Philippines Catastrophe Risk Assessment and Modeling
Component 1: Hazard Data and Loss Data Collection and Management

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Executive Summary

Various data sets for the purposes of catastrophe risk modeling have been collected, processed, and organized for the Philippines. Some datasets that did not exist or were not available (such as the historical earthquake database and the consequence databases) were produced specifically for this project. This report, prepared for the "Component 1: Hazard Data and Loss Data Collection and Management" task as defined in the Terms of Reference (ToR) of this project, discusses in detail the data collected to enable an earthquake, tropical cyclone, and flood hazard modeling and loss estimation study for the Philippines. The data collected has been delivered to the World Bank, as per the requirements of the ToR. Metadata for each dataset, to the extent possible, has also been provided. The scope of the data collected within the Component 1 task is consistent with publically available information that informs the catastrophe model development. The final catastrophe model used for the loss and risk calculations may use additional datasets, such as those that are proprietary or not suitable for dissemination (e.g., internal model working files), which are not discussed herein.

The main objectives achieved under Component 1 are the following:

1. Development of a database of historical events, called a ***historical catalog***, which provides information about the location of past events (e.g., epicenter for earthquakes and track for tropical cyclones), the date of the event, and specific event characteristics (e.g., magnitude for earthquakes and central pressure along the track for tropical cyclones).
2. Development of a ***consequence database***, which includes information on the impact (e.g., casualties and monetary loss) caused by major historical events in the Philippines.
3. Generation of GIS maps that show the location and characteristics of historical events and, when known, their impact on population and the built environment.
4. Collection, processing, and organization of a set of ancillary GIS maps, such as:
    - i. Country Administrative Boundaries
    - ii. Topographic maps
    - iii. Surface geology maps
    - iv. Soil maps
    - v. Vs30 maps
    - vi. Land use/land cover (LULC) maps
5. Identification of independent reporting/monitoring agencies for each of the major perils in case risk mitigation strategies involving, for example, catastrophe bonds will be implemented.

The historical earthquake database presented in this report was developed by merging and harmonizing five publically available earthquake catalogs. Earthquake magnitudes were converted to moment magnitude using regression-based relationships from regional data. The final earthquake catalog contains over 21,000 earthquake events and covers the period from 1589 to 2012. Only earthquakes with magnitude M_w 4.5 or greater and epicenters within latitude 3 to 23 and longitude 115.5 to 130 are selected for the final historical database. In general, the catalog is approximately complete from 1964 for events of magnitude 5.0 or greater, and from 1860 for events of magnitude 6.5 or greater. The International Best Tracks Archive for Climate Stewardship (IBTrACS) project was selected as the basis of the historical tropical cyclone database for the Philippines, which contains over 1,600 cyclones occurring in the northwest pacific basin covering the period from 1951 to 2011.

A consequence database was developed which includes a collection of data and information from significant historical natural events (including tropical cyclones, floods, earthquakes, and associated secondary effects) that have had an impact on the population and the built environment in the Philippines. The database contains data for over 520 tropical cyclone and flood events, dating from 1905 to 2013, and about 300 earthquake events, dating from 1599 to 2012. The databases include several fields, such as life loss, injuries, people affected, buildings damaged, economic damage, etc., for each event. The database indicates that, on average, tropical cyclone and flood events result in over 1,000 lives lost and over one billion USD in damage per year. Similarly, on average, earthquake events result in about 400 lives lost and 100 million USD in damage per year. The majority of the consequence database events have been linked to the historical catalogs from which GIS representations of the consequence database have been developed. Recent major natural catastrophe events are briefly described. The report concludes with a brief description of the ancillary data, along with maps of the data.

1. Introduction

The Philippines is exposed to a multitude of natural hazards such as earthquakes, typhoons (tropical cyclones), and flooding (see Figure 1) that result in significant property damage and socio-economic impacts. Philippines is widely acknowledged as one of the most disaster-prone countries in the world (Delica, 1994). Roughly 20 tropical disturbances enter the Philippines Area of Responsibility (PAR) on average per year, of which about 11 are classified as typhoons (Benson, 1997). 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 actually reach land and a further two offshore tropical cyclones result in damage every year (Brown et al., 1991). The eastern part of the country, particularly the north east, is 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. Extreme consequences of the two typhoons included casualties due to massive 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 sizable 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 and intensity. Tropical cyclones and floods are the principal hazards falling into the first category. 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 Philippine economic recovery. The second category comprises more severe disasters with considerably longer return periods, such as major earthquakes, volcanic eruptions, or droughts (Benson, 1997).

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[1] 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 project ToR.

According to the project ToR, the natural hazards to be considered in this study are earthquake ground shaking, typhoon wind, flood associated with typhoon-induced precipitation, and flood 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 1, which focuses on collecting hazard and loss data that can be used to inform the catastrophe risk assessment of the Philippines. For each natural hazard (or peril) considered in this study, a historical database cataloging major natural catastrophe events that have affected the Philippines was compiled. A consequence database for each peril was assembled to consolidate data on casualties, injuries, economic loss, etc. that have resulted from natural catastrophe events. Finally, ancillary datasets useful in catastrophe risk modeling were also collected as part of this effort. The data was collected though collaboration with local technical and government agencies and through data available from public sources.

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 the development and 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.

[1] The term "disaster" is used interchangeably with the term "catastrophe" throughout the report.

The physical loss estimates that have been presented or will be developed for the assets[2] 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.

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.

[2] 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.

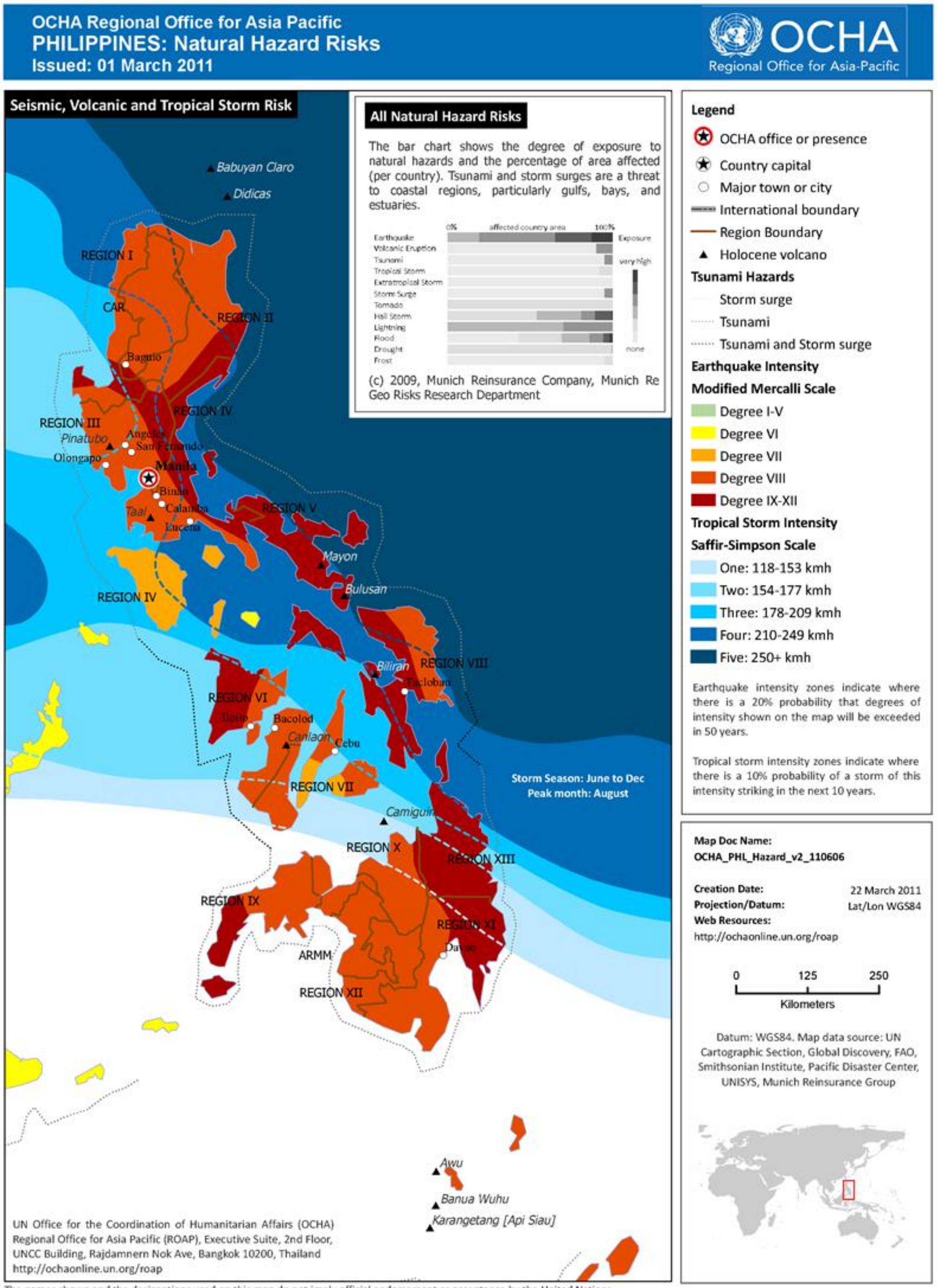


Figure 1. Natural Hazards in the Philippines (Source: OCHA)

2. Objectives

The main objectives of Component 1 of the Philippines Catastrophe Risk Assessment and Modeling study are to (a) assemble a database of major historical events (e.g., earthquakes and tropical cyclones) for the Philippines, (b) develop a consequence database of economic losses caused by selected events, and (c) collect ancillary data sets that may be useful for further catastrophe risk modeling activities.

This component includes four primary outputs:

1. A geo-referenced catalogue of historical major events, including earthquakes, tropical cyclones, and floods in the Philippines.
2. A database of historical economic losses caused by past natural disasters.
3. Maps of historical event locations (e.g. earthquake epicenters, tropical cyclone tracks, etc.) and damage with estimated or observed values, as available.
4. Ancillary hazard data including: country administrative boundaries, surface soil and geology maps, digital elevation data (topographical maps), and land cover/land use, seismic source zones and active earthquake faults.

Section 3 and Section 4 of this report discuss the generation and the limitations of the historical catalogs and of the consequence database, respectively. Section 5 discusses the ancillary data acquired, including earthquake source data. Section 6 identifies the suggested reporting/monitoring agencies and Section 7 includes a selected list of the references used.

3. Historical Event Databases

3.1 Historical Earthquake Database

3.1.1 Data Sources

Publically available historical earthquake catalogs focusing on the Philippines are limited, and existing global catalogs are neither comprehensive nor fully consistent with one another. To alleviate these issues, five historical earthquake catalogs were uniformly processed and merged to obtain a relatively complete and homogeneous catalog for the entire region. The five publically available catalogs considered are the following:

1. The ISC-GEM Global Instrumental Earthquake Catalogue, which covers the period 1900 – 2009;
2. The USGS PAGER-CAT catalog which covers the period 1900 – 2008;
3. The Philippine historical earthquake catalog from Bautista & Oike (2000), which covers the period from 1589 – 1895;
4. The International Seismological Centre (ISC) Bulletin[3], which covers the period from 1904 – 2012;
5. Abe's Catalog of Major Earthquakes of the World which covers the period from 1892 – 1992.

Note that the ISC Bulletin includes data from almost 500 different agencies, including the National Earthquake Information Center (NEIC), the United States Geological Survey (USGS), the Global Centroid-Moment-Tensor (CMT) Project, the Philippine Institute of Volcanology and Seismology (PHIVOLCS), and the Manila Observatory. Please refer to the documentation of each respective catalog for more information.

3.1.2 Magnitude Conversion and Data Processing

The five existing catalogs were not originally compiled using the same procedure and are not equally reliable and consistent. The most obvious inconsistency is the difference in magnitude scale. Before merging the five existing catalogs, the magnitude values assigned to each event were converted to a common scale, in this case moment magnitude (M_w). All the magnitude values (other than those already in M_w) reported in the original catalogs were converted to M_w using regression-based magnitude relationships derived specifically for this study using data from events in the region, or available in the literature. Equations 1-6 list the regression relationships used:

$$M_w = \begin{Bmatrix} M_s * 0.6281 + 2.3636 \text{ for } M_s \le 6.1 \\ M_s * 0.8708 + 0.9225 \text{ for } M_s > 6.1 \end{Bmatrix} \quad \text{(Eq. 1)}$$

[3] From 1904-2010, the entire “Reviewed ISC Bulletin” was considered; from 2011-2012, the “ISC Bulletin” with magnitude ≥ 2.5 was considered

$$M_w = m_b * 1.043 + 0.0008 \qquad \text{(Eq. 2)}$$
$$M_w = M_{uk} * 0.8401 + 1.1353 \qquad \text{(Eq. 3)}$$
$$M_w = m_B * 1.33 + 2.36 \qquad \text{(Eq. 4)}$$
$$M_w = M_j - 0.171 \qquad \text{(Eq. 5)}$$
$$M_w = M_L * 1.321 - 1.8631 \qquad \text{(Eq. 6)}$$

where M_s is surface-wave magnitude, m_b is body-wave magnitude, M_L is local magnitude, m_B is broad-band body-wave magnitude, M_j is the local magnitude defined and calculated by Japan Meteorological Agency (JMA), and M_{uk} is an unspecified or other (M, m_d, M_G, M_{Lv}) magnitude scale. For the purposes of the magnitude harmonization, $M_{w(mB)}$ and M_{wp} are taken as equivalent to M_w. The final M_w values in the database are rounded to the nearest first decimal point.

Equations 1-3 are derived based on PAGER-CAT data in the Philippines region, which provides both M_w and other magnitude scale values for select events that can be used to derive regression relationships (e.g., see Figure 2). Note that the relationships derived are similar to previously developed global relations by Scordilis (2006). Equation 4 is from Bormann and Saul (2008), Equation 5 is from Utsu (1982), and Equation 6 is from a previous study of earthquakes in the Pacific region by AIR Worldwide (AIR, 2010). Table 1 shows a disaggregation of the number of events in the final historic catalog by original magnitude unit type and original magnitude value bin. Overall, 80% of the events in the final historical database were originally given in m_b and 11% in the desired M_w unit. For magnitudes 5.5 and greater, 68% of the events are given in the desired M_w unit.

Note that the ISC Bulletin generally reports more than one magnitude value for each event in its catalog, each from the various contributing agencies that make up its database. The more appropriate value, such as those from agencies reporting M_w and those from more prominent agencies (such as the Global CMT Project), was selected for each event. The original authors of the magnitude value are indicted in the final database. Similarly, the "preferred" parameters available in the PAGER-CAT database were selected.

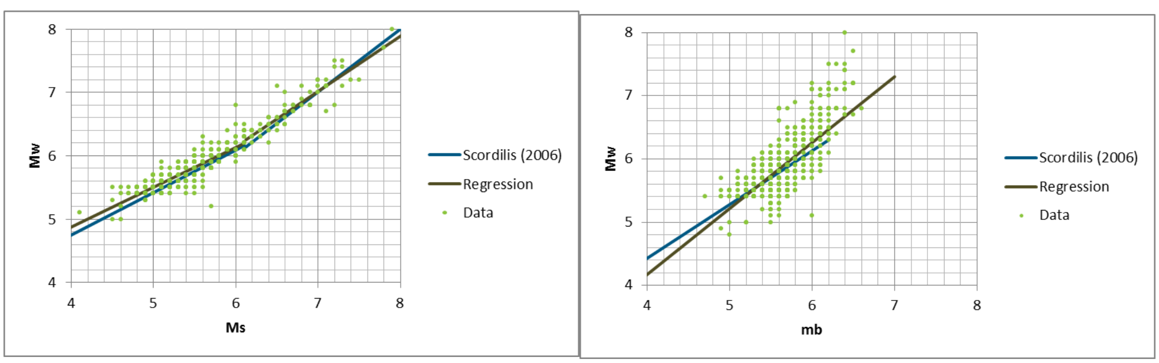


Figure 2. Regression-Based Magnitude Relationships Developed from USGS PAGER-CAT Data in the Philippine Region along with Previously Published Relationships (e.g., Scordilis, 2006)

Table 1. Disaggregation of Original Magnitude Units in the Historical Catalog

Original Unit Value	M	m_b	m_d	M_j	M_L	M_{Lv}	M_s	M_w	$Mw_{(mB)}$	M_{wp}	M_{UK}	m_B	Total
< 4.5	164	5,277	10	0	0	10	348	0	0	0	0	0	*5,809*
4.5-5.0	61	9,205	2	0	9	1	95	223	402	0	1	0	*9,999*
5.0-5.5	83	2,281	2	0	12	0	105	858	143	0	0	35	*3,519*
5.5-6.0	54	80	0	0	3	0	143	754	33	0	0	1	*1,068*
6.0-6.5	30	1	0	0	0	0	81	249	10	2	1	0	*374*
6.5-7.0	6	1	0	0	1	0	57	122	3	0	12	1	*203*
> 7.0	0	0	0	2	0	0	38	80	3	0	3	8	*134*
Total	*398*	*16,845*	*14*	*2*	*25*	*11*	*867*	*2,286*	*594*	*2*	*17*	*45*	*21,106*

During the merging of the original catalogs, the highest credibility was given to the GEM catalog, followed by the PAGER-CAT catalog, followed by Abe's Catalog, and followed by the ISC catalog. The Bautista & Oike catalog was used in its entirety as it generally covered an older time range not covered by the other catalogs. Note that the Bautista & Oike catalog is the only catalog not derived from instrumental records. The final catalog was manually corrected for duplicate events and obvious errors. Only earthquakes with magnitude M_w 4.5 or greater and epicenters within latitude 3 to 23 and longitude 115.5 to130 are selected for inclusion in the final historical database.

Figure 3 (left panel) shows the epicenters of the 7,980 historical earthquakes with $M_w \geq 5.0$ that occurred from 1589 to 2012 that are included in the final historical catalog. For clarity, large magnitude earthquakes ($M_w \geq 7.0$) are shown in the right panel of Figure 3. The oldest event in the final historical catalog is a M_w 5.5 earthquake that occurred on December 3, 1608 near the current-day city of Tacloban. The largest event in the final catalog is a M_w 8.3 earthquake that occurred on August 15, 1918 off the coast of current-day Sarangani Province.

From the two figures, two events seem to stand out: the 7.1 M_w earthquake in the center of the Sebu Sea and the 7.2 M_w earthquake off-coast in the Philippine Sea. The parameters for these events are derived from the Abe Catalog in 1899 and the PAGER-CAT catalog in 1913, respectively. These are very old events which may have high uncertainty associated in the parameters collected. In general, some level of uncertainty is to be expected in the parameters for all events in the historical catalog, including recent events.

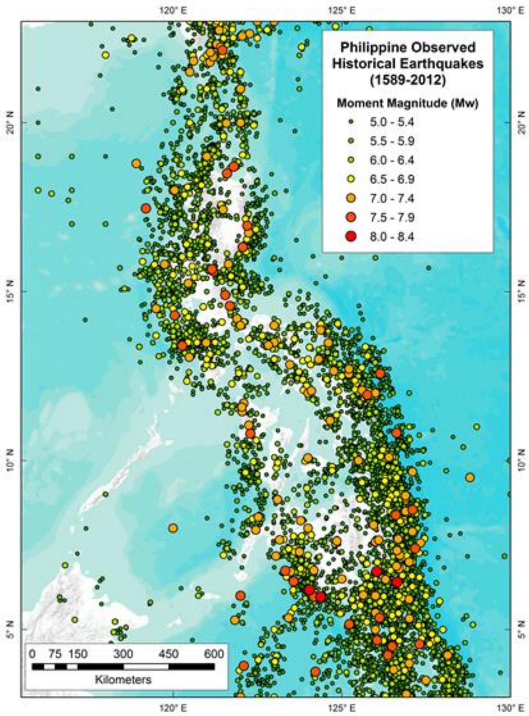


Figure 3. The Historical Earthquake Database Developed for the Philippine Region: Entire Catalog (left), only Large Magnitude Events (right)

The final historical earthquake catalog includes 21,106 earthquakes, out of which 1,041 are from the GEM catalog, 286 are from the PAGER-CAT catalog, 19,296 are from the ISC Bulletin catalog, 473 are from the Bautista & Oike catalog, and 10 are from the Abe catalog. Completeness time in the catalog varies for different regions. In general, the catalog is approximately complete from 1964 for events of magnitude 5.0 or greater, and from 1860 for events of magnitude 6.5 or greater (see Figure 4).

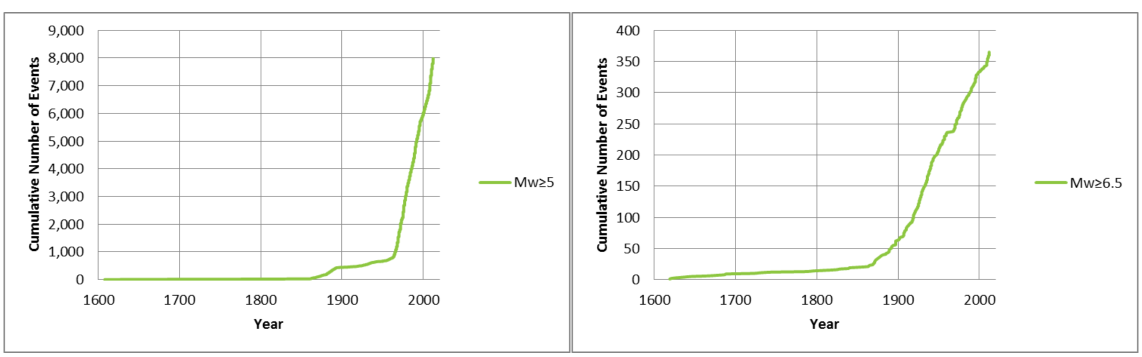


Figure 4. Cumulative Number of Events in the Final Historical Earthquake Database with Magnitude (M_w) classes 5.0 (left) and 6.5 (right).

