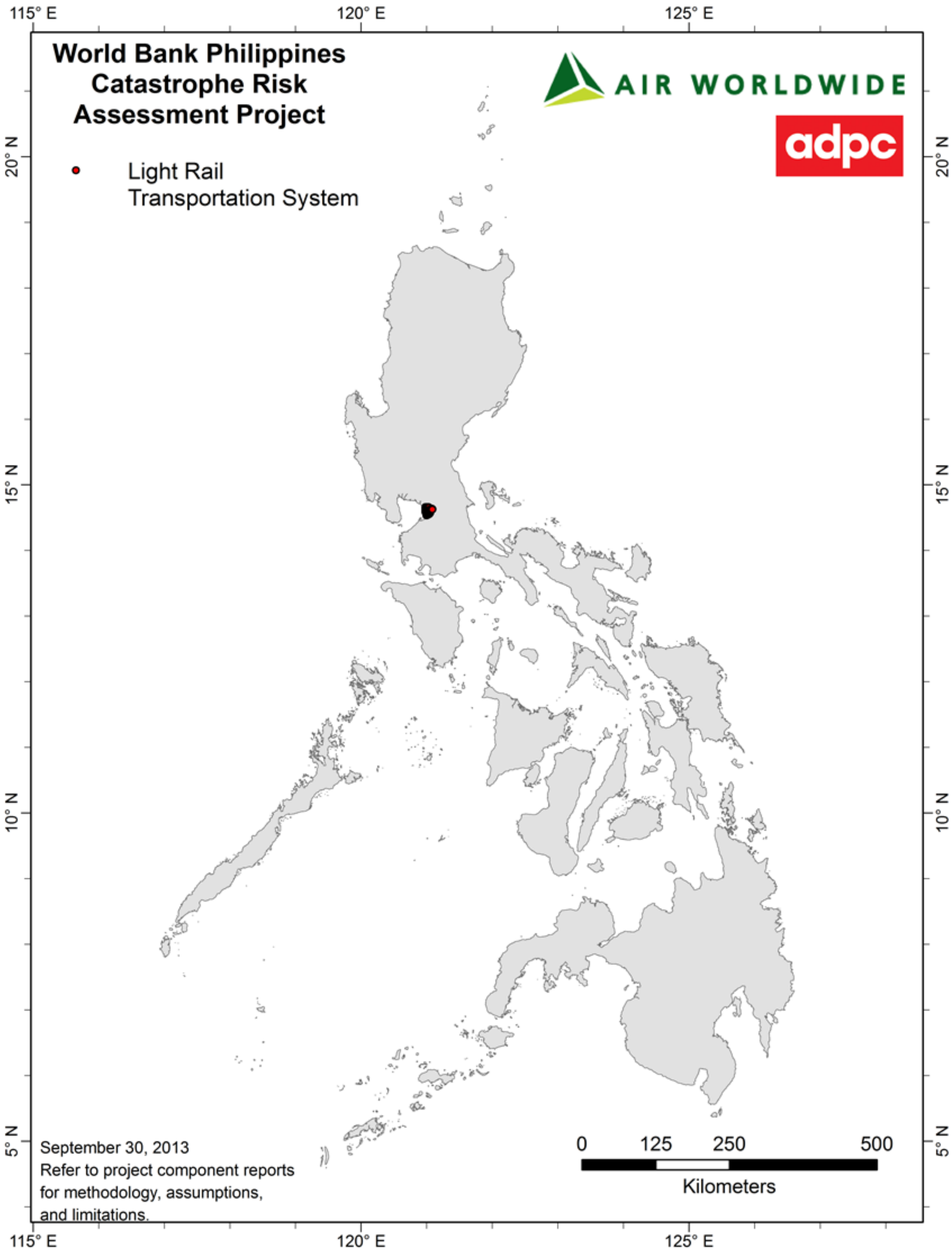

World Bank Philippines Catastrophe Risk Assessment Project
National Roadway (Paved)
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
September 30, 2013
Refer to project component reports for methodology, assumptions, and limitations.
0
125
250
500
Kilometers