The final merged catalog has not been de-clustered to remove aftershocks and foreshocks. The methodologies of Resenberg (1985) or Gardner & Knopoff (1974) are recommended if de-clustering is desired, although the outcome is highly dependent on the input parameters and assumptions selected. Note that given the lack of reliable instrumental or felt records, location and magnitude parameters for some large events (especially pre-1900) are not provided by the five data sources from which the parameters were collected, and thus are not included in the historical database. As such, there are some events that are indexed in the consequence database (discussed later in Section 4.2) that are not included in the historical database. About 3% of earthquakes in the final historical earthquake catalog did not list an assigned hypocenter depth and at least 20% of all events in the catalog had a default depth value (in general, these events are flagged in database). Figure 5 shows the distribution of depths for earthquakes ($M_w \geq 5.0$ only) whose depth values are known.

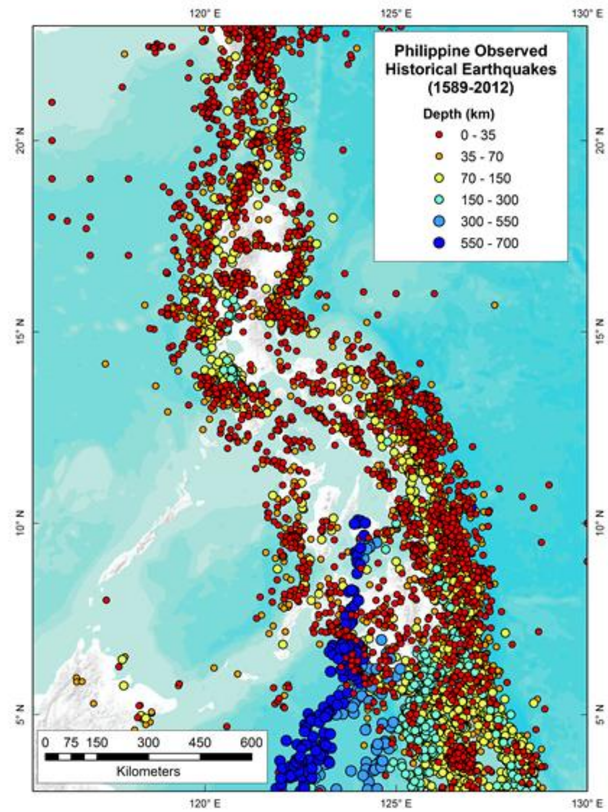


Figure 5. Depth Distribution of Events (M_w≥5 only) with Reported (non-default) Depths in the Philippine Region

3.2 Historical Tropical Cyclone Database

The International Best Tracks Archive for Climate Stewardship (IBTrACS) project was selected as the basis of the historical tropical cyclone[4] database for the Philippines. Specifically, the data is extracted from Version v03r04 of the IBTrACS-WMO, which was released on October 1, 2012. This dataset includes storms from 1951 to 2011 with data provided by the Regional Specialized Meteorological Center (RSMC) Tokyo, Japan. Data from earlier storms may be derived from other sources (e.g., García-Herrera et al., 2006 and Ribera et al., 2005); however, these were not integrated in the historical database due to lack of quality and consistency. The World Meteorological Organization (WMO) has endorsed IBTrACS as an official archiving and distribution resource for tropical cyclone best track data.

Figure 6 shows the approximate full coverage of the historical tropical cyclone dataset while Figure 7 shows a zoomed-in area around the Philippines. The number of storms in the catalog, as classified by central pressure based on the Saffir-Simpson Hurricane Scale (SSHS, see Table 2), is shown in Table 3. The SSHS category corresponds to the maximum category reached during the duration of the tropical cyclone, and not necessarily the category at landfall. Based on the data indicated in Table 3, the entire Northwestern Pacific Basin sees about 27 tropical cyclones per year, and about 7 make landfall in the Philippines per year.

Due to Coriolis Effect, a cyclone structure cannot be maintained too close to the equator. This is seen as a corridor along the equator with no storm activity. Thus, tropical cyclone activity in the southern parts of the Philippines, which is very close to the equator, is minimal. Tropical cyclones that affect the Philippines follow two general directions (Elsner & Liu, 2003), a straight track in the general westward direction or a parabolic track generally recurving west to north. In this region, tropical cyclones spin in the counter-clockwise direction. Due to the combination of direction and spin, winds tend to be greater in the north, particularly in the northwest, for tropical cyclones passing over the Philippines.

The tracks of Categories 1 through 5 storms (SSHS) are shown in Figure 8 to Figure 12, respectively. Note that the catalog also includes tropical storms with winds below typhoon strength. These weaker storms have been included in the catalog because they are capable of producing torrential precipitation resulting in devastating floods.

[4] “Typhoons” are a subcategory of “Tropical Cyclones” that produce wind speeds of 119 km/h or greater. These terms are used interchangeably when appropriate.

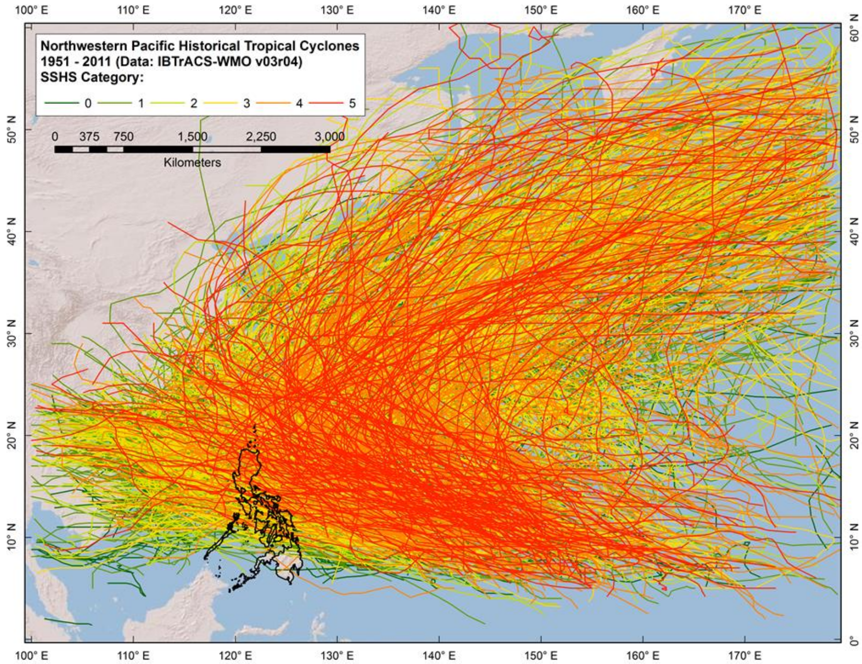


Figure 6. Historical Cyclone Tracks in the Domain Extracted from the Historical Dataset

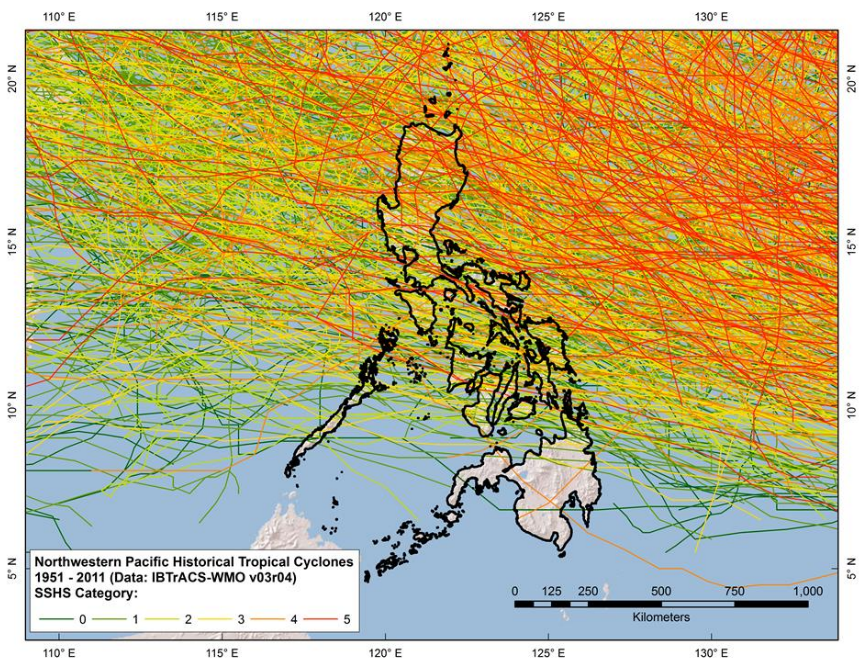


Figure 7. Historical Cyclone Tracks near the Philippines Extracted from Historical Dataset

Table 2. Saffir-Simpson Hurricane Scale (SSHS)

SSHS Category	Wind Damage Level	Sustained Wind Speed (km/hr)	Storm Surge (m)	Central Pressure (mbar)
0	None/Minimal	<119	<1.0	995+
1	Minimal	119 – 153	1.0 – 1.7	980 – 994
2	Moderate	154 – 177	1.8 – 2.6	965 – 979
3	Extensive	178 – 209	2.7 – 3.8	945 – 964
4	Extreme	210 – 249	3.9 – 5.6	920 – 944
5	Catastrophic	250+	5.7+	<920

Note: The ranges of values are approximate. For the historical database, the central pressure ranges were used to define the category.

Table 3. Number of Cyclones in the Historical Database (1951-2011)

SSHS Category	Making Landfall	Basin Total
0	41	181
1	146	500
2	84	265
3	62	264
4	57	258
5	35	145
Total	425	1,613

Note: The SSHS category corresponds to the maximum category reached during the duration of the tropical cyclone (e.g., not necessarily the category at landfall).

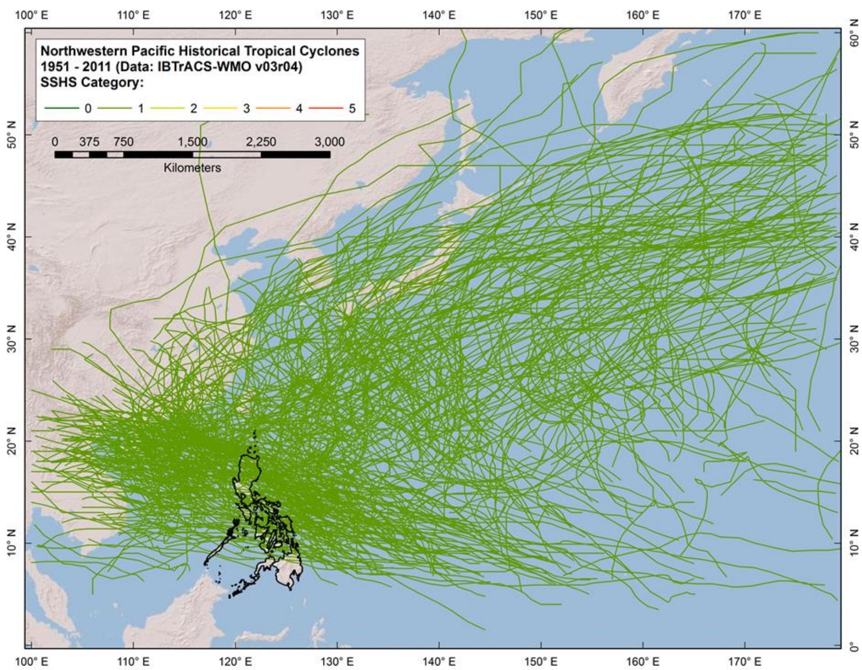


Figure 8. Tracks of the Category 1 Historical Storms

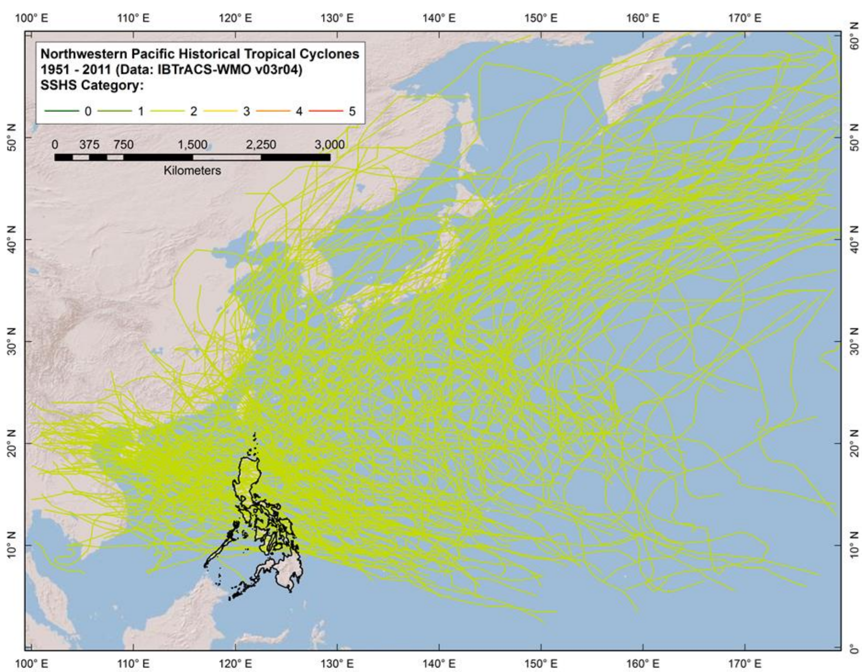


Figure 9. Tracks of the Category 2 Historical Storms

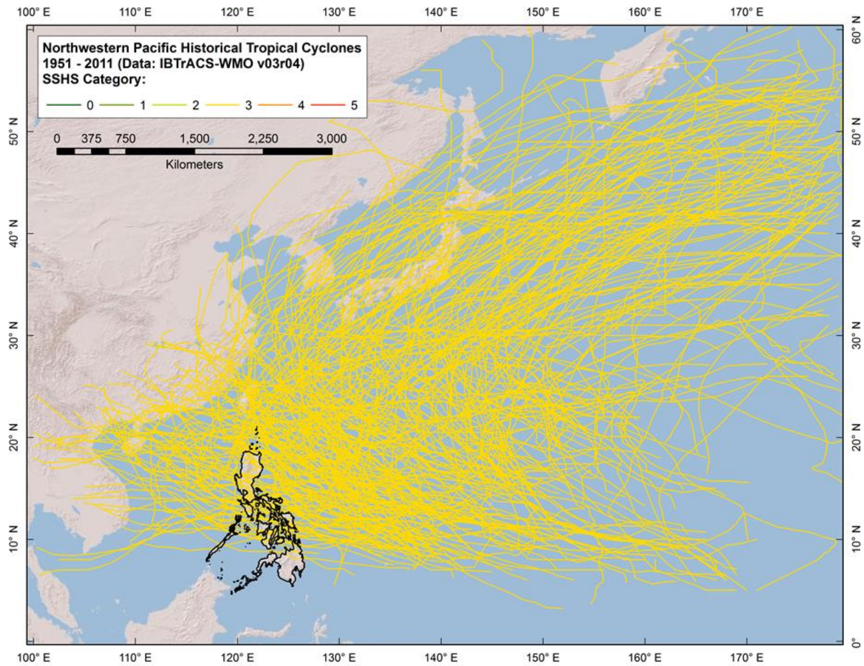


Figure 10. Tracks of the Category 3 Historical Storms

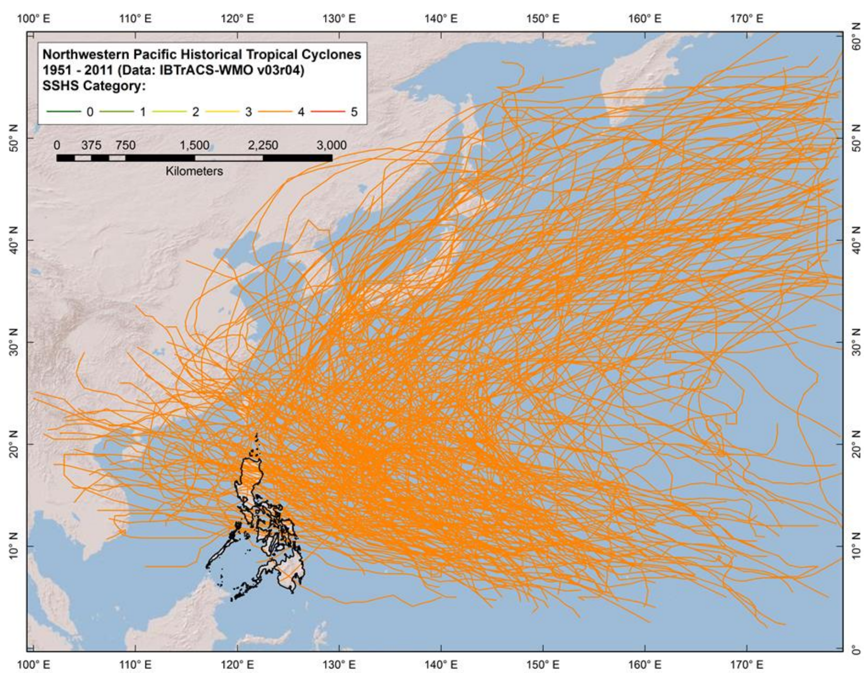


Figure 11. Tracks of the Category 4 Historical Storms

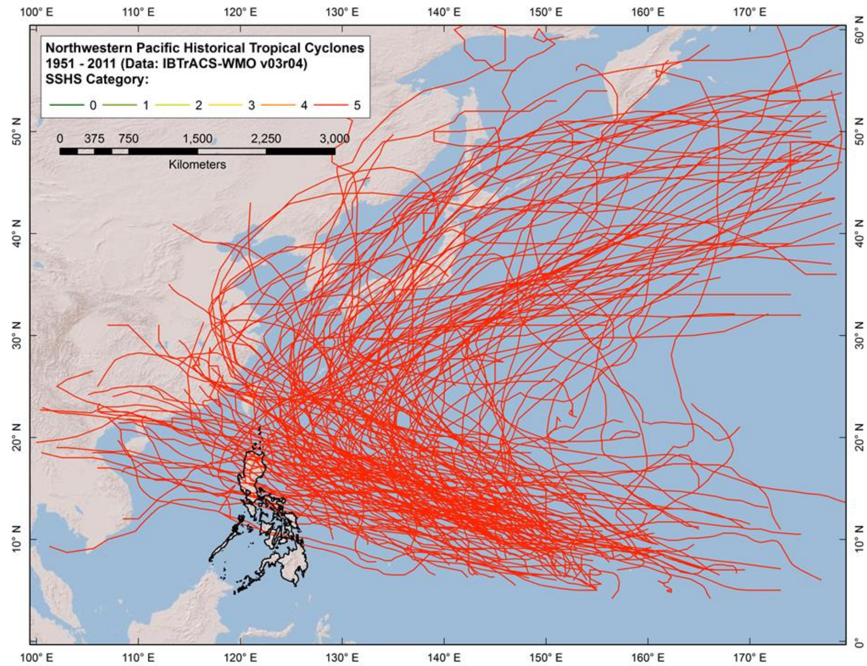


Figure 12. Tracks of the Category 5 Historical Storms

3.3 Historical Flood Database

Due to the complexity and significant temporal variations, historical flood databases are generally not feasible. As such, a historical flood database for the Philippines is not available in the same context as the earthquake and tropical cyclone database. However, various datasets, including Tropical Rainfall Measuring Mission (TRMM) data issued by NASA and the Japan Aerospace Exploration Agency (JAXA), which is designed to monitor and study tropical rainfall, can be used to inform flood modeling. A database of significant flood events that have had an impact on the population and built-up environment is described later in Section 4.

4. Consequence Database

This section presents and discusses the consequence database, which includes a collection of data and information from significant historical events (including tropical cyclones, floods, earthquakes, and associated secondary effects) that have had an impact on the population and the built environment in the Philippines. The database contains data for over 520 typhoon/flood events and about 300 earthquake events. The dozens of fields in the database includes information such as number of lives lost, people affected, buildings destroyed, and economic impact (e.g., monetary loss) from physical damage. The consequence database is developed from a variety of public sources (e.g., see Tschoegl et al., 2006), which are detailed in the following sections.

4.1 Earthquake Events

4.1.1 Data Sources

Consequence data from major historical earthquake events occurring in the Philippines has been collected from a large variety of sources. This data was assembled into a database and represents a comprehensive inventory of reported earthquake events that have had a significant impact on the population and built environment of the Philippines. Data was collected, assembled, and processed from publically available disaster databases, including:

1. The National Geophysical Data Center / World Data Service (NGDC/WDS) Significant Earthquake Database which covers the period 2150 B.C. – present.
2. The USGS PAGER-CAT earthquake catalog, which covers the period 1900 – 2009.
3. The USGS EXPO-CAT earthquake catalog, which covers the period 1973 – 2007.
4. The USGS Significant Earthquakes of the World, which covers the period 1977 – present.
5. The GLIDE number database, maintained by the Asian Disaster Reduction Center (ADRC), which generally covers the period from the mid-1990s – present.
6. Disaster information reports issued by the Asian Disaster Reduction Center (ADRC).
7. The RSOE-EDIS database, which covers the period 1994 – present.
8. The Emergency Events Database (EMDAT), maintained by the Centre for Research on the Epidemiology of Disasters (CRED), which generally covers the period 1900 – present.
9. The Utsu Catalog of Damaging Earthquakes in the World, which covers the period 3000 B.C. – 2010.

Data was also gathered from other sources, including scholarly articles, manuscripts, encyclopedias, reports issued by various agencies, and news articles. Select examples of these sources include:

1. The Earthquake Engineering Research Institute (EERI) Learning from Earthquakes Reconnaissance Archive which generally covers the period 1971 – present.
2. Reports, event posters, and information issued by the USGS.

3. The online information repository "ReliefWeb," which scans websites of international and non-governmental organizations, governments, research institutions and the media for news, reports, press releases, appeals, policy documents, analysis and maps related to humanitarian emergencies worldwide (e.g., NDCC/NDRRMC reports/updates, OCHA reports, etc.).
4. News articles, such as those issued by Reuters or the Associated Press.
5. Online encyclopedias (e.g. Wikipedia) and other records published online, with their respective listed references.
6. Yearly summary reports from the Sigma Database issued by the Swiss Reinsurance Company, which covers the period 2000 – present.

In addition, data was collected from local sources in the Philippines and other literature focusing on the region. Select examples of these sources include:

1. Reports and information issued by the Philippine National Disaster Risk Reduction and Management Council (NDRRMC) website, which generally covers the period mid-2000s – present.
2. Reports and information contained in the Philippine Institute of Volcanology and Seismology (PHIVOLCS) website.
3. The Philippine Historical Earthquake Catalog from Bautista & Oike (2000), which covers the period 1589 – 1895.
4. A figure entitled "Philippine Significant Earthquakes 1608-2002" issued by the Philippine National Disaster Coordinating Council (NDCC).
5. The Catalogue of Violent and Destructive Earthquakes in the Philippines (Maso, 1910) which covers the period 1599 –1909.
6. The Southeast Asia Association of Seismology, Series on Seismology, vol. IV - Philippines (Garcia et al., 1985), with a focus on the Catalogue of Destructive Earthquakes in the Philippines, which covers the period 1589 – 1983.
7. A report titled "The Economic Impact of Natural Disasters in the Philippines" (Benson, 1997) which includes a table of earthquake losses issued by the Philippine NDCC which covers the period 1970 – 1994.
8. A paper by PHIVOLCS (Punongbayan, 1994) that provides a table of destructive earthquakes in the Philippines which covers the period 1589 – 1992.

Data for the earthquake events was supplemented with data for related perils, including tsunami and volcano events. Select examples of this supplementary data include:

1. The National Geophysical Data Center / World Data System (NGDC/WDS) Global Historical Tsunami Database, which covers the period 2000 B.C. – present.
2. An abstract titled "Development of the Philippine Historical Tsunami Catalog" by Leonila et al. (2007).

3. The National Geophysical Data Center / World Data Service (NGDC/WDS) Significant Volcanic Eruptions Database, which covers the period 1750 B.C. – present.
4. The Volcano Global Risk Identification and Analysis Project (VOGRIPA) maintained by the Global Volcano Model (GVM) Project.

Data from over 300 unique earthquake events covering the period 1599 to 2012 have been collected for the consequence database, each of which has some account of an effect to the population (including felt reports) and/or damage to the built environment. The raw data from most of the sources listed above are also included in the database. Table 4 lists the number of events referenced from each major data source; note that many events were reported by multiple sources. It is clear that the database assembled herein is more comprehensive than past databases, as no single existing database covers all the events. However, many events, especially very damaging events, contain data from multiple sources, and variable accounts exist for the quantitative data, particularly economic losses. By design, the range of accounts has been preserved and appropriately referenced.

Table 4. Number of Earthquake Events Collected for the Consequence Database from the Major Data Sources

Source	Number of Events	Minimum Year	Maximum Year
NGDC/WDS Significant Earthquake Database	190	1599	2012
GLIDE Number Database	5	1990	2012
Asian Disaster Reduction Center (ADRC)	6	1999	2012
RSOE-EDIS Database	5	2011	2012
Emergency Events Database (EMDAT)	13	1918	2009
Philippine Institute of Volcanology and Seismology (PHIVOLCS) Website	12	1968	2003
Earthquake Engineering Research Institute (EERI) Archive	4	1976	1994
ReliefWeb	11	1989	2012
Utsu Catalog of Damaging Earthquakes in the World	270	1599	2009
Wikipedia	44	1599	2012
United States Geological Survey (USGS)	69	1976	2012
USGS PAGER-CAT	111	1901	2008
USGS EXPO-CAT	56	1973	2003
Philippine Historical Catalog (Bautista & Oike)	77	1608	1895
Catalogue of Violent and Destructive Earthquakes in the Philippines (Maso)	135	1599	1909
Philippine Significant Earthquakes 1608-2002 (NDCC)	70	1608	2002
Catalogue of Destructive Earthquakes in the Philippines 1589 -1983	62	1599	1983
Destructive earthquakes in the Philippines (1589 – 1992) (Punongbayan)	48	1599	1990
Other reports and sources	29	1955	2012

4.1.2 Explanation of the Data and Data Fields

Data from the multiple sources were collected, assembled, and processed. Each event was manually checked for errors, reasonability, and completeness, with a focus on events within the last 50 years. In addition to the data fields provided in the raw data from the various sources, several summary data fields were created specifically for the consequence database. Some of these fields are outlined below:

- **Tsunami Flag** – Events that have any report of a tsunami wave are flagged. Also, events with destructive tsunami waves (e.g., those that caused reported deaths, injuries, and/or damage) are flagged. Furthermore, for events that did not have reports of a tsunami, a flag was used to indicate whether the earthquake occurred on land (on-shore) or on water (off-shore).
- **Landslide Flag** – Events that have any report of a landslide are flagged. Also, events with destructive landslides (e.g., those that caused reported deaths, injuries, and/or damage) are flagged.
- **Buildings Damaged** – The reported estimate of the number of buildings (typically houses and dwellings) that were damaged by the event.
- **Buildings Destroyed** – The reported estimate of the number of buildings (typically houses and dwellings) that were destroyed by the event.
- **People Affected** – The reported estimate of the number of people affected, including those rendered homeless, displaced, evacuated, or disrupted (e.g., affected by loss of utilities) as a result of the event.
- **People Injured** – The reported estimate of the number of people injured as a result of the event. Occasionally, this includes injuries due to secondary effects, such as stampedes.
- **Life Loss** – The reported estimate of the number of people killed, missing, or presumed dead as a result of the event. Occasionally, this includes life loss due to secondary effects, such as heart attacks.
- **Economic Loss** – The estimated economic impact due to direct damage as a result of the event, generally the physical damage to buildings (residential, commercial, and public) and infrastructure. The economic loss is typically reported in U.S. dollars (USD), corresponding to the monetary loss at the time of the event (e.g., current/nominal USD). Some data were reported in Philippine pesos and were converted appropriately by using filtered rates for specific (time-of-event) dates based on information supplied by leading market data contributors (e.g., OANDA Corporation currency conversion services and World Bank data). In general, there is no consensus on the format of what type of losses are reported by the different sources and for the different events. For example, a source may only list the losses due to damage of infrastructure and public buildings for a certain event, while another source may list the losses due to damage of residential buildings for another event. The scope of the loss report is seldom defined. Thus, the losses provided in the consequence database should be used with caution. Break-down of losses (e.g., losses per sector and type of coverage), are occasionally available for events with detailed reports. These events are flagged in the database.

Note that for several of the data fields described above, three types of values are provided, a minimum value, a maximum value, and a preferred value. The minimum and maximum values are due to (1) the different values reported across the multiple data sources or (2) the range given by a single data source. For example, the NGDC/WDS data provides a five-level scale for those events not offering a quantitative evaluation of consequence. This five-level scale is converted to a rough estimate range of values based upon a systematic application of the event description terminology. For example, sources that report “severe” (synonymous with “major”, “extensive”, “heavy”, etc.) losses, the estimated range is defined as 5 to 24 million USD. The descriptive terms relate approximately to current dollar values, but were originally developed to relate to 1990 dollars; as such, there is some inconsistency in this classification. This system of classification was adapted for other sources as well. A preferred value for each field was selected based on manual analysis of the reported values of a specific event, or was simply taken as the midpoint of the range of reported values. The data for these three types of values (minimum, maximum, and preferred) for each field were appropriately referenced.

The summary data fields in the consequence database include the consequence of all effects resulting from a given event. The effects may also include secondary effects such as tsunami and landslides. The raw data provided in the consequence database (such as the NGDC/WDS and PAGER-CAT data) occasionally indicates the estimated consequence of the effect of ground shaking only for some events. Since this is not available for all events in general, this was not provided in the summary data fields. Volcano related earthquake consequence was not included in the database. With the exception of large aftershocks, the estimated consequence is generally aggregated for the main event and aftershock sequence.

In addition to the consequence data, the event parameters (earthquake date, location, magnitude and depth) are provided, which are consistent with the historical catalog (see Section 3). Over 73% of the earthquake events have been mapped to events in the earthquake historical catalog. The remaining events, which are typically older events that occurred before the instrumental period, or have uncertain event parameters, are not included in the historical database. All events after 1960 in the consequence database have been mapped to the historical database. Location data (and to some extent, magnitude and depth data), have been provided to the events not included in the historical database. However, this data may be a rough approximation and should be used with caution (for example, the latitude/longitude listed may be simply the location of the city that felt the earthquake).

4.1.3 Brief Description of the Most Significant Earthquake Events in Recent Times

4.1.3.1 The 1976 Moro Gulf Earthquake

A few minutes after midnight on August 17, 1976, a violent M_w 8.0 earthquake occurred in the island of Mindanao spawning a tsunami that devastated more than 700 kilometers of coastline bordering Moro Gulf in the North Celebes Sea. The offshore event generated by the Cotabato trench was one of the largest tsunamigenic earthquakes to have been reported in Mindanao. The event resulted in massive destruction of properties and many fatalities, especially in the cities and provinces of Cotabato and the shores of Pagadian City. According to event surveys, the tsunami alone was responsible for 85% of deaths, 65% of injuries, and 95% of those missing. Properties lost not only included establishments for residential and commercial use, but also bancas (a type of outrigger boat native to the Philippines) which represent the livelihood of many families. (PHIVOLCS, 2013)

Figure 13 shows the estimated maximum ground shaking intensity during the event (e.g., the USGS ShakeMap) and Table 5 lists a breakdown of the estimated population affected based on EERI reconnaissance (Stratta et al., 1977).

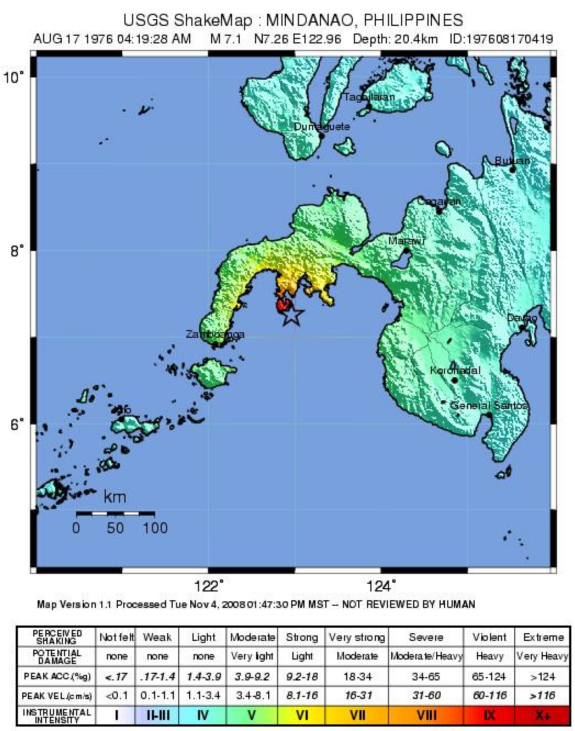


Figure 13. The USGS Shakemap for the 1976 Moro Gulf Earthquake

Table 5. Consequence from the 1976 Moro Gulf Earthquake (Source: EERI Reconnaissance Report, Stratta et al., 1977)

TABLE 3. CASUALTIES AND NUMBER OF PERSONS RENDERED HOMELESS

Affected Areas	Casualties									Homeless Families
	Dead			Missing			Injured			
	EQ*	TS*	Total	EQ	TS	Total	EQ	TS	Total	
Region IX										
Zamboanga City			153			15			151	97
Zamboanga del Sur			563			521			4,110	818
Zamboanga del Norte			-			-			-	-
Pagadian City			418			29			2,500	3,980
Basilan City			30			6			10	129
Sulu			89			107			15	25
Region XII										
Lanao del Norte			80			162			2	1,488
Lanao del Sur			561			89			273	879
Maguindanao			1,198			429			645	2,761
Sultan Kudarat			305			51			106	1,081
North Cotabato			-			-			1	50
Cotabato City	110	57	167	0	93	93	422	21	443	879
Total			3,564			1,502			8,256	12,183

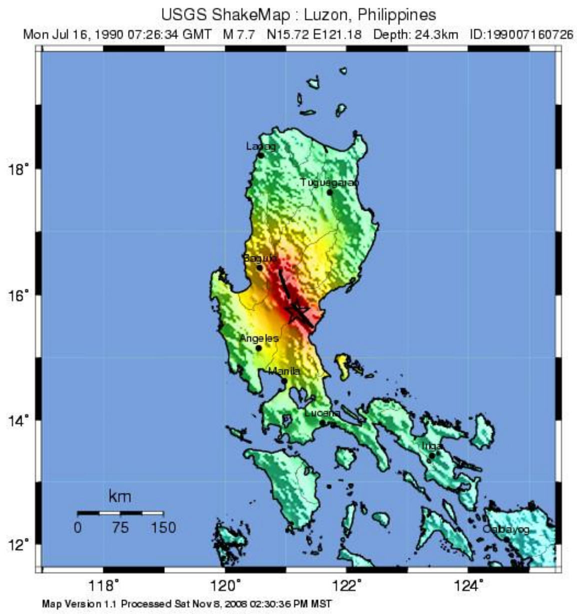
*EQ = earthquake; TS = tsunami.

4.1.3.2 The 1990 Luzon Earthquake

On July 16, 1990, the Philippines suffered a major M_w 7.7 earthquake with an epicenter near San Jose City, Nueva Province, Luzon. Some 100,000 square kilometers, including all of North Luzon as well as parts of Central Luzon were affected, with the most serious damage occurring over an area of some 15,000 square kilometers. The cities of Baguio, Dagupan, Agoo, Aringay, and Pura were most affected, while Tarlac, Cabantuan, Rizal, and Manila were marginally damaged (Rantucci, 1994). The earthquake was followed by some 130 aftershocks, at least 15 of which recorded a magnitude of 5.0 or more. The earthquake precipitated liquefaction, flooding (due to various factors such as liquefaction, diversion of waterways and blockage or destruction of natural gullies), sea-water intrusion in coastal areas, and massive landslides, the latter of which continued for several months as the earthquake had occurred at the beginning of the region's annual monsoon. The earthquake also triggered the intrusion of molten rock and the subsequent renewed activities of Mt. Pinatubo and Mt. Taal, which subsequently inflicted massive further damage on the same region (Rantucci, 1994).

Some 1,283 deaths were officially recorded as a consequence of the earthquake, largely in Baguio City, although several sources indicate more lives lost. Over 100,000 houses were damaged or destroyed. In Baguio City alone, about a third of the buildings were damaged. One report of the total damage was at estimated as 12.2 billion Pesos (current value); some 56% of it to infrastructure, 12% to agriculture and 32% to private property, principally non-housing (see Table 6). The earthquake produced a 125 km long ground rupture from Dinglan, Aurora to Kayapa, Nueva Vizcaya.

Figure 14 shows the estimated maximum ground shaking intensity during the event (e.g., the USGS ShakeMap) and Table 6 lists a breakdown of the economic damage from official data (NDCC, 1990).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 14. The USGS Shakemap for the 1990 Luzon Earthquake

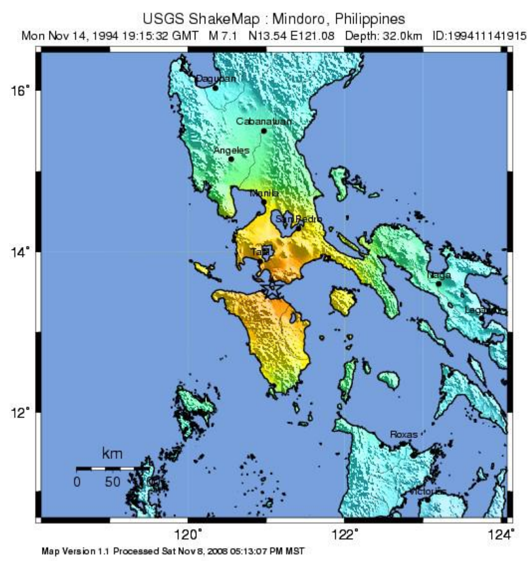
Table 6. Damage Breakdown of the 1990 Luzon Earthquake (Source: NDCC, 1990)

Sector	Estimated cost of direct physical destruction alone (1990 million Pesos)	Percent of total
Agriculture	**1,425**	**11.7%**
Crops	550	4.5%
Fisheries	408	3.3%
Livestock	40	0.3%
Facilities	100	0.8%
Irrigation systems	327	2.7%
Fish processing plants	0	0.0%
Infrastructure	**6,845**	**56.0%**
Roads/Bridges	3,472	28.4%
Public buildings (including schools)	1,843	15.1%
Public facilities	1,530	12.5%
Private Properties	**3,955**	**32.4%**
Houses	147	1.2%
Other privately owned establishments	3,763	30.8%
Vital/utility services	45	0.4%
Total	**12,225**	**100.0%**

4.1.3.3 The 1994 Southern Tagalog Earthquake

On November 14, 1994, a strong M_w 7.1 earthquake occurred near Verde Island in the Philippines. The epicenter of the event was along the coastline of the island of Mindoro, located approximately 140 km south of Manila. The event was a major right-lateral strike-slip event along the Aglubang River Fault. The earthquake resulted in approximately 78 deaths and 430 injuries. It spawned a series of tsunami waves along a 40 km stretch of the island's northern shore, from the municipalities of Puerto Galera to Pinamalayan. In addition, large portions of the sides of the Baruyan River sank during the tsunami. Some 7,560 houses were damaged during the event, of which 1,530 were either completely destroyed or washed away by the tsunami. The majority of houses totally destroyed were located in the municipalities of Calapan and Baco, and the bulk of houses only partially damaged were situated in the municipalities of Naujan and Gloria. Damaged infrastructure included 24 bridges, eight of which were rendered impassable for days. Three major power plants, two on the island of Luzon and one in the Visayas islands, tripped during the earthquake. This caused widespread power disruptions on Mindoro Island and parts of Manila, Leyte, and Samar.

Figure 15 shows the estimated maximum ground shaking intensity during the event (e.g., the USGS ShakeMap).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 15. The USGS Shakemap for the 1994 Southern Tagalog Earthquake

4.1.3.4 The 2012 Visayas Earthquake

On February 2, 2012, a strong M_w 6.7 event off the coast of Negros Oriental, Philippines, resulted in at least 51 people killed, 62 missing, 112 injured, 23,000 displaced, about 15,000 buildings destroyed or damaged, at least 17 bridges and many roads destroyed or damaged and utilities disrupted on Negros. Many landslides occurred, including two that buried 30 homes at Guihulngan and 100 homes at La Libertad. Large waves were reported at La Libertad. Some buildings were damaged and landslides occurred on Cebu. Utilities were disrupted at Iloilo, Panay. The most affected towns were Tayasan, Jimalalud, La Libertad, and the city of Guihulngan, in Negros Oriental. The event resulted in an estimated 15 million USD in damage on Negros and Cebu. (USGS, 2012)

Figure 16 shows the estimated maximum ground shaking intensity during the event (e.g., the USGS ShakeMap) and Figure 17 shows the estimated population affected by region.