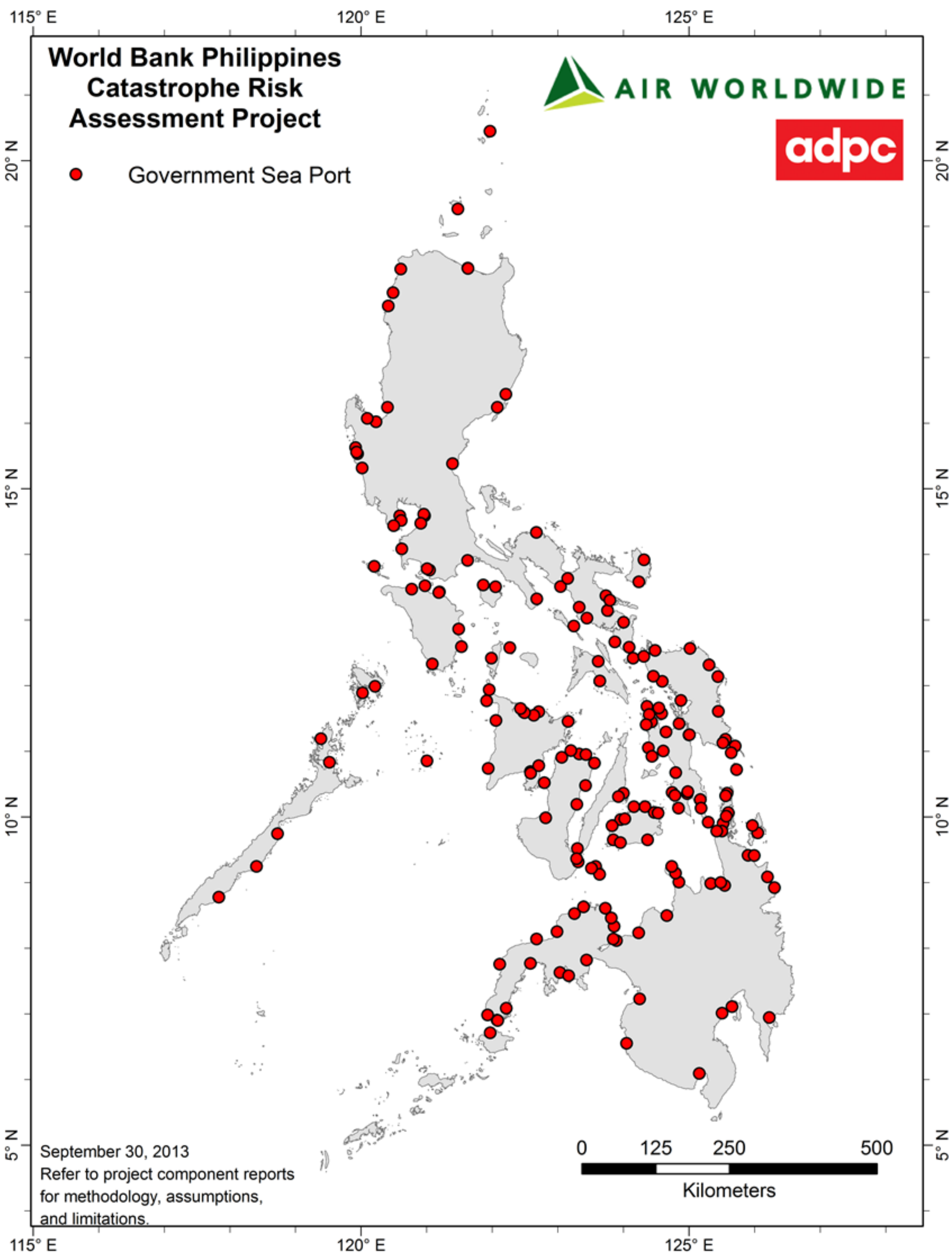

World Bank Philippines
Catastrophe Risk
Assessment Project
CAAP Airport
Community Class
Principal Class
International Class
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
0
125
250
500
Kilometers
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.