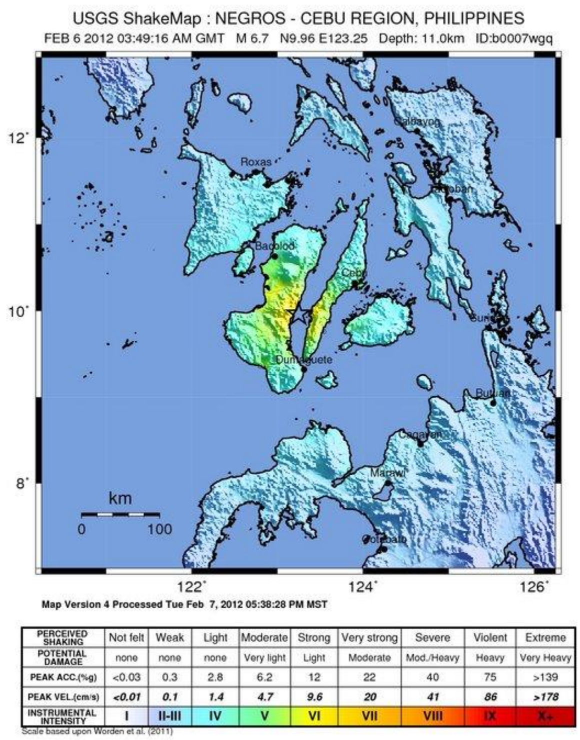


Figure 16. The USGS Shakemap for the 2012 Visayas Earthquake

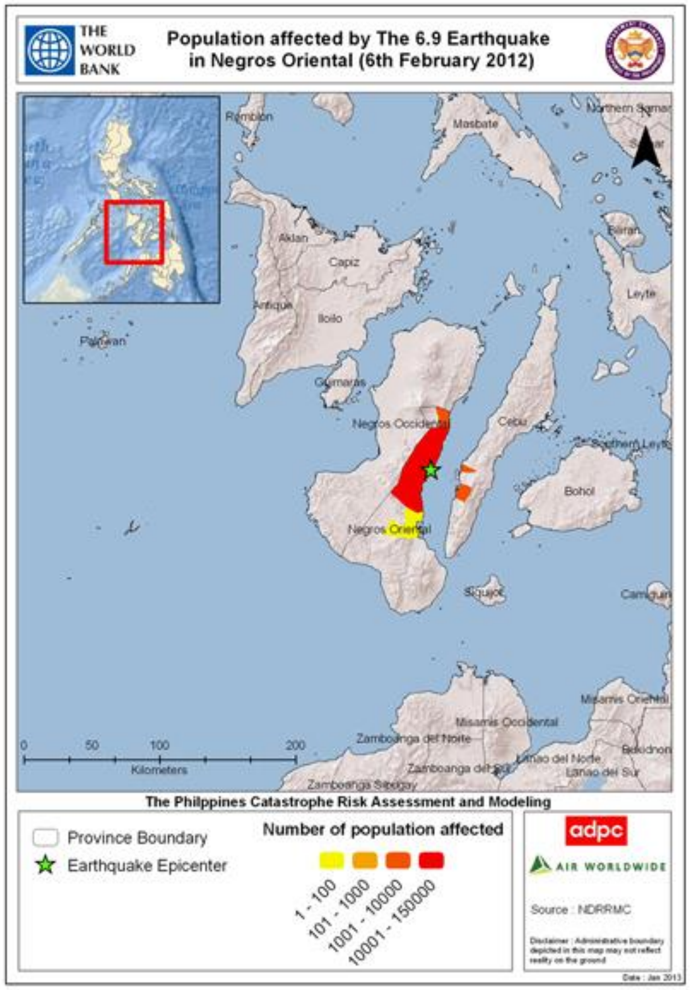


Figure 17. The Population Affected due to the 2012 Visayas Earthquake

4.1.4 Earthquake Consequence Summary

Table 7 lists the number of events, catastrophic events (i.e., defined as events with either 100+ injuries, 5+ killed, 1,000+ damaged or destroyed buildings, or 5+ million current USD in losses, current values), estimated economic loss (current and trended), and estimated life loss (actual and trended) extracted from the consequence database. In total, it is estimated that earthquakes in the Philippines have resulted in at least 16,000 lives lost and 1.4 billion USD in damages (non-trended values). In general, the Philippines experience a significant earthquake event 1.5 times a year and a catastrophic event once every three years. On average, earthquakes events result in about 400 lives lost and 100 million USD in damage per year (trended 2012 values based on 1960 – 2010 data).

Figure 18 plots some of the most significant earthquake events in the Philippines since 1960, i.e. those that have reports of lives lost or economic loss from physical damage. Of the 298 events in the consequence database, 81 events have reports of tsunami, while 21 events have reports of significantly destructive tsunamis. Likewise, 46 events have reports of landslides, while 6 events have reports of significantly destructive landslides. The smallest magnitude earthquake in the consequence database is M_w 4.8; only four events have a M_w of less than 5.0.

Table 7. Summary Data of the Earthquake Consequence Database

Time period	Number of Events	Number of Catastrophic Events	Estimated Economic Damage (Current Million USD)	Estimated Economic Damage (Trended Million 2012 USD)	Estimated Life Loss	Estimated Life Loss (Trended 2012 Value)
16th Century	24	15	190	n/a	1,274	n/a
17th Century	15	7	105	n/a	1,124	n/a
18th Century	100	20	298	n/a	2,815	n/a
1900s	14	6	60	n/a	408	n/a
1910s	14	3	39	n/a	109	n/a
1920s	17	7	62	n/a	871	n/a
1930s	5	1	12	n/a	1	n/a
1940s	5	2	5	n/a	90	n/a
1950s	5	2	6	n/a	487	n/a
1960s	2	2	9	302	274	792
1970s	19	2	146	2,348	7,115	16,328
1980s	22	8	14	98	42	75
1990s	30	2	469	2,658	1,721	2,681
2000s	16	1	6	16	11	13
2010 – 2012	10	1	21	21	114	114

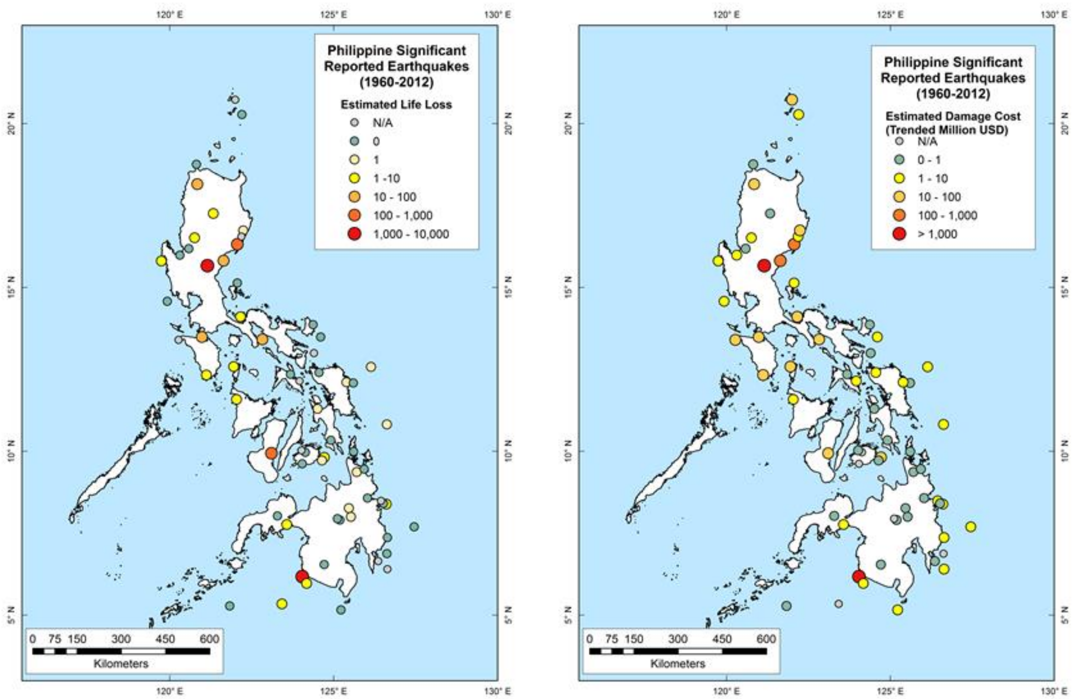


Figure 18. Significant Earthquake Events in the Philippines Since 1960

4.1.5 Tsunami Events

Due to the abundance of coastlines and high regional seismicity, the Philippines is prone to earthquake-induced tsunami risk. Based on the National Geophysical Data Center / World Data System (NGDC/WDS) Global Historical Tsunami Database, over 80 earthquake-induced tsunami events have been reported in the Philippines between 1627 to 2012, with resulting observed wave heights ranging from negligible (e.g., a few centimeters) to 8.5 meters. The largest reported tsunami events have occurred at the Celebes and Sulu Seas in southern Philippines. The Celebes Sea area, Manila Bay, Calauag Bay, and Caraga Bay are among the areas with the most frequent tsunami activity. At least one reported teletsunami event significantly affected the Philippines, i.e., the 1960 Chile earthquake that reportedly reached wave heights up to three meters and killed about 20 people (Bautista et al., 2007).

Figure 19 plots the historical run-ups and corresponding earthquake sources in the Philippines as reported by the NGDC/WDS Global Historical Tsunami Database. Table 8 lists some of the most significant reported tsunami events in the Philippines.

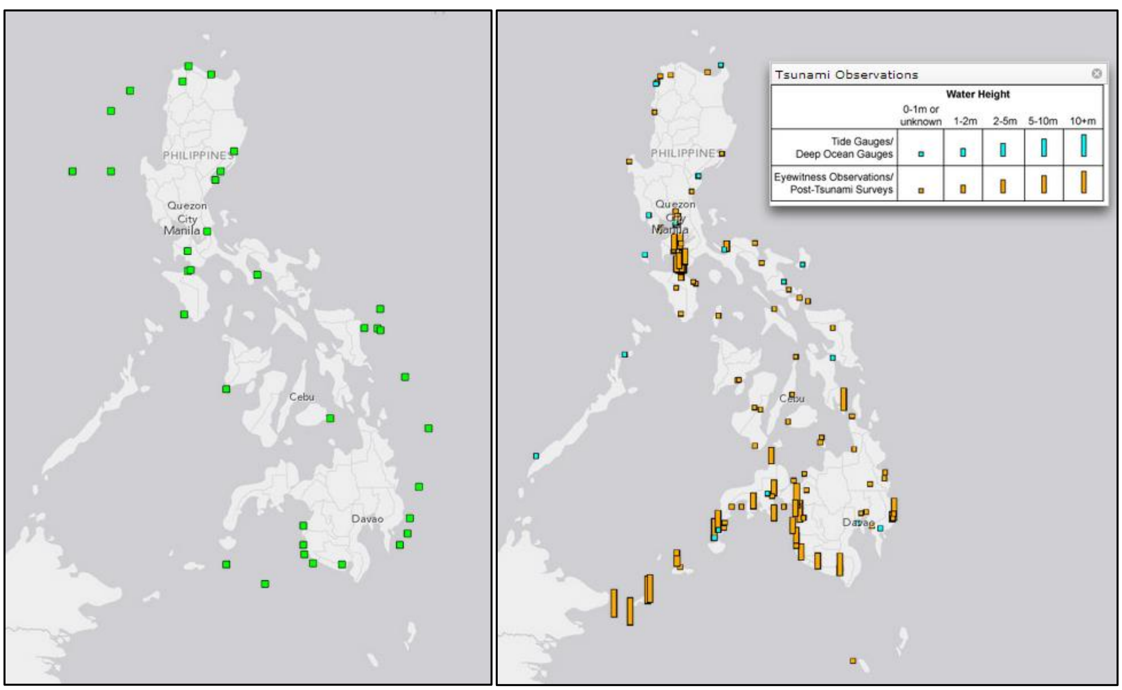


Figure 19. Reported Earthquake Sources (left) and Tsunami Run-Ups (right) in the Philippines (Source: NGDC/WDS, 2013)

Table 8. Significant Tsunami Events in the Philippines

Date	Source Latitude	Source Longitude	Earthquake Magnitude (Mw)	Source Location	Maximum Observed Water Height (m)	Number of Deaths from Tsunami	Damage from Tsunami (million USD at time of event)
September 21, 1897	6	122	7.5	Sulu Sea	7	13	0 - 1
January 30, 1911	14	121	Volcano Induced	Taal Lake	3	54	0 - 1
August 15, 1918	5.97	124.38	8.3	Celebes Sea	7.2	6	1 - 5
May 22, 1960	-38.14	-73.41	9.6	Off-Shore Chile	3	20	n/a
September 28, 1965	14	121	Volcano Induced	Taal Lake	4.7	355	n/a
October 31, 1975	12.57	126.14	7.5	Philippine Trench	4	1	0 - 1
August 16, 1976	6.18	124.05	7.96	Moro Gulf	8.5	4,376	134
November 14, 1994	13.49	120.99	7.08	Verde Island Passage	7.3	81	3.7
March 5, 2002	5.97	124.18	7.47	Celebes Sea	3	n/a	0 – 1

Note: All data taken from the NGDC/WDS Global Historical Tsunami Database, unless mentioned otherwise. The maximum observed water height for the 1960 event is taken from Bautista et al., 2007.

4.1.6 Volcano Events

There are a few examples in the historical record that suggest a connection between large earthquakes and volcanic eruptions. The Philippines is located along the Pacific Ring of Fire and has numerous volcanoes distributed in five volcanic belts (Benson, 1997). The country therefore experiences considerable volcanic activity, with major events occurring approximately once every ten years (Rantucci, 1994). Recent major eruptions include those of Mt. Taal in 1965, Mt. Mayon in 1984, and Mt. Pinatubo in 1991. As of 2012, PHIVOLCS lists 23 volcanoes as active in the Philippines, 21 of which have observed historical eruptions; an additional 27 volcanoes are potentially active. From 1970 to 1994, the NDCC estimates that volcanoes have caused 14.7 billion Pesos (1994 values) in damages and almost 1,000 deaths (Benson, 1997), most of which is attributed to the eruption of Mt. Pinatubo in June 1991.

Figure 20 shows a map of active volcanoes in the Philippines as reported by PHIVOLCS. Table 9 lists some of the most significant volcanic eruptions (e.g., those with a volcanic explosivity index "VEI" of 3 or greater) that have impacted the Philippines in recent history. Secondary volcano effects, such as those that occur after the main eruption, can also have significant impacts on the population, including lahars (pyroclastic flows). For example, in 2006, an estimated 1,266 people died from post-eruptive lahars down the slopes of Mt. Mayon produced during a tropical cyclone (NOAA, 2013).

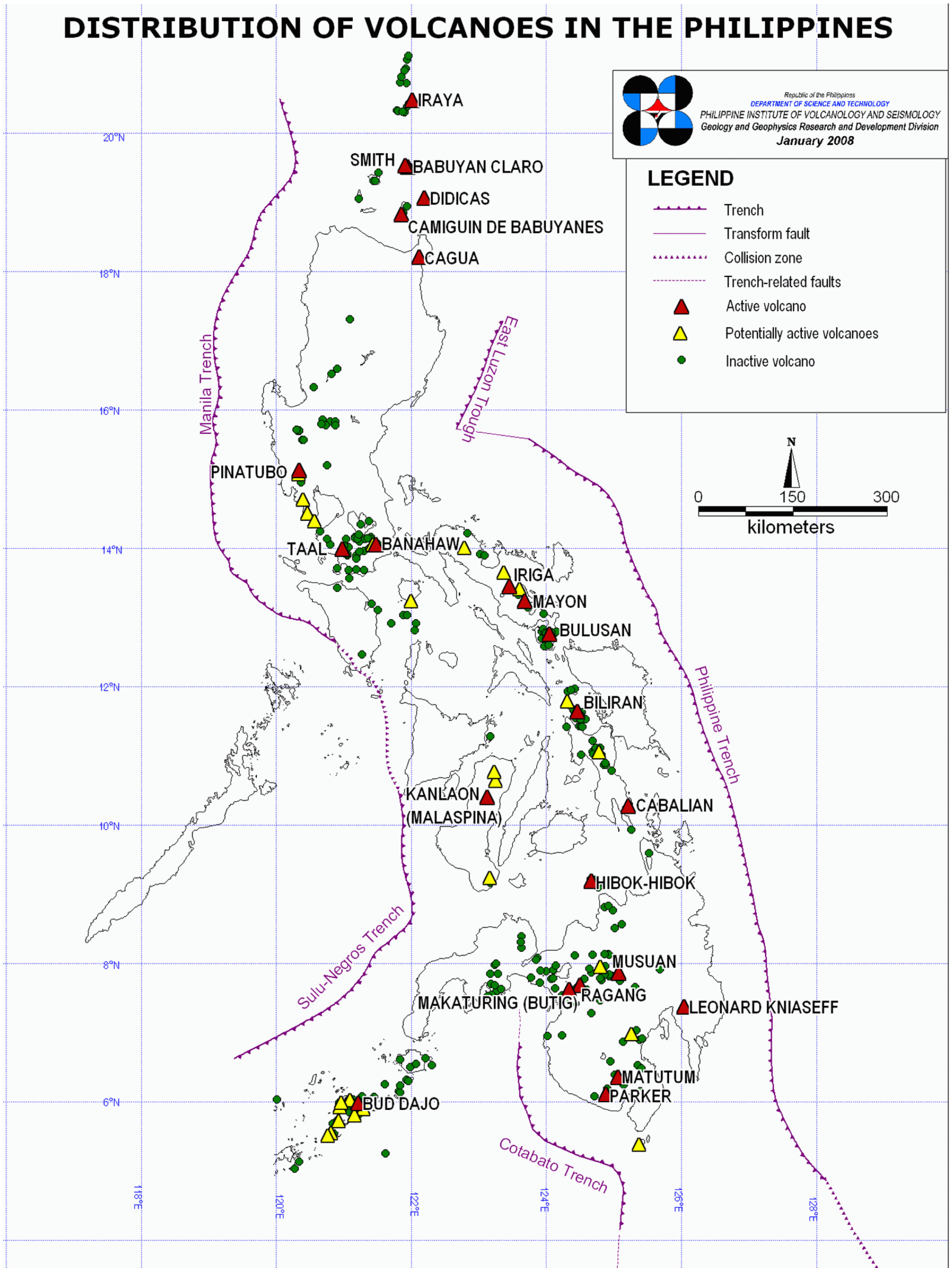


Figure 20. Map of Active Volcanoes in the Philippines (Source: PHILVOLCS, 2008)

Table 9. Significant Volcanic Eruption Events in the Philippines

Date	Volcano	VEI	Number of Lives Lost	Damage from Eruption (million USD at time of event)
May 13, 1754	Taal	4	12	n/a
February 1, 1814	Mayon	4	1,200	n/a
January 30, 1911	Taal	4	1,335	n/a
September 1, 1948	Hibok-Hibok	3	68	n/a
September 28, 1965	Taal	4	355	10
April 20, 1968	Mayon	3	6	5
September 8, 1984	Mayon	3	0	n/a
June 15, 1991	Pinatubo	6	450	211

Note: Data taken from the National Geophysical Data Center / World Data Service (NGDC/WDS) Significant Volcanic Eruptions Database and EMDAT

4.2 Tropical Cyclone and Flood Events

4.2.1 Data Sources

Consequence data from major historical tropical cyclone and flood events occurring in the Philippines has been collected from a large variety of sources. This data was assembled into a database and represents a comprehensive inventory of reported tropical cyclone (including typhoons and tropical storms/depressions) and flood events, and other related events, such as storm surges and landslides, which have had a significant impact on the population and built environment of the Philippines. Data was collected, assembled, and processed from publically available disaster databases, including:

1. The Emergency Events Database (EMDAT), maintained by the Centre for Research on the Epidemiology of Disasters (CRED), which generally covers the period 1900 – present.
2. The Global Active Archive of Large Flood Events maintained by the Dartmouth Flood Observatory (DFO), which covers the period 1985 – present.
3. National Disaster Coordinating Council Office of Civil Defense Operations Center (NDCC/NDRRMC) Database of Destructive Typhoons which covers the period from 1970 – 2003.
4. The online information repository "ReliefWeb," which scans websites of international and non-governmental organizations, governments, research institutions and the media for news, reports, press releases, appeals, policy documents, analysis and maps related to humanitarian emergencies worldwide (e.g., NDCC/NDRRMC reports/updates, OCHA reports, etc.).
5. The GLIDE number database, maintained by the Asian Disaster Reduction Center (ADRC), which generally covers the period from the mid-1990s – present.
6. Disaster information reports issued by the Asian Disaster Reduction Center (ADRC).

4.2.2 Explanation of the Data and Data Fields

Over 520 unique event entries from tropical cyclones, flooding, and secondary hazards have been collated from the previously mentioned sources for the consequence database. Each event has some recorded notable effect on the population or damage to the building inventory. Many entries, especially those from very damaging events, contain data from multiple sources, and, as expected, discrepancies exist for the quantitative data, particularly economic losses. By design, the discrepancies have been preserved and each relevant piece of data in the consequence database is appropriately referenced. This consequence database represents a comprehensive collection of significant tropical cyclone and flood events reported in the literature, with a focus on events since the 1970s.

Each event in the consequence database is flagged as a tropical cyclone event or a flood event, for the most part, on their designation in the original data sources. However some events were designated as both a tropical cyclone event and a flood event when the data indicated that the flooding may have been caused by a tropical cyclone. Many tropical cyclones cause damage and loss from flooding, in addition to damage from wind. Tropical cyclones that do not make landfall may still pass close enough to the Philippines, leading to heavy rainfall and possible flooding, which can cause damage and affect the population. Due to these issues, some events may not be well categorized and there is a possibility of double counting the effects of some events. The consequence database also flags events with reported significant consequences from associated landslides and storm surge.

The referenced sources discussed previously typically report a brief summary of the disaster consequence (e.g., number of people affected and/or number of lives lost), and some accounts are strictly qualitative (e.g., "buildings and crops were damaged"). For each entry in the consequence database, data from each field is typically an aggregate account of the total consequence from a particular event (including related secondary events/effects), with most or all of the damage occurring in the Philippines. The main data fields of the consequence database are outlined below:

- **Deaths** – The total number of people reported dead or presumed dead as a result of the event.
- **Injuries** – The total number of people reported injured as a result of the event.
- **People Displaced** – A measure of the number of people required to vacate their residence due to the peril, such as those homeless or evacuated.
- **People Affected** – A measure of the estimated number of people affected by the event. People affected include those that became homeless, displaced, evacuated, or disrupted (e.g., affected by loss of utilities) by the peril.
- **Buildings Partially Destroyed** – The reported estimate of the number of buildings (typically houses and dwellings) that were damaged by the event.
- **Buildings Destroyed** – The reported estimate of the number of buildings (typically houses and dwellings) that were destroyed by the event.
- **Economic Damage** – The estimated total economic impact of the event, which usually consists of direct physical damage (e.g., damage to infrastructure, crops, and housing). Estimated loss is typically reported in U.S. dollars (USD) or Philippine pesos, corresponding to the monetary loss at the time of the event (e.g., current/nominal USD). Some data were reported in Philippine pesos and were converted appropriately by using rates for specific (time-of-event) dates based on information supplied by leading market data contributors (e.g., OANDA Corporation currency conversion services and World Bank data). A break-down of losses by sector (e.g., infrastructure, agriculture, private properties) and specific location (e.g., Region) may be available for some events, such as those events where detailed assessment reports were available.

Note that for several of the data fields described above, three types of values are provided, a minimum value, a maximum value, and a preferred value. The minimum and maximum values are due to (1) the different values reported across the multiple data sources or (2) the range given by a single data source. A preferred value for each field was selected based on manual analysis of the reported values of a specific event, or was simply taken as the midpoint of the range of reported values. The data for these three types of values (minimum, maximum, and preferred) for each field were appropriately referenced. The data for these three types of values (minimum, maximum, and preferred) for each field were appropriately referenced.

In addition, the IDs and notes from the original data sources are provided in the consequence database. Also, where available, the WMO storm name (and associated IBTrACS serial number – refer Section 3.2) and PAGASA storm name was provided.

4.2.3 Brief Description of the Most Significant Tropical Cyclone and Flood Events in Recent Times

4.2.3.1 Typhoon Joan (1970)

Typhoon Joan claimed nearly 800 lives and left about 80,000 people homeless. The storm formed on October 8, 1970, near the Caroline Islands and moved westward for three days along the southern periphery of a subtropical high, gradually intensifying until reaching typhoon status on October 11. By the following day, the storm had intensified by 50 mb and achieved super typhoon status. A weakness in the ridge shifted Joan to the northwest, aiming the storm directly at Luzon. On October 13, Joan made landfall in the Lagonoy Gulf region with sustained winds estimated at 280 km/h. Sustained winds of 170 km/h with gusts above 200 km/h were recorded at the Loran U.S. Coast Guard station, about 30 miles north of landfall. Closer to landfall, a minimum sea level pressure of 951 mb and wind gusts exceeding 275 km/h were estimated at Virac. Joan weakened while traversing southern Luzon, passing 30 km south of Manila on the morning of the 14th. Wind gusts as high as 155 km/h and a minimum pressure of 976.9 mb were recorded at the Ninoy Aquino International Airport with the observed sustained winds of 139 km/h. Joan was followed a week later by Super Typhoon Kate, which also affected the Philippines exacerbating an already dire situation.

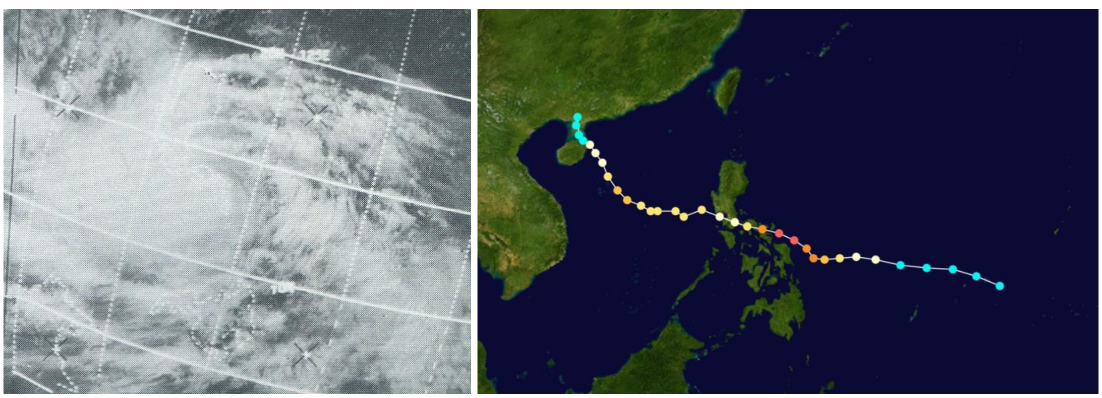
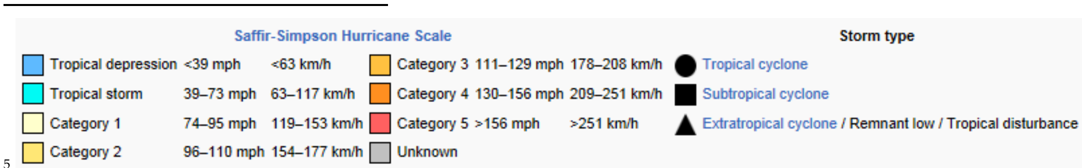


Figure 21. Typhoon Joan (1970) Satellite Image and Track (Source: Wikipedia)[5]

5 

4.2.3.2 Great Philippine Floods of 1972

One of the deadliest flooding incidents during the history of the Philippines hit central and north Luzon in July 1972. Existing records cite that more than 650 people died and 220 million USD in damage was sustained. The continual heavy rainfall is attributed to monsoon rains and a passing subsequent typhoon. It is reported that the Manila area received more than 70 inches of rain during the month of July and that the rice crop for the season was lost. Widespread food shortages, in addition to cholera and typhoid epidemics, also resulted.

4.2.3.3 Typhoon Ike (1984)

Typhoon Ike caused extreme wind and flooding damage when it crossed the Philippines, resulting in over 1,000 fatalities. Over two million people were affected. In Surigao del Norte, at least 27 towns were completely destroyed by the typhoon. Some towns were washed away after Lake Mainit overflowed its banks, killing hundreds of people caught in the floodwaters. Cebu and Surigao City were severely affected by Ike.

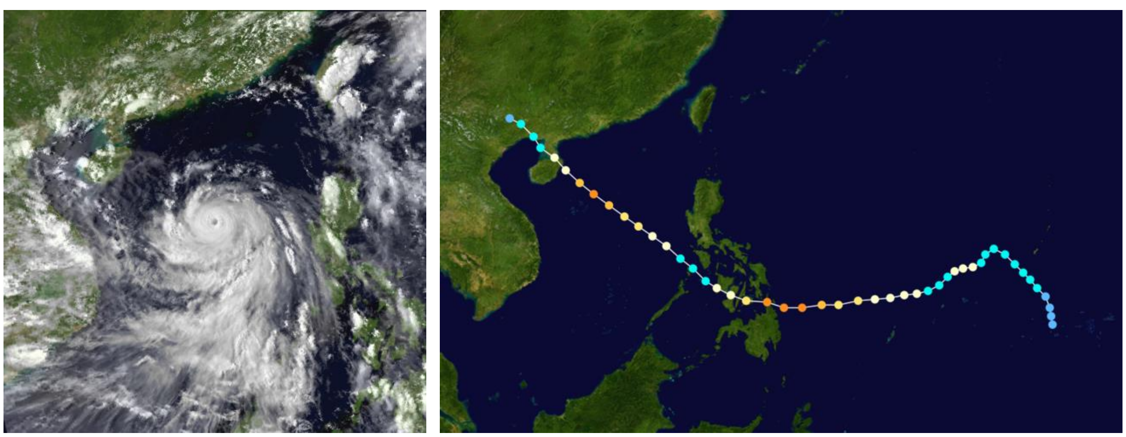


Figure 22. Typhoon Ike (1984) Satellite Image and Track (Source: Wikipedia)

4.2.3.4 Typhoon Thelma (1991) and the Ormac City Floods

Typhoon Thelma (Uring), which claimed over 5,000 lives, was one of the deadliest storms in Philippines history. The storm formed at the end of October 1991 near the eastern Caroline Islands, moved west-southwest to reach the Philippines with wind speed reaching peaking at 40 knots (74 kph), and dissipated on November 8, 1991, near eastern Vietnam. As Thelma crossed the Philippines, it displaced more than 45,000 people and affected 220,000 to over 600,000 people in Leyte (Western Visayas region and Eastern Visayas region) with flooding and landslides. Massive flash floods occurred in Ormoc City in Leyte, which killed thousands of people who were swept away by swift moving mud and water.

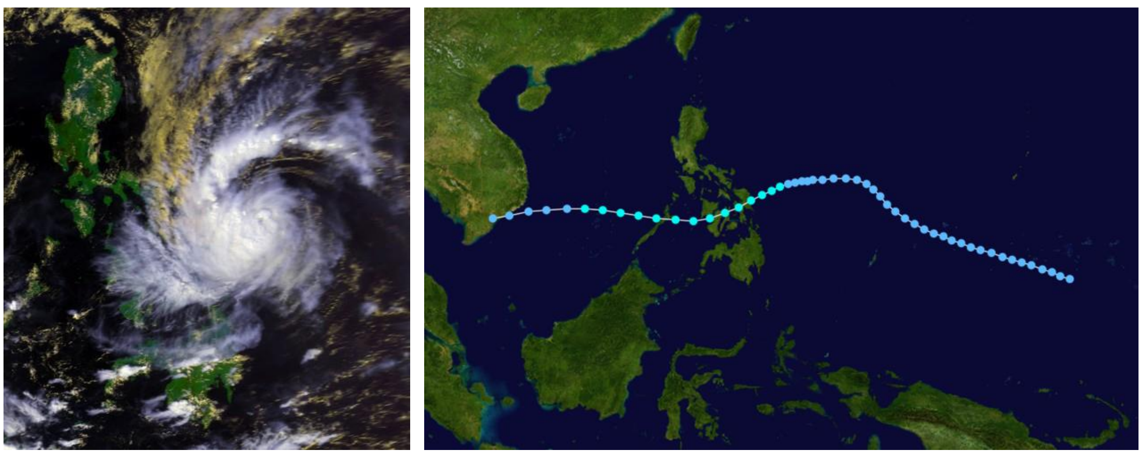


Figure 23. Typhoon Thelma (1991) Satellite Image and Track (Source: Wikipedia)

4.2.3.5 Typhoon Angela (1995)

Initially taking form on October 25, 1995, about 500 km south of Guam, Typhoon Angela slowly intensified while moving westward. On November 1, Angela rapidly intensified to a peak intensity of 287 km/h and a minimum sea level pressure of 872 mb, the second lowest pressure ever observed in the Pacific Basin. Angela maintained this peak intensity for the next 36 hours before striking the northern Bicol region of Luzon on November 2 with estimated one-minute sustained wind speeds of 226 km/h. Wind gusts of 260 km/h and 205 km/h were recorded at the Catanduenas Island radar site and Virac, respectively. Angela weakened while traversing southern Luzon, and on November 3, the storm passed directly over Manila, where the Ninoy Aquino International Airport reported a minimum sea-level pressure of 976 mb. The storm emerged into the South China Sea and continued moving west-northwest before weakening and finally dissipating west of Hainan Island. The typhoon affected Manila, Calabarzon, and Bicol and claimed over 900 lives, destroyed more than 96,000 homes, and let a third of the country without power. The northern Bicol region was the worst hit; in Calauag a dam failure caused extensive damage and cost around 100 lives.

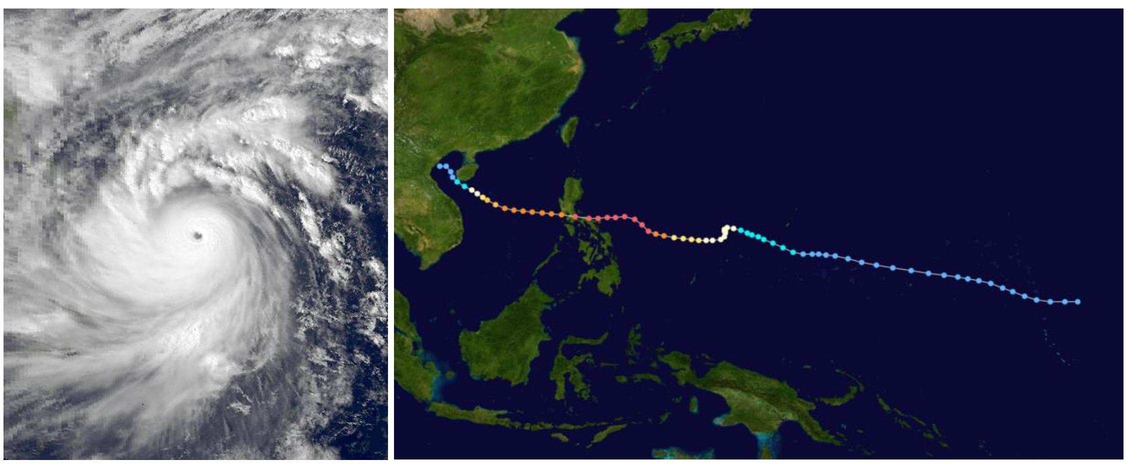


Figure 24. Typhoon Angela (1995) Satellite Image and Track (Source: Wikipedia)

4.2.3.6 Tropical Depression Winnie (2004)

Tropical Depression Winnie was a catastrophic tropical cyclone that killed nearly 1,600 people after triggering widespread flooding in the Philippines. Although a weak tropical cyclone, Tropical Depression Winnie brought torrential rainfall to much of the Visayas and Luzon.

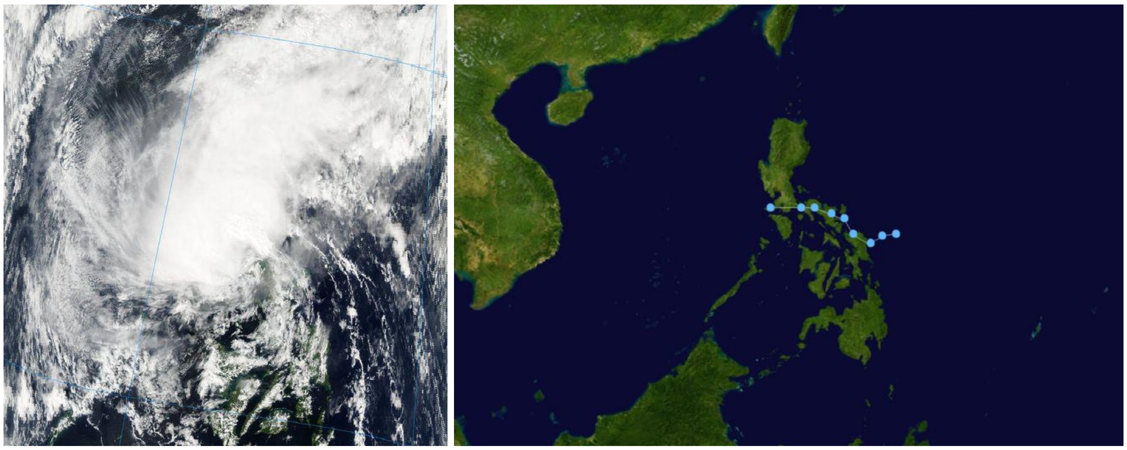


Figure 25. Tropical Depression Winnie (2004) Satellite Image and Track (Source: Wikipedia)

4.2.3.7 Typhoon Durian (2006)

Durian formed southeast of Chuuk, Micronesia, on November 25 and slowly intensified over the next few days while moving west-northwest until reaching typhoon strength on November 28. The storm rapidly intensified over the next 24 hours and reached super typhoon status on November 29 while approaching southern Luzon. Durian made landfall on November 30, with one-minute sustained winds estimated at 207 km/h, making it the fourth typhoon within a period of four months to make landfall in the area. The storm then crossed the Lagonoy Gulf and continued westward, making landfall on the Bondoc Peninsula, on Marinduque Island, and again on Mindoro Island before reaching the South China Sea. As Durian reached Catanduanes, it uprooted trees and homes and while drenching some areas with over 460 mm of rain. At the Mayan Volcano, which had erupted a few months earlier, the rain and wind combined with loosened rock and mud, resulting in massive landslides that destroyed three villages and killed nearly 200 people.

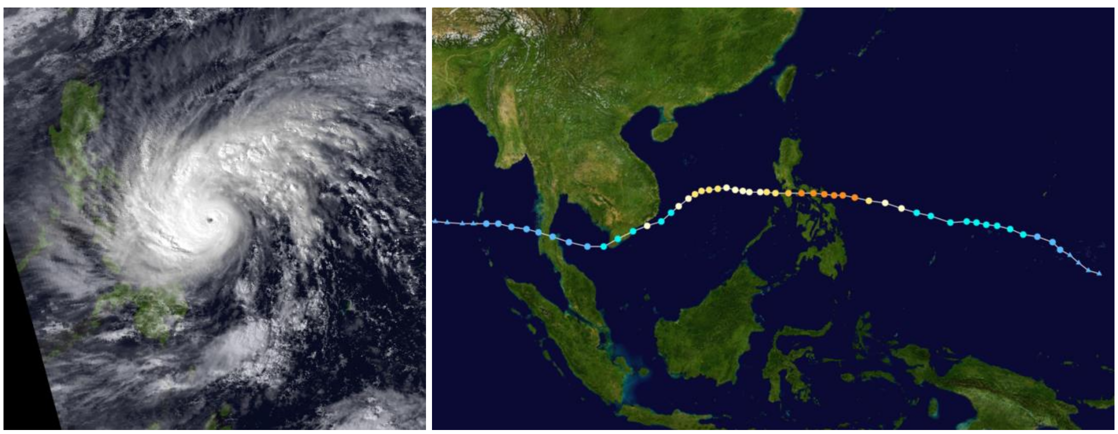


Figure 26. Typhoon Durian (2006) Satellite Image and Track (Source: Wikipedia)

4.2.3.8 Typhoon Fengshen (2008)

Typhoon Fengshen formed on June 18, 2008, about 100 km northwest of Palau and tracked west-northwest, intensifying into a typhoon in just 24 hours. The storm was poorly forecasted by all reporting agencies (as evidenced by the wide range in final best track intensity estimates), with no indication of a potential impact on the Philippines. However, Fengshen tracked westward and made landfall on Samar Island on June 20 with a central pressure of 970 mb and one-minute sustained winds estimated at between 132 km/h and 172 km/h. The storm intensified by 20 mb while crossing the Sibuyan Sea and on June 21, abruptly turned north-northwest. The eye of Fengshen passed over Manila, where a sudden albeit brief calm was reported, with one-minute sustained winds estimated at between 132 km/h and 172 km/h. Fengshen killed more than 1,300 people, the majority of whom were on the Princess of the Stars ferry, which sank off the coast of San Fernando, Romblon, located in the Visayas. In Iloilo City, tens of thousands found their homes completely submerged when a nearby reservoir burst. In Manila, power outages occurred throughout the city and surrounding areas.

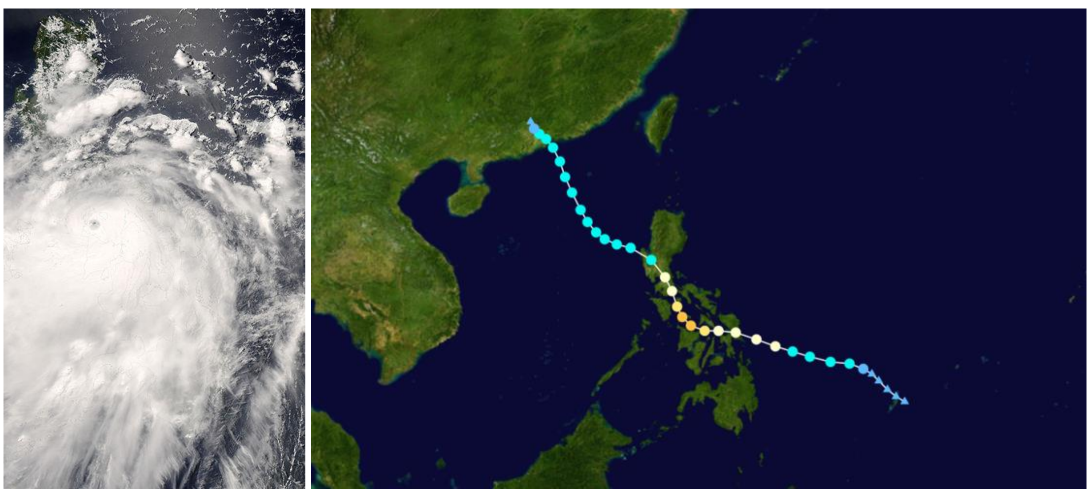


Figure 27. Typhoon Fengshen (2008) Satellite Image and Track (Source: Wikipedia)

4.2.3.9 Typhoon Ketsana (Ondoy) and Parma (2009)

In September 2009, Typhoon Ketsana (Ondoy) lashed at Metro Manila. Ketsana (Ondoy) formed on September 23, 2009, to the northwest of Palau, and made landfall in northern Luzon on September 26. Within a week, Typhoon Parma (Pepeng) carved a trail of destruction in Northern Luzon for almost two weeks. Extreme consequences of the two typhoons included casualties in the hundreds due to massive flooding and landslides brought about by continual rain. These two tropical cyclones killed over 750 people, displaced more than 700,000 people, and affected over 6.5 million people. Almost one billion USD in economic damage was inflicted by the typhoons.