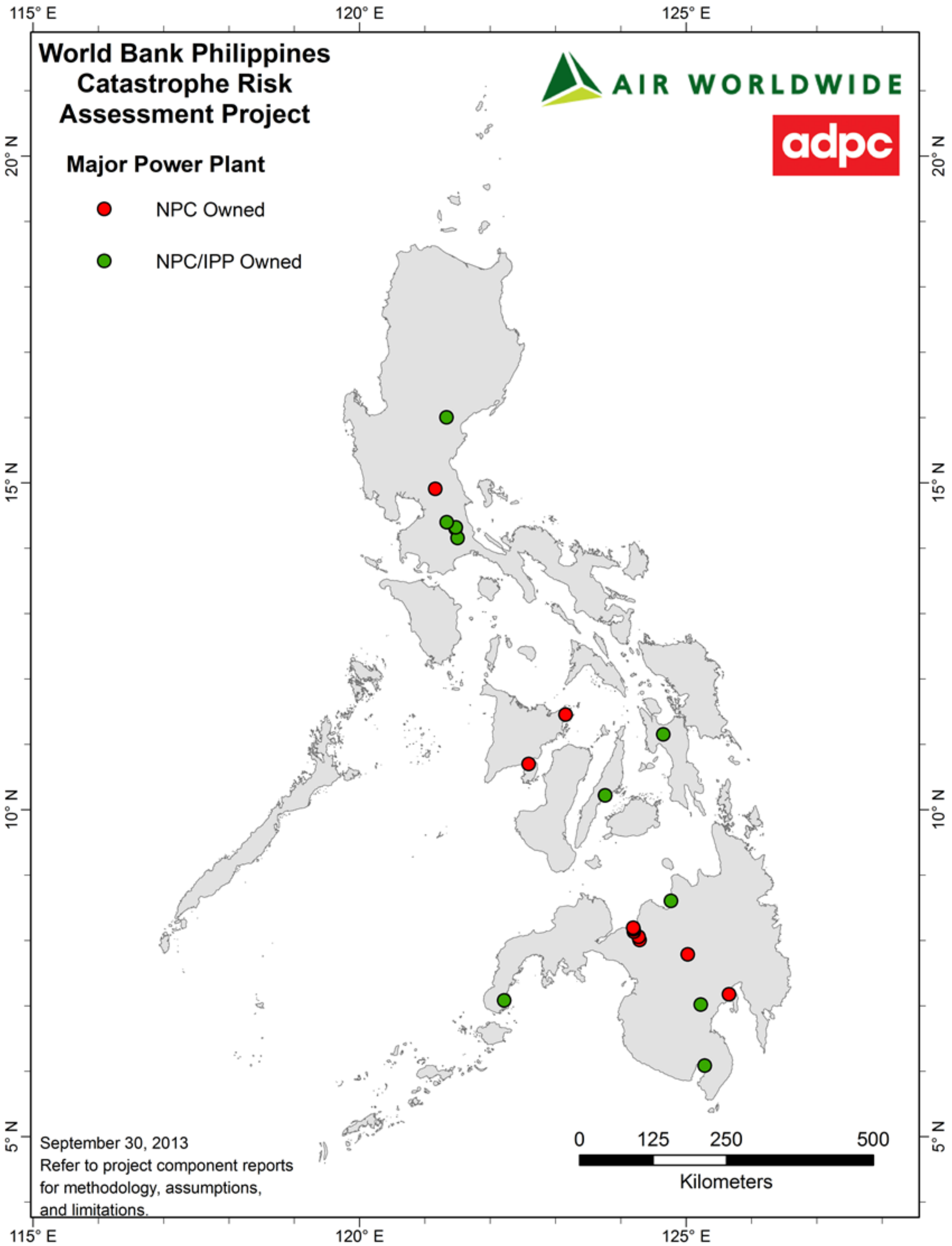

115° E
120° E
125° E
World Bank Philippines
Catastrophe Risk
Assessment Project
National Government Bridge
Conventional Bridge
Major Bridge
AIR WORLDWIDE
adpc
20° N
15° N
10° N
5° N
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.
0
125
250
500
Kilometers