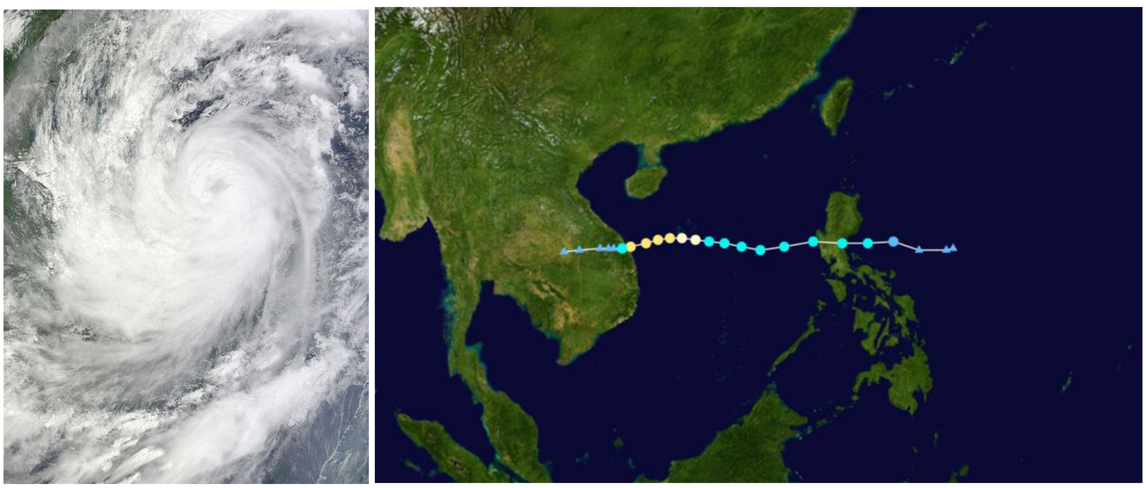


Figure 28. Typhoon Ketsana (2009) Satellite Image and Track (Source: Wikipedia)

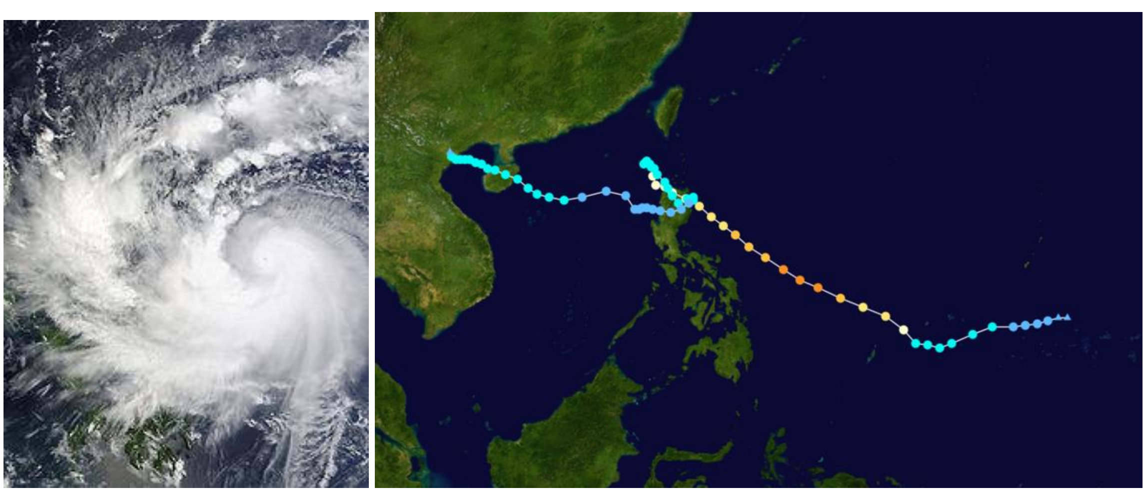


Figure 29. Typhoon Parma (2009) Satellite Image and Track (Source: Wikipedia)

4.2.3.10 Washi (2011)

Tropical cyclone Washi (Sendong) is a recent catastrophic storm to cross the Philippines and affected over one million people in Mindanao. The storm formed south-southeast of Guam on December 13, 2011, and moved westward toward the Philippines. On December 15, the storm passed into the area of responsibility for the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PASAGA) and made landfall at peak strength on the east coast of Mindanao the next day. Flooding and flash floods ensued, with 815 villages (barangays) flooded and almost 15,000 houses totally destroyed and over 37,000 houses partially destroyed.

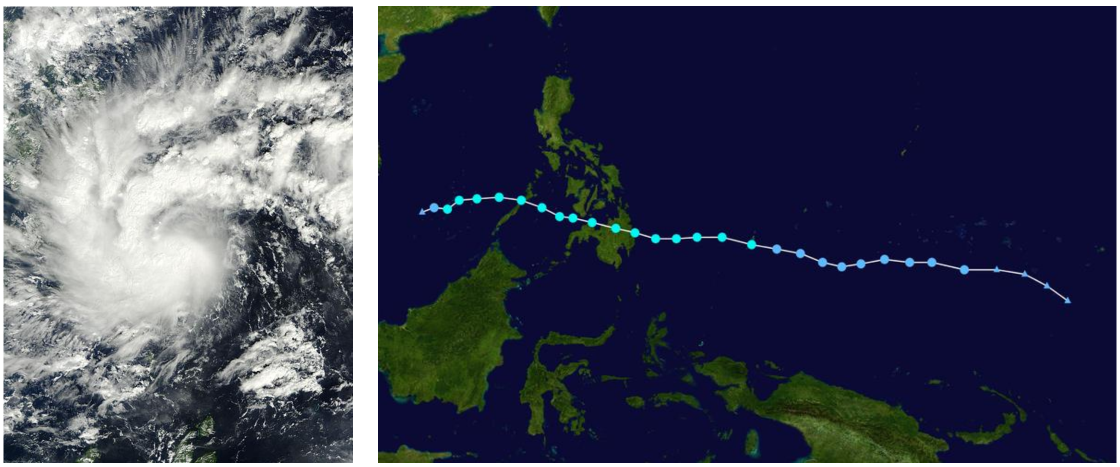


Figure 30. Typhoon Washi (2011) Satellite Image and Track (Source: Wikipedia)

4.2.3.11 Typhoon Bopha (2012)

Typhoon Bopha was the strongest reported tropical cyclone to ever hit the southern Philippine island of Mindanao, making landfall as a Category 5 super typhoon with winds of 160 mph (260 km/h) (Wunderground, 2012). Bopha originated unusually close to the equator, becoming the second-most southerly Category 5 super typhoon, reaching a minimum latitude of 7.4°N on December 3. Only Typhoon Louise of 1964 came closer to the equator at this strength, at 7.3°N (Wunderground, 2012). Bopha made landfall late on December 3 on Mindanao, an island that had been devastated by Tropical Storm Washi in December 2011. The storm caused widespread destruction on Mindanao, affecting over 6 million people and causing more than 800 fatalities. After hitting Davao Oriental and Compostela Valley provinces, Typhoon Bopha crossed the southern and central regions of Mindanao, cutting power to two provinces and triggering landslides. Bopha resulted in close to one billion USD in damages, making it one of the costliest disasters ever to hit the Philippines.

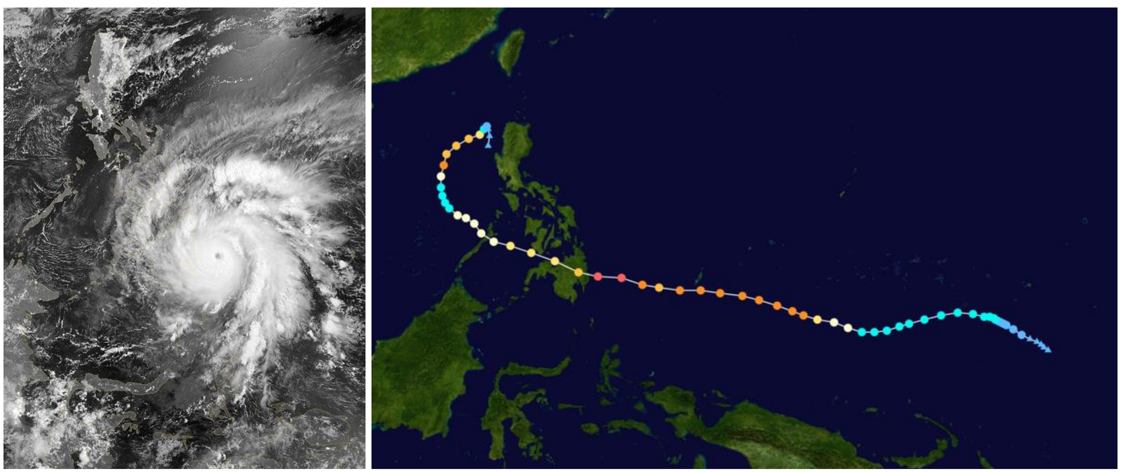


Figure 31. Typhoon Bopha (2012) Satellite Image and Track (Source: Wikipedia)

4.2.4 Tropical Cyclone and Flood Consequence Summary

This section outlines key statistics of the consequence database, with the main intent of providing a summary of the reported consequence of tropical cyclone and flood events. The consequence database contains 521 entries, dating from 1905 to 2013. Of these entries, close to 400 events are defined as catastrophic, i.e., those reported with at least 10,000 people affected, at least 10 million USD (non-trended) in losses, or at least 10 deaths. About 30% of the entries are classified as flood-only events, while the rest are classified as tropical cyclone events (with or without flooding). About 85% of the tropical cyclone events have an associated IBTrACS Serial Number, from which the storm may be linked to the Tropical cyclone Historical Database (refer Section 3.2). Most of the storms without a serial number are too old, too new, or did not reach the required strength to be included in the Historical Database.

Table 10 and Table 11 list a summary of the tropical cyclone and flood events, respectively, in the consequence database. In total, it is estimated that tropical cyclone and flooding events in the Philippines have resulted in at least 38,000 lives lost and 10 billion USD in damages (non-trended values). Furthermore, more than 165 million people in the Philippines have been affected by tropical cyclones, floods, and secondary hazards; a significant number given that the total population in 2010 was about 92 million people. Based on the consequence database, the Philippines experience a significant tropical cyclone event about 7.5 times a year and a catastrophic tropical cyclone about 6 times a year. On average, tropical cyclone events result in about 1,000 lives lost and one billion USD in damage per year (trended 2012 values based on 1970 – 2010 data). Similarly, based on the consequence database, the Philippines experience a significant flood event about 5 times a year and a catastrophic flood event about 3 times a year. On average, flood events result in about 120 lives lost and 160 million USD in damage per year (trended 2012 values based on 1990 – 2010 data).

Figure 32 plots some of the most significant tropical cyclone events in the Philippines from 1951 to 2011 extracted from the consequence database, i.e. those that have reports of more than 500 deaths or economic losses of more than 100 million USD (non-trended), and those with known IBcTRACs Serial Numbers. Similarly, Figure 33 plots some of the most significant flood events in the Philippines from 1985 to 2008 extracted from the consequence database, i.e. those that have reports of more than 500 deaths or economic losses of more than 100 million USD (non-trended), and those with associated Dartmouth Flood Observatory Polygons. Note that the hashed areas represent the affected regions, and not necessarily the flood inundation extent.

It is important to note that while the data search for the consequence database was exhaustive for the data sources previously listed, data for each entry may not be entirely comprehensive, as some accounts of consequence may not have been recorded or reported. For example, quantitative data for economic loss and loss of life is reported for only about 68% and 83% of the database entries, respectively. Furthermore, the database can be considered approximately complete from the 1970s for tropical cyclone events and the 1990s for flood events. Nevertheless, the consequence database is a valuable tool as it provides details for specific significant events (which may be used for case studies or catastrophe model validation purposes) and offers a qualitative assessment of natural disaster consequence in the Philippines.

Table 10. Summary Data of Tropical Cyclone Events in the Consequence Database

Time period	Number of Events	Number of Catastrophic Events	Estimated Economic Damage (Current Million USD)	Estimated Economic Damage (Trended Million 2012 USD)	Estimated Deaths	Estimated Deaths (Trended 2012 Value)
Pre-1950s	12	10	10	N/A	2,858	N/A
1950s	8	8	50	N/A	2,023	N/A
1960s	16	14	112	4604	1,655	5,637
1970s	60	35	628	11258	3,402	8,471
1980s	59	48	1,996	14588	5,348	9,636
1990s	91	72	2,818	12276	9,851	14,613
2000s	85	76	1,881	3761	6,669	7,509
2010 – 2013	22	19	1,247	1326	2,866	2,898

Note: Trend factors may not be well suited for events prior to the 1990s

Table 11. Summary Data of Flood Events in the Consequence Database

Time period	Number of Events	Number of Catastrophic Events	Estimated Economic Damage (Current Million USD)	Estimated Economic Damage (Trended Million 2012 USD)	Estimated Deaths	Estimated Deaths (Trended 2012 Value)
1950s	3	3	N/A	N/A	194	N/A
1960s	2	2	N/A	N/A	62	206
1970s	14	7	249	7,396	845	2,123
1980s	19	13	61	457	866	1,640
1990s	33	24	816	2,878	1,121	1,585
2000s	61	33	155	297	718	807
2010 – 2013	36	24	325	364	440	447

Note: Trend factors may not be well suited for events prior to the 1990s

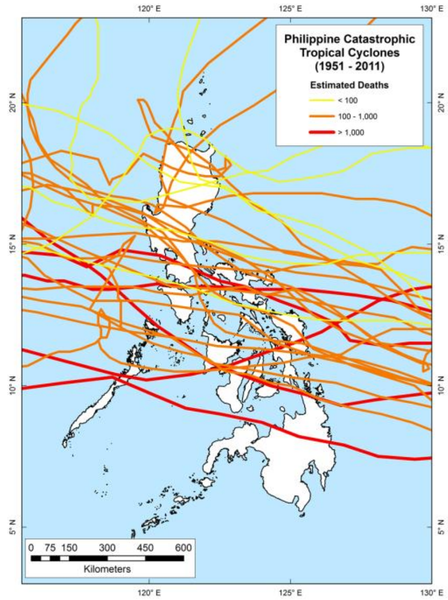


Figure 32. Tropical Cyclone Tracks of Significant Events in the Philippines Extracted from the Consequence Database

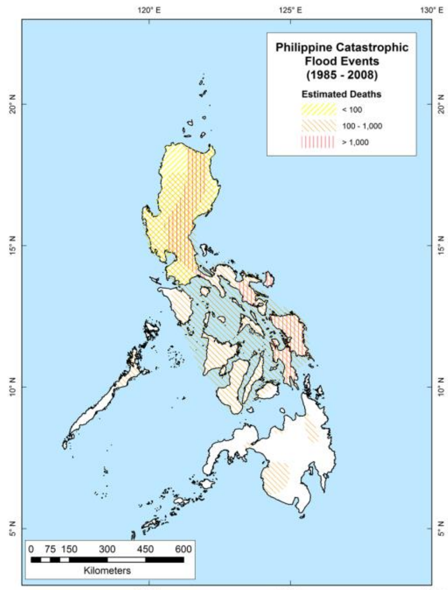


Figure 33. Affected Areas of Significant Flood Events in the Philippines Extracted from the Consequence Database

4.2.5 Landslide Events

The Philippines is comprised of numerous mountainous and hilly regions, which expose large population groups to potential landslides. For example, a massive rock slide occurred on February 17, 2006 in the Philippine province of Southern Leyte that resulted in more than 1,000 deaths (Red Cross, 2007). The deadly landslide followed a ten-day period of heavy rains. The increasing trends in annual and monthly rainfall intensities aggravate the severity of this problem. With the growth of population and informal settlements, especially around urban centers, large numbers of people are living on unstable landslide prone areas. In Metro Manila, almost 3 million people are living in informal settlements that are vulnerable to landslides (IRIN, 2010). Additionally, small-scale unregulated mining exacerbates the landslide risk through non-engineered tunneling, such as in the Compostela Valley in the Davao Region. An estimated 30% of recent landslides are due to a combination of heavy rain and unregulated mining (IRIN, 2010). The EMDAT database reports 30 significant mass movement events since 1980, which has resulted more than 2,600 deaths. The consequence database flags events with reports of significant landslides associated with tropical cyclone and flood events.

4.3 Consequence Metric Trending Methodology

Many of the consequence metrics, such as monetary loss, were reported in terms of values at the time the event occurred. Suggested trending factors are provided in the consequence database to convert consequence metrics to present day values, in order to help compare the impact of each event on an equivalent basis. The methodology used to develop these trending factors is described in this section.

Since monetary loss is usually reported in current (nominal) USD at the time of event, a macro-economic approach is used for the estimation of present-day losses due to exposure growth. The following equation has been used to adjust the historical event losses to the present-day losses:

$$L_{2012} = L_N \cdot \frac{Pop_{2012}}{Pop_N} \cdot \frac{GDP_{2012}}{GDP_N} \cdot \frac{DFL_{2012}}{DFL_N}$$

Where,

L_N = Reported contemporaneous loss at year N in USD
POP_N = National population at year N
GDP_N = Fixed real GDP per capita in local currency at year N
DFL_N = Local currency deflator at year N
N = year when the event occurred

In the above equation, the population growth approximates the increase in the number of assets over time. The real GDP per capita growth approximates the wealth increase over time (which is somewhat related to the material and labor costs). The GDP deflator (defined as the nominal GDP divided by the real GDP) approximates the inflation over time. The values of the parameters in the equation above were obtained from datasets issued by the World Bank (see Table 12). Note that economic data for the Philippines from the World Bank is not available prior to 1960.

Similarly, a population trend factor, which can be used to approximately trend consequence data such as buildings damaged/destroyed, and people affected/injured/killed, can be derived by taking the ratio of the population in 2012 over the population of the year of the event of interest.

Note that the trend factors provided herein should only be used as a proxy. There is very high uncertainty in the trend factors for events earlier than the 1990s using the approach provided herein. Other methods may be used to trend consequence data, such as the consumer price index (CPI) or alternative approaches (e.g., Neumayer & Barthel, 2011). In general, each event would need to be studied in detail to determine its impact if it were to occur today.

Table 12. Philippine Economic and Population Data from the World Bank and Representative Trend Factors

Year	GDP per capita (constant LCU)	GDP deflator	Official exchange rate (LCU per US$, period average)	Total Population	Economic Trend Factor	Population Trend Factor
1960	$ 30,567	1.70	2.01	26,010,295	37.76	3.71
1961	$ 31,224	1.75	2.02	26,893,021	34.79	3.59
1962	$ 31,646	1.87	3.73	27,800,656	57.38	3.47
1963	$ 32,788	2.03	3.91	28,727,140	51.78	3.36
1964	$ 32,847	2.12	3.91	29,664,173	47.89	3.25
1965	$ 33,512	2.21	3.91	30,606,162	43.74	3.15
1966	$ 33,947	2.32	3.90	31,551,090	39.68	3.06
1967	$ 34,709	2.37	3.90	32,501,839	36.94	2.97
1968	$ 35,378	2.52	3.90	33,463,836	33.08	2.88
1969	$ 35,971	2.67	3.90	34,444,983	29.85	2.80
1970	$ 36,265	3.07	5.90	35,451,392	37.83	2.72
1971	$ 37,151	3.52	6.43	36,485,095	34.16	2.64
1972	$ 38,068	3.74	6.67	37,545,635	31.57	2.57
1973	$ 40,296	4.38	6.76	38,633,697	25.10	2.50
1974	$ 40,559	5.80	6.79	39,749,340	18.36	2.43
1975	$ 41,618	6.34	7.25	40,892,836	16.99	2.36
1976	$ 44,022	6.87	7.44	42,064,468	14.80	2.29
1977	$ 45,198	7.44	7.40	43,265,378	12.88	2.23
1978	$ 46,219	8.13	7.37	44,497,521	11.15	2.17
1979	$ 47,476	9.34	7.38	45,763,245	9.20	2.11
1980	$ 48,540	10.67	7.51	47,063,923	7.80	2.05
1981	$ 48,817	11.92	7.90	48,399,114	7.10	1.99
1982	$ 49,193	12.96	8.54	49,767,259	6.81	1.94
1983	$ 48,745	14.80	11.11	51,166,963	7.62	1.89
1984	$ 43,947	22.69	16.70	52,596,291	8.06	1.83
1985	$ 39,638	26.69	18.61	54,052,849	8.23	1.78
1986	$ 39,897	27.48	20.39	55,537,110	8.47	1.74
1987	$ 40,516	29.54	20.57	57,046,529	7.62	1.69
1988	$ 42,126	32.39	21.09	58,572,071	6.68	1.65
1989	$ 43,601	35.32	21.74	60,102,139	5.94	1.61
1990	$ 43,812	39.90	24.31	61,628,668	5.71	1.57
1991	$ 42,511	46.49	27.48	63,146,876	5.57	1.53
1992	$ 41,657	50.18	25.51	64,659,225	4.78	1.49
1993	$ 41,565	53.61	27.12	66,173,874	4.66	1.46
1994	$ 42,409	58.96	26.42	67,703,053	3.95	1.42
1995	$ 43,398	63.41	25.71	69,255,386	3.41	1.39
1996	$ 44,913	68.27	26.22	70,831,419	3.05	1.36
1997	$ 46,201	72.52	29.47	72,427,130	3.07	1.33
1998	$ 44,933	88.75	40.89	74,040,838	3.51	1.30
1999	$ 45,321	94.60	39.09	75,669,587	3.05	1.27
2000	$ 46,316	100.00	44.19	77,309,965	3.12	1.25
2001	$ 46,658	105.55	50.99	78,964,389	3.32	1.22
2002	$ 47,360	109.94	51.60	80,630,416	3.11	1.20
2003	$ 48,709	113.46	54.20	82,293,990	3.02	1.17
2004	$ 50,954	119.72	56.04	83,936,698	2.77	1.15
2005	$ 52,384	126.70	55.09	85,546,427	2.46	1.13
2006	$ 54,137	132.97	51.31	87,116,275	2.07	1.11
2007	$ 56,719	137.08	46.15	88,652,631	1.69	1.09
2008	$ 58,078	147.43	44.32	90,173,139	1.45	1.07
2009	$ 57,765	151.52	47.68	91,703,090	1.50	1.05
2010	$ 61,135	157.91	45.11	93,260,798	1.27	1.03
2011	$ 62,459	164.32	43.31	94,852,030	1.13	1.02
2012	$ 63,812	170.98	41.59	96,470,412	1.00	1.00

5. Ancillary GIS Data

To enable modeling of hazard and risk assessment for earthquakes, tropical cyclones, and floods, several geo-referenced datasets are needed. The scope of the data collected within the Component 1 task is consistent with data collected from local technical agencies and with publically available information that informs the catastrophe model development. The final catastrophe model used for the loss and risk calculations may use additional datasets, such as those that are proprietary to AIR Worldwide or not suitable for dissemination (e.g., internal model working files), which are not discussed herein. In particular, the focus of this section is to discuss the data that was collected and organized, such as:

1. Country Administrative Boundaries
2. Surface geology
3. Soil Maps
4. Shear Wave Velocity Maps (Vs30)
5. Seismic source zones
6. Active earthquake faults
7. Topography
8. Land use/land cover (LULC)

The country administrative boundaries are, of course, the building block of any hazard and risk assessment for a sovereign country, and from which the loss results and other information of the model can disaggregated. Vs30 maps and, to some extent, surface geology and soil maps, are needed to develop relationships for the amplitude and the frequency content of earthquake ground shaking. The seismic source zones and active earthquake faults inform the location and frequency of earthquakes. Topographic maps are important inputs to the tropical cyclone and flood models. The LULC maps are useful to compute surface roughness, which is influential in estimating wind speed at surface generated by tropical cyclones, and the amount of precipitation runoff which is necessary for estimating runoff flood risk.

Besides those mentioned above, many other datasets are collected from external sources and processed in-house or produced within the project. The datasets pertinent to the development of exposure databases and vulnerability will be discussed in the Component 2 report.

5.1 Country Administrative Boundaries

The administrative boundaries of the Philippines were acquired from the GADM database of Global Administrative Areas (Version 2.0, issued December 2011). The main source of information of this dataset is from the Philippine Ministry of Agriculture. The data is provided in GIS vector format.

The Philippines is divided into four administrative levels, from the highest division to the lowest:

1. Region (Rehiyon)
2. Province (Probinsya/Lalawigan)
3. Municipality/City (Munisipalidad/Bayan / Siyudad/Lungsod)
4. Village/Neighborhood (Barangay)

As of June 30, 2012, the Philippine National Statistical Coordination Board indicates there are 17 regions, 80 provinces (plus Metropolitan Manila, which is both a province and region), 1,634 municipalities/cities, and 42,027 Barangays. The GADM data contains 17 regions, 81 provinces (plus Metropolitan Manila), 1,647 municipalities/cities and 41,933 Barangays. The slight discrepancies in numbers are typically due to the recent changes in the administrative boundaries that occurred after the development of the GIS data. For example, Shariff Kabunsuan is included as a province in the GIS data, but was no longer correct after 2008.

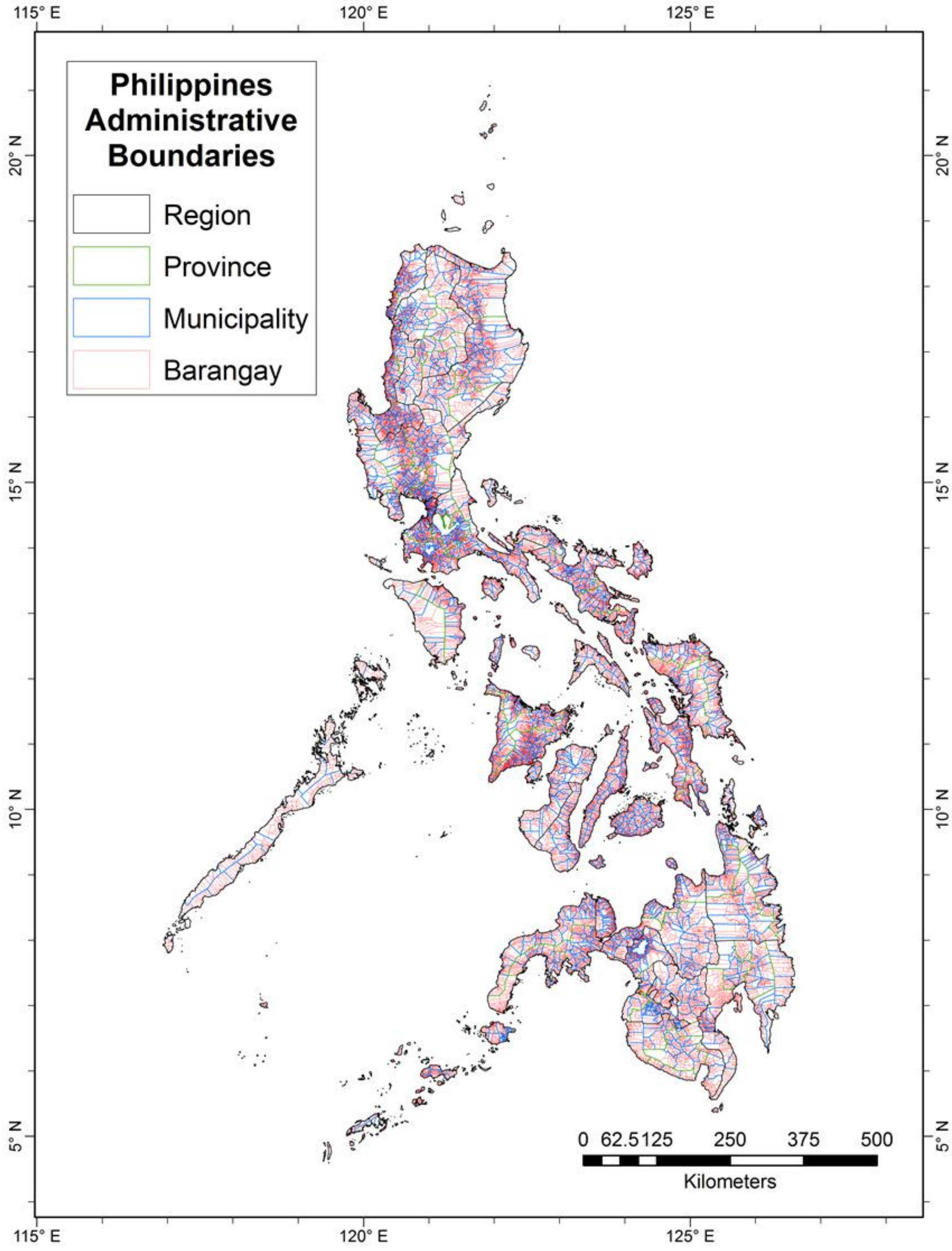


Figure 34. Philippines Country Administrative Boundary Map

5.2 Surface Geology

Geologic maps show the distribution of geologic features, including different kinds of rocks. Geologic maps are useful to infer the type, depth, and stiffness of soil sediments that may be present on some of these geologic units. Detailed geologic maps are, therefore, useful to inform the amount of amplifications that seismic waves may be subject to when filtered by these soil units. The geologic maps are sourced from the Philippine Mines and Geosciences Bureau (DENR-MGB). The data is provided in GIS vector format.

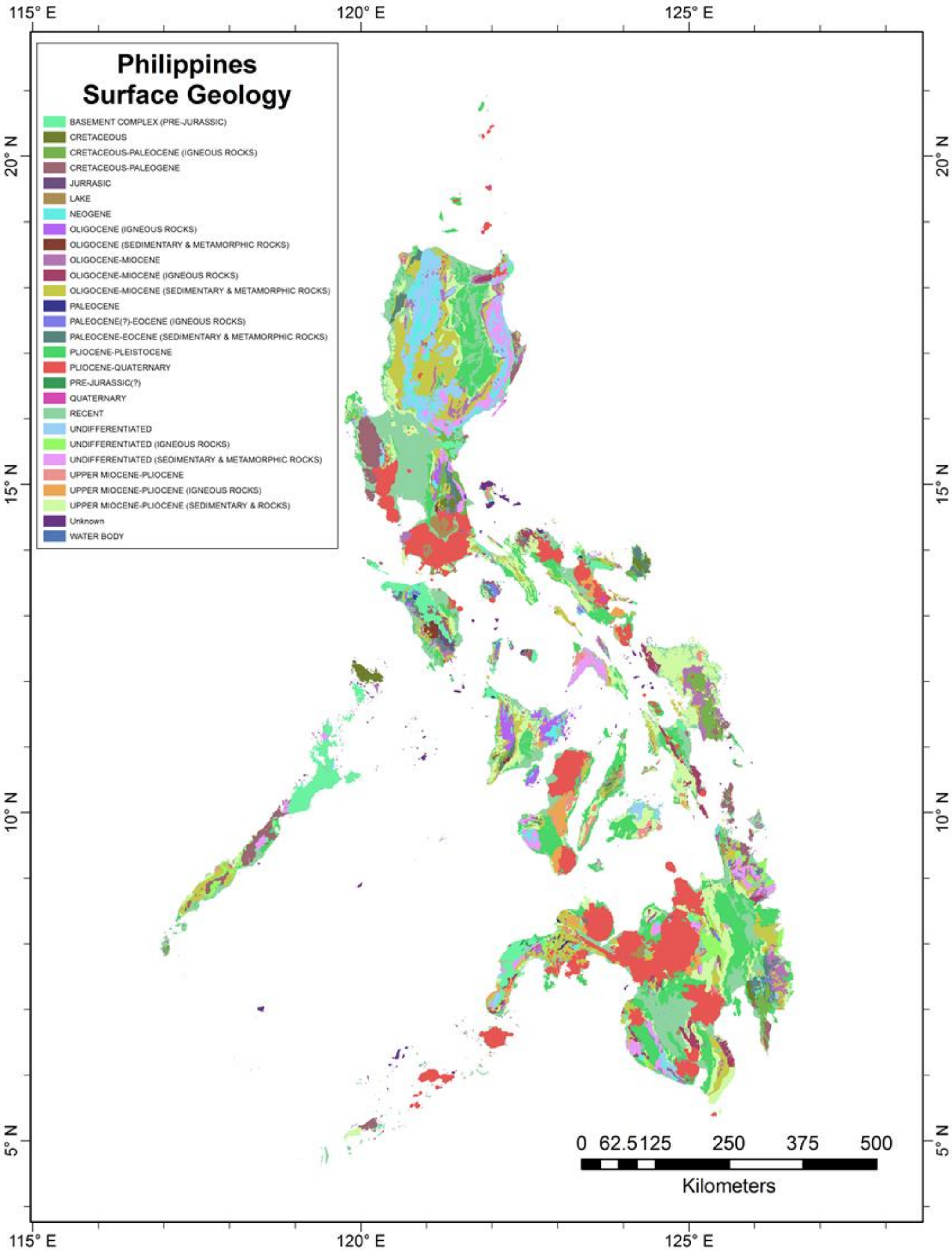


Figure 35. Philippines Surface Geology Map

5.3 Soil Maps

Similar to geologic maps, soil maps show the distribution of soils. Each color in a soils map represents a different soil classification. Soil maps are useful to infer the type, depth, and stiffness of soil sediments that may be present on some of these geologic units. Detailed soil maps are, therefore, useful to inform the amount of amplifications that seismic waves may be subject to when filtered by these soil units. In addition, soil maps can be used to infer properties of soil saturation for flood modeling. The soil maps are sourced from the Philippine Department of Environment and Natural Resources. The data is provided in GIS vector format.

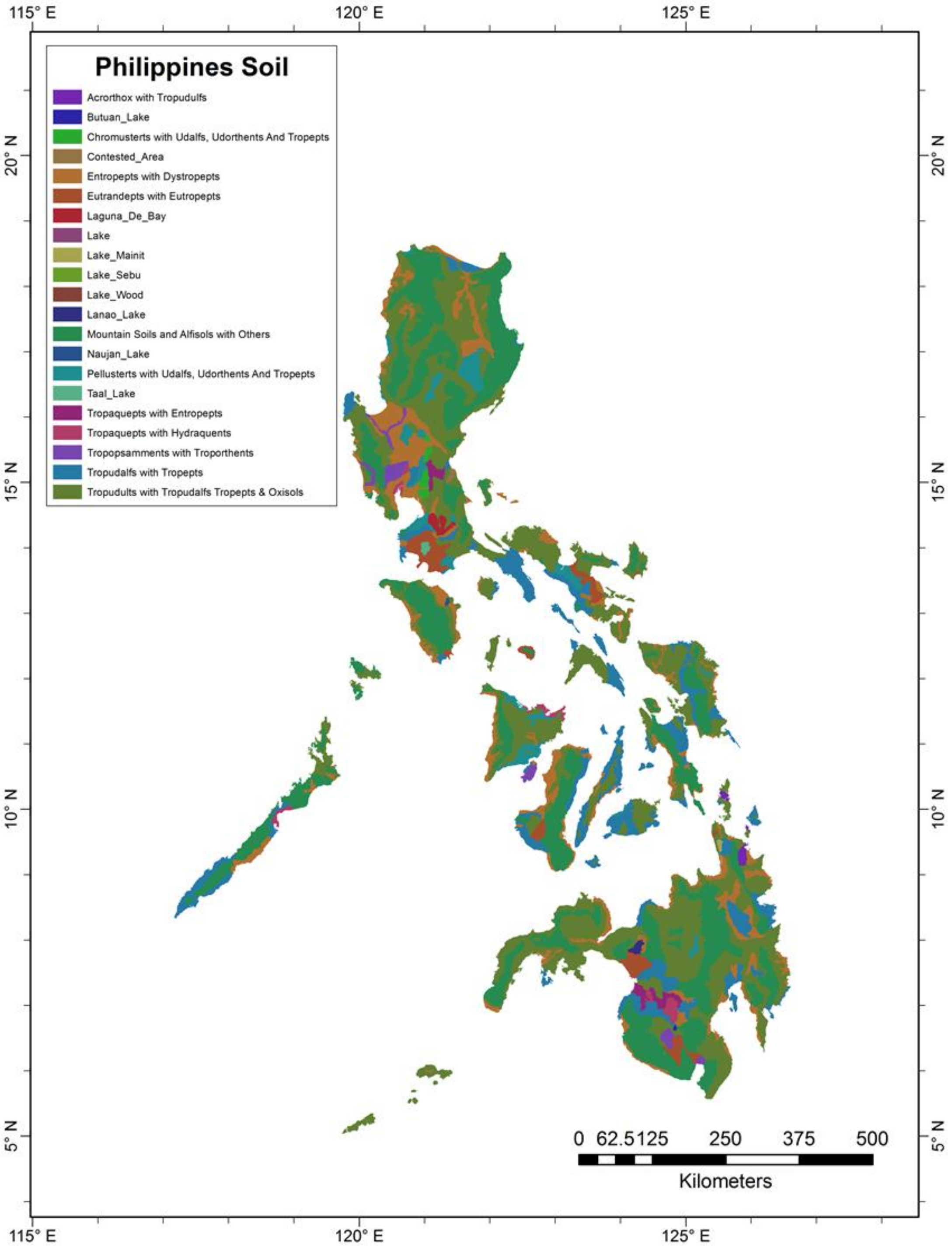


Figure 36. Philippines Soil Map

5.4 Shear Wave Velocity Maps (Vs30)

Country or regional scale site condition maps based on detailed surface geology maps for the Philippines are limited. Furthermore, existing microzonation maps are not always suitable for deriving surface site conditions in a consistent fashion. As such, it is customary to use the method developed by Allen and Wald (2009) which uses topographic data as a proxy for site conditions. The methodology by Allen and Wald circumvents this inconsistency problem and it is widely used for hazard and risk assessment purposes around the globe.

The shear wave velocity maps derived using this methodology show the shear wave velocity of seismic waves in the top 30 meters of soil, which is denoted as Vs30. High values of Vs30 (e.g., 760m/s or greater) refer to rock-type site conditions, which show no significant amplification of incipient seismic waves. Very low values of Vs30 (e.g., 180m/s or lower) refer to soft soil sites where significant soil amplification is expected. Average medium to stiff soil conditions have Vs30 values in the 300 to 500m/s range.

Although these maps are developed according to the current state-of-the-art approach it should be noted that in some cases discrepancies may be found between the values of Vs30 estimated by this method and those that may be measured in the field. If detailed surface geology maps at a regional scale, such as those customarily developed for micro-zonation studies, were to become available they could be used for earthquake ground motion assessment in lieu of those developed here.

The data is provided in GIS raster format at a resolution of 30 arc seconds (roughly one kilometer).

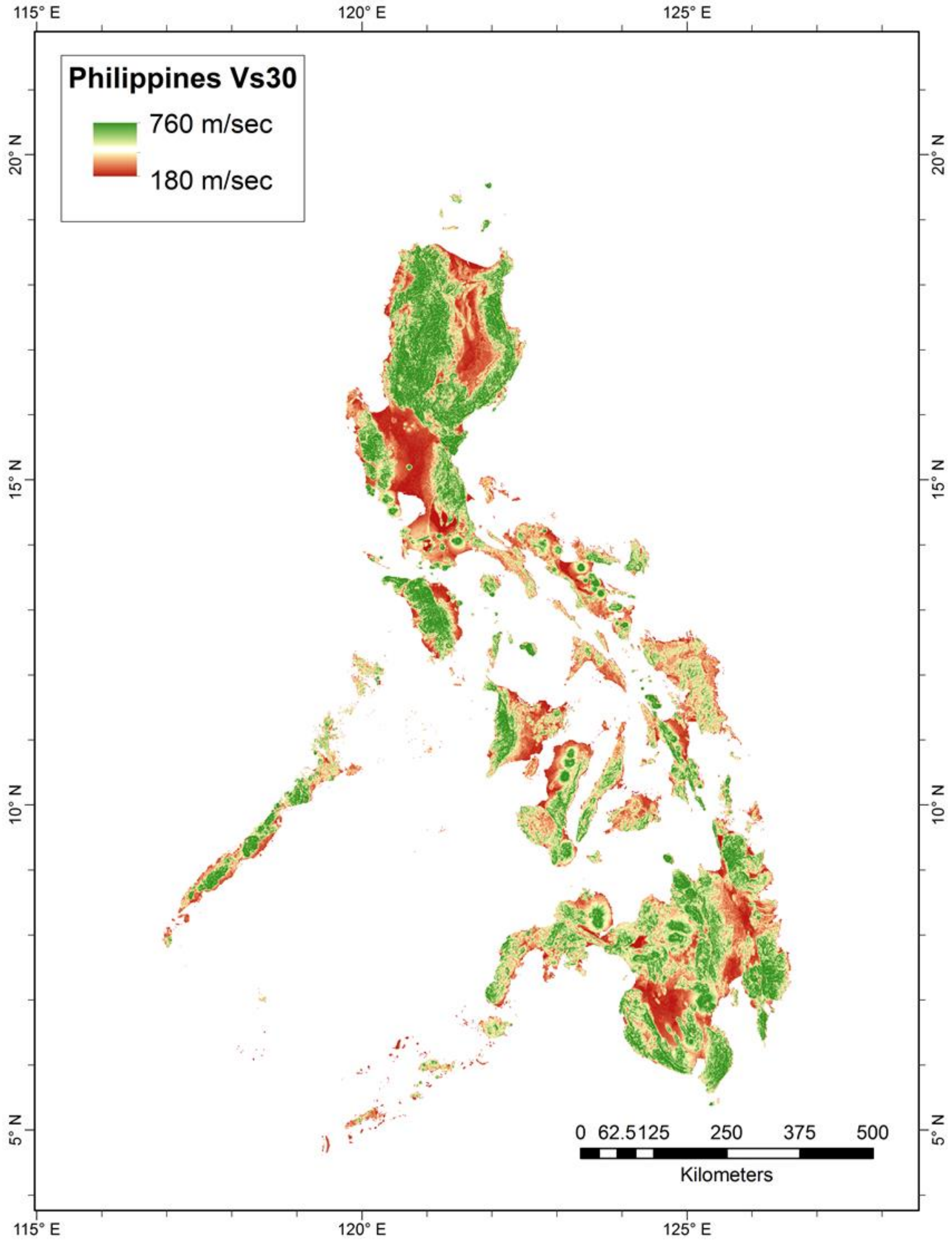


Figure 37. Philippines Vs30 Map

5.5 Seismic Source Zones

Seismic source zones for the Philippines, in which seismic activity can be treated approximately homogenous, was sourced from Torregosa et al. (2001 & 2002). Twenty seven source zones (see Figure 38) were designated by the spatial moving average method, which determines the occurrence rate of earthquakes with M_S greater than or equal to 4.0 within a 100 km radius to obtain the average number of occurrences per square kilometer at a given point. Polygons were drawn enclosing adjacent areas with nearly uniform occurrence rates. Linear regression analysis was done to obtain the b-value of each seismic source zone. The properties of each zone (occurrence rate, b-value, maximum magnitudes, and area) are given in Table 13. No seismic source zone was assigned to the western portion of the Philippines which historically has had very few, widely scattered earthquakes. Historical earthquake occurrence data for the determination of these seismic zones was obtained from the Philippine Institute of Volcanology and Seismology (PHIVOLCS).