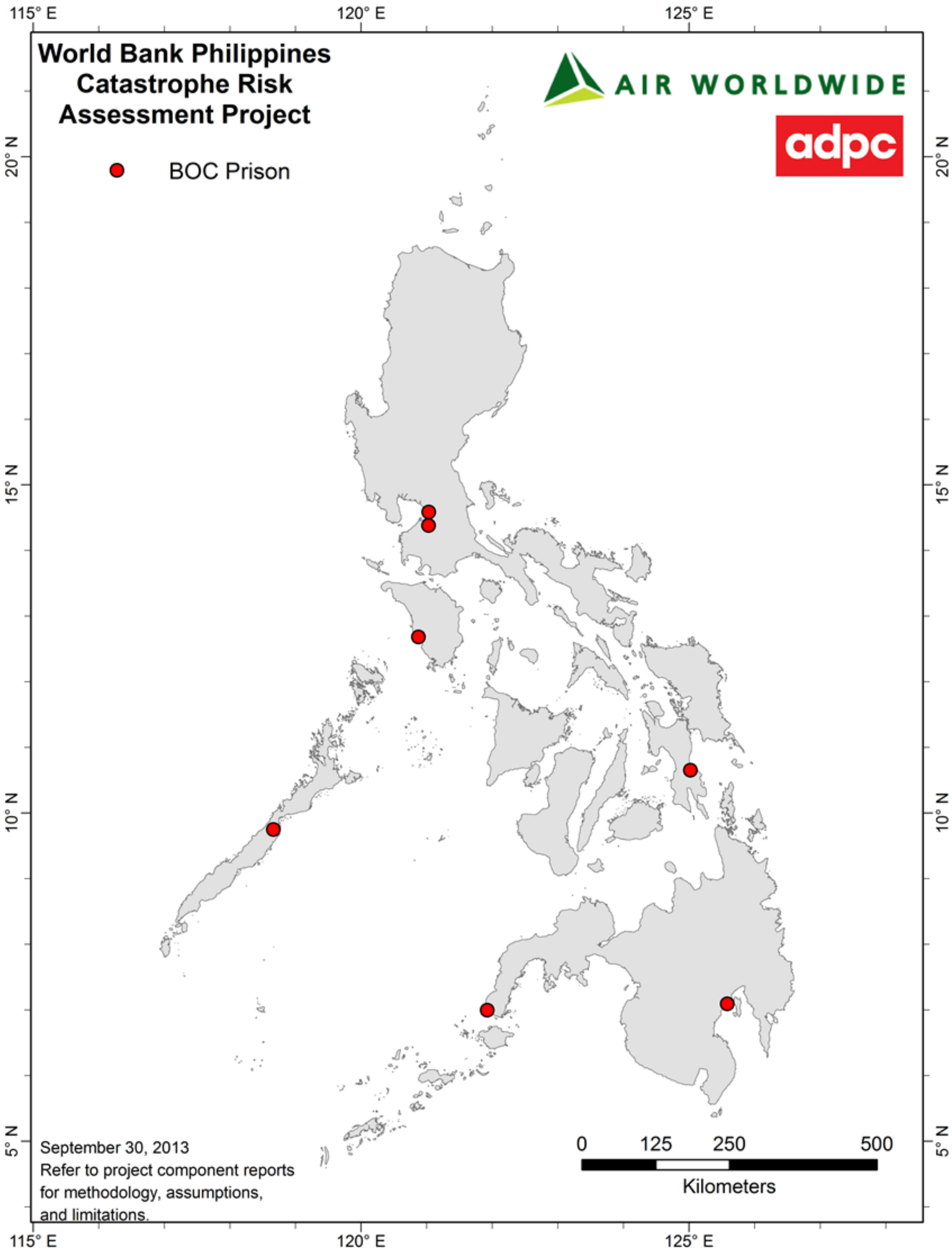

World Bank Philippines
Catastrophe Risk
Assessment Project
Government Hospital
Level 1
Level 2
Level 3
Level 4
DOH
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
0
125
250
500
Kilometers
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.


World Bank Philippines
Catastrophe Risk
Assessment Project
Government Medical
Facility
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.
0
125
250
500
Kilometers


World Bank Philippines
Catastrophe Risk
Assessment Project
Light Rail
Transportation System
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.
0
125
250
500
Kilometers


115° E
120° E
125° E
World Bank Philippines
Catastrophe Risk
Assessment Project
AIR WORLDWIDE
adpc
Government Sea Port
20° N
15° N
10° N
5° N
0
125
250
500
Kilometers
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.


World Bank Philippines
Catastrophe Risk
Assessment Project
Major Power Plant
NPC Owned
NPC/IPP Owned
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
0
125
250
500
Kilometers
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.


World Bank Philippines
Catastrophe Risk
Assessment Project
BOC Prison
AIR WORLDWIDE
adpc
115° E
120° E
125° E
20° N
15° N
10° N
5° N
September 30, 2013
Refer to project component reports
for methodology, assumptions,
and limitations.
0
125
250
500
Kilometers