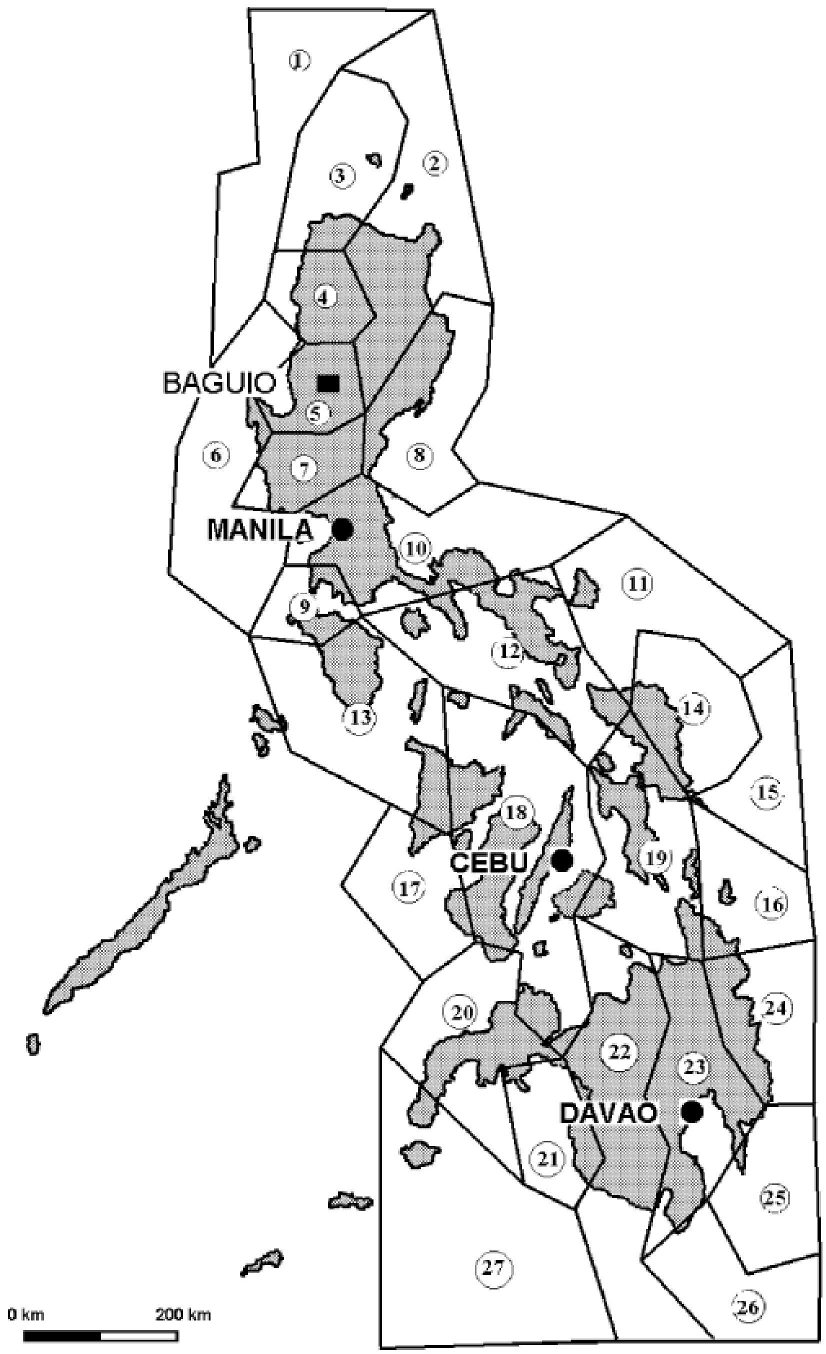


Figure 38. Seismic Source Zones in the Philippines (Source: Torregosa et al., 2002)

Table 13. Seismic Source Zone Parameters ($M_S \geq 4.0$) in the Philippines (Source: Torregosa et al., 2002)

zone	occurrence rate per sq. km.	b value	historical max. magnitude (Ms)
1	1.46E-05	0.940	7.3
2	1.49E-05	1.056	7.2
3	6.60E-05	1.571	6.9
4	2.94E-05	1.458	6.5
5	6.40E-05	1.431	6.6
6	1.33E-05	1.093	7.7
7	4.17E-05	1.215	7.8
8	5.96E-05	1.792	7
9	1.35E-04	1.489	7.7
10	6.37E-06	0.598	7.6
11	2.04E-05	1.217	7.1
12	1.23E-05	0.743	7.4
13	1.96E-05	1.043	8.3
14	8.10E-05	1.072	7.3
15	1.51E-05	1.939	6
16	1.38E-04	1.453	7.7
17	1.41E-05	1.353	6.3
18	6.28E-06	1.330	6.7
19	3.50E-05	1.210	7
20	1.17E-05	0.888	7.3
21	3.36E-05	1.074	7.9
22	1.26E-05	1.130	7.3
23	3.46E-05	1.429	7.4
24	1.04E-04	1.274	7.7
25	1.23E-04	1.301	7.3
26	3.24E-05	0.880	7.9
27	3.33E-06	1.111	6.5

5.6 Active Earthquake Faults

Information on fifty-nine active faults (see Figure 39) was sourced from Torregosa et al. (2001 & 2002), which were originally compiled from PHIVOLCS and the previous reports of Acharya (1980a), Knittel (1988), Barrier et al. (1991), and Sajona et al. (1993). The fault parameters are given in Table 2. The relationship between maximum credible earthquake magnitude and fault rupture length is derived from Acharya (1980b). The recurrence times of expected maximum magnitudes were determined by the Slemmons (1978) method.

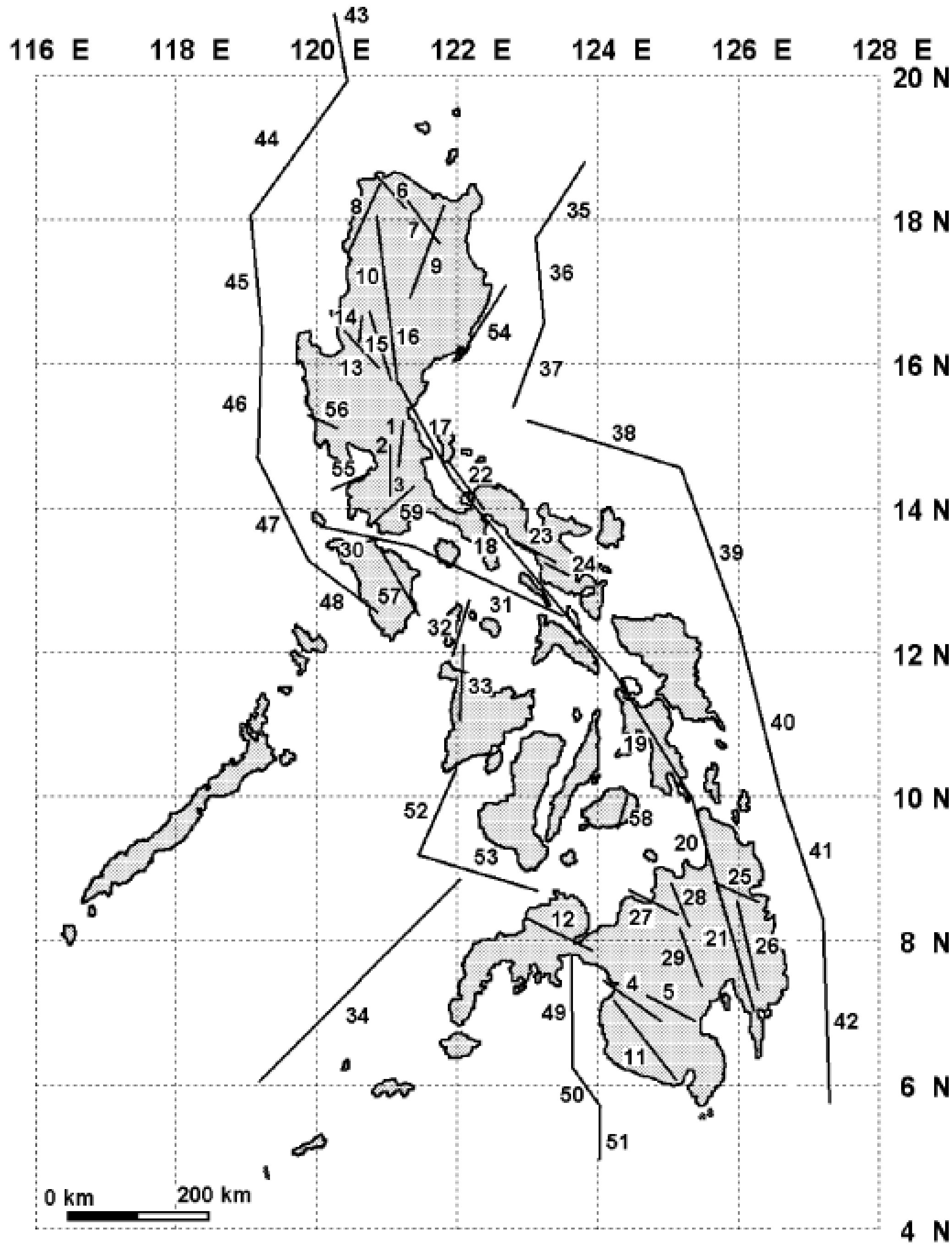


Figure 39. Philippine Active Earthquake Faults (Source: Torregosa et al., 2002)

Table 14. Philippine Active Earthquake Fault Parameters (Source: Torregosa et al., 2002)

Segment number	Fault	Length (km)	Rupture length (km)	Max expected magnitude	Occurrence rate per year
1	Marikina fault segment 1	70	35.2	6.3	1.82E-03
2	Marikina fault segment 2	80	40.1	6.4	1.43E-03
3	Marikina fault segment 3	80	40.1	6.4	1.43E-03
4	Cotabato fault segment 1	87	43.3	6.4	1.43E-03
5	Cotabato fault segment 2	108	54.0	6.6	1.11E-03
6	Abra1	144	71.8	6.8	8.33E-04
7	Abra2	144	71.8	6.8	8.33E-04
8	Abra3	128	64.0	6.7	1.00E-03
9	Abra4	152	75.9	6.9	5.56E-04
10	Abra5	144	71.9	6.8	8.33E-04
11	Mindanao1	168	84.1	6.9	5.56E-04
12	Mindanao2	116	57.8	6.7	1.00E-03
13	Phil. FaultLuzon 1	77	38.5	6.3	1.82E-03
14	Phil. Fault Luzon 2	50	25.0	6.0	2.50E-03
15	Phil. Fault Luzon 3	113	56.4	6.6	1.11E-03
16	Phil. Fault Luzon 4	119	59.7	6.7	1.00E-03
17 - 21	Phil. Fault	1127	330.0	8.0	5.00E-03
22	Phil. Fault Bicol segment 1	122	60.9	6.7	1.00E-03
23	Phil. Fault Bicol segment 2	70	35.1	6.3	1.82E-03
24	Phil. Fault Bicol segment 3	51	25.7	6.0	2.50E-03
25	Phil. Fault Surigao segment	75	37.6	6.3	1.82E-03
26	Phil. Fault Davao segment	143	71.5	6.8	8.33E-04
27	Cental Mindanao Fault segment 1	92	46.1	6.5	1.25E-03
28	Cental Mindanao Fault segment 2	73	36.3	6.3	1.82E-03
29	Cental Mindanao Fault segment 3	95	47.6	6.5	1.25E-03
30	Lubang/Verde Passage Fault	152	75.8	6.9	5.56E-04
31	Sibuyan Sea Fault	240	120.2	7.2	5.00E-04
32	Tablas Fault1	107	53.7	6.6	1.11E-03
33	Tablas Fault2	121	60.5	6.7	1.00E-03
34	Sulu Trench	535	118.7	7.2	6.67E-04
35 - 38	East Luzon trench	530	117.2	7.2	6.67E-03
39 - 42	Philippine Trench	1258	388.2	8.1	6.67E-03
43 - 48	Manila Trench	1042	294.5	7.9	5.00E-03
49 - 51	Cotabato Trench	320	62.7	6.7	1.00E-03
52 - 53	Negros Trench	336	66.5	6.8	8.33E-04
54	Casigura Fault	134	66.8	6.8	8.33E-04
55	Manila Bay Fracture Zone	59	29.6	6.1	2.50E-04
56	Iba Fracture ZoneAcharya	50	25.0	6.0	2.86E-04
57	Mindoro faullt	114	56.8	6.6	1.11E-03
58	Bohol fault	52	25.8	6.0	2.50E-03
59	Taal Fracture Zone	85	42.7	6.4	1.43E-04

5.7 Topography

Topography data was provided by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2), which was released on October 17, 2011 by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). This dataset covers the entire domain of the Philippines and has a horizontal resolution of 1 arc second (roughly 30 meters) and a vertical resolution of one meter (e.g., integer value). The data is provided in GIS raster format. Note that the topography data may contain rare instances of spurious values (e.g., voids and spikes).

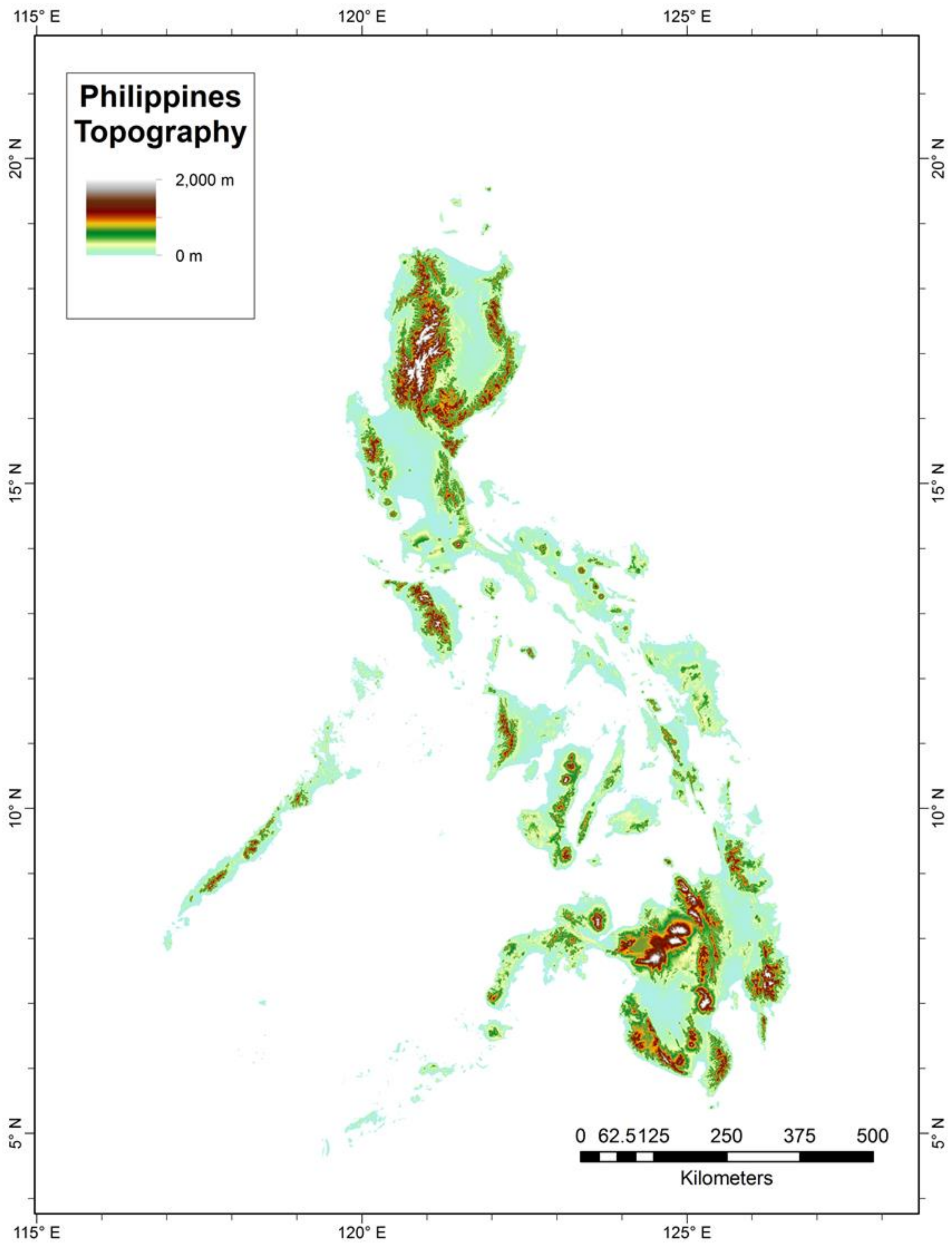


Figure 40. Philippines Topography Map

5.8 Land Use / Land Cover (LULC)

Land Use / Land Cover (LULC) maps are useful to determine surface roughness factors and precipitation runoff percentages, among other things. Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures. Land use is a more complicated term, and usually refers to signs of human activities such as agriculture, forestry and building construction that altered the original land surface processes. The land use / land cover (LULC) maps are sourced from the Philippine Department of Environment and Natural Resources (2008). The data is provided in GIS vector format.

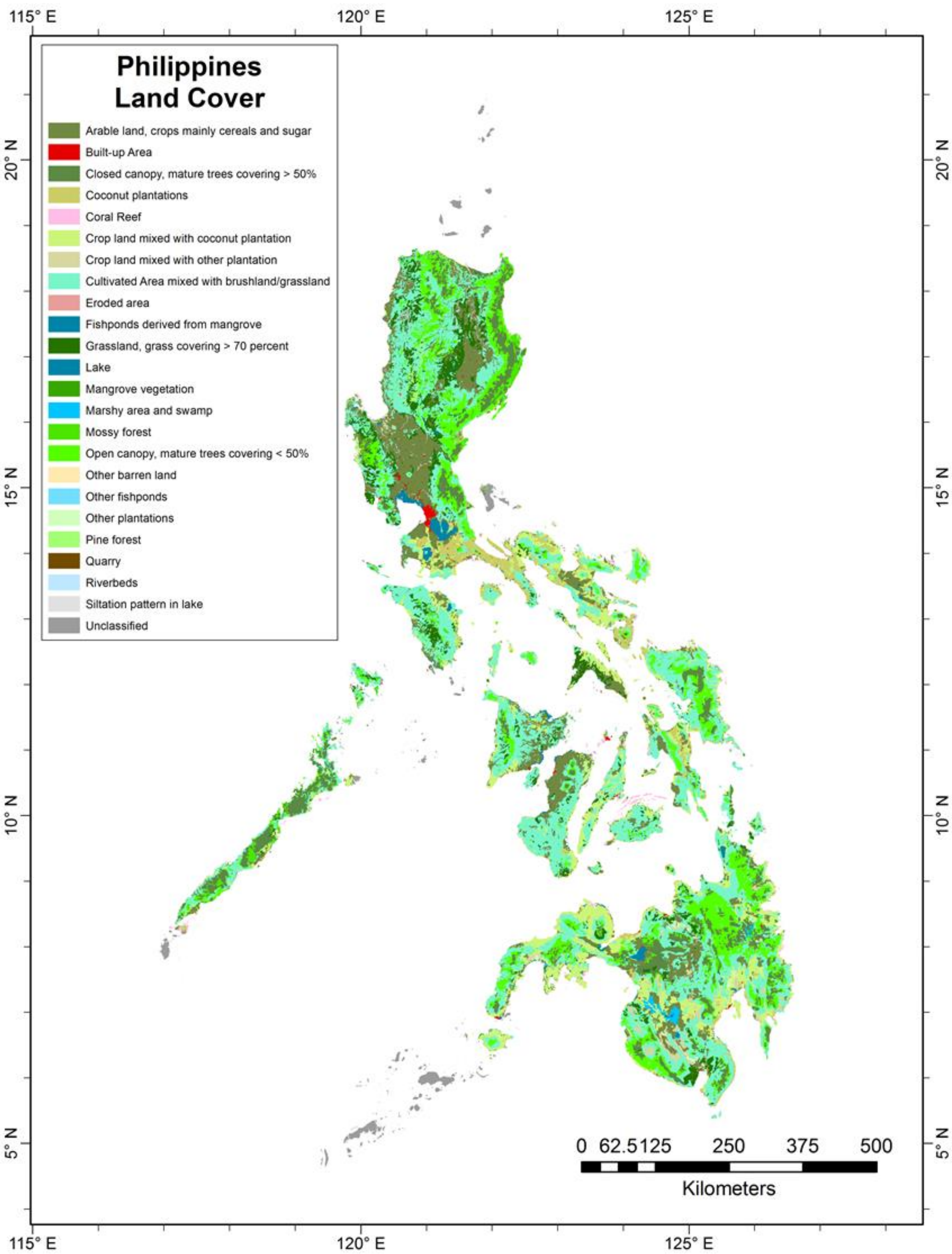


Figure 41. Philippines Land Use / Land Cover Map

6. Reporting/Monitoring Agencies

For implementation of some risk mitigation strategies (e.g., catastrophe bonds) it is necessary that reputable and reliable organizations are selected to report the occurrence and the characteristics of large natural events that may impact the countries at stake.

There are several organizations in the world at large and in the region which could serve as official reporting agencies. For example, some organizations with in-depth knowledge of the tropical cyclone activity in the Pacific (both hemispheres) are:

- Joint Typhoon Warning Center (JTWC)
- Japan Meteorological Agency (JMA)
- Shanghai Typhoon Institute
- Philippine Atmospheric, Geophysical and Astronomical Services Administration (PASAGA)

and for earthquakes are:

- United States Geological Service (USGS)
- International Seismological Centre (ISC)
- Philippine Institute of Volcanology and Seismology (PHIVOLCS)

The criteria that were used to select the reporting/monitoring organization for the purpose of this project are as follows (note that no final decision is being made on the selection of the reporting agency at this time):

- Independency (i.e., the organization should not have any real or perceived conflict of interest with the economic or political environment in the region)
- Dependability
- Accuracy
- Uniformity across regions of the world

In the past, AIR has identified the **United States Geological Survey** (USGS) as the primary source for the earthquake event characteristics and the **Joint Typhoon Warning Center** (JTWC) for tropical cyclone characteristics in the region.

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Note: All webpages accessed February 2013

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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.