Residential Building Suitability Map for Leyte Island, Philippines
Imprint

As a federally owned enterprise, we support the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Items from the named author does not necessarily reflect the views of the publisher.

Published by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany
T +49 228 44 60-0 (Bonn)
T +49 61 96 79-0 (Eschborn)

Responsible
Max-Johannes Baumann
Environment and Rural Development Program
Program Director and Principal Advisor

2/F PDCP Building, Rufino cor. Leviste Streets, Salcedo Village, Makati, Philippines
T +63 2 892 9051
I: www.enrdph.org
E: max.baumann@giz.de

Source and Copyrights
© 2015 GIZ

Author
Olaf Neussner of Arken Consulting

Arken Consulting GmbH
Ackerstr. 11b
10115 Berlin, Germany
Phone: +49 -30 - 200 541 51
berlin@arken-consulting.com
www.arken-consulting.com

Layout / Design
Ryan G. Palacol

Copyright on Photos
The photos in this publication are owned by GIZ unless otherwise indicated on the photo

Maps
The geographical maps are for information purposes only and do not constitute recognition under international law of boundaries and territories. GIZ does not guarantee in any way the current status, accuracy or completeness of the maps. All liability for any loss or damage arising directly or indirectly from their use is excluded.

Printed and distributed by
Environment and Rural Development Program
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Place and date of publication
Manila, Philippines
September 2015
Table of Contents

Acronyms & abbreviations ................................................................. ii
Summary ......................................................................................... iii
Acknowledgement ........................................................................ iv

1 Top reasons to use building suitability maps ........................................ 1
2 Actual benefits and gains .................................................................. 2
3 Success factors ................................................................................ 12
4 Obstacles and limitations .................................................................. 14
5 Development of suitability maps ........................................................ 16
  5.1 Typhoon (Wind hazard) ................................................................. 22
  5.2 Storm Surge .............................................................................. 27
  5.3 Earthquakes ............................................................................... 32
  5.4 Tsunami ..................................................................................... 40
  5.5 Flood ........................................................................................ 43
  5.6 Landslide .................................................................................. 46
  5.7 Ground Rupture ......................................................................... 48
6 Appendix: Data sources .................................................................... 51
7 Literature ......................................................................................... 52
Acronyms & Abbreviations

CAPRA
DEM
GIS
GIZ
JICA
LGU
MGB
MMI
NOAH
PGA
PEIS
PHIVOLCS
SRTM
SSA
USGS
WS

Probabilistic Risk Assessment Program
Digital Elevation Model
Geographic Information System
Deutsche Gesellschaft für Internationale Zusammenarbeit
Japan International Cooperation Agency
Local Government Unit
Mines and Geosciences Bureau
Modified Mercalli Intensity
National Operational Assessment of Hazards
Peak Ground Acceleration
Philippine Earthquake Intensity Scale
Philippine Institute of Volcanology and Seismology
Space Shuttle Radar Topographic Mission
Storm Surge Advisory
United States Geological Survey
Wind Speed
Summary

After typhoon Haiyan (local name Yolanda) struck the Philippines in November 2013 discussions evolved around the question “where is it safe to build and where is it not?” Hazard maps were consulted and it quickly became clear that they do provide only part of the information needed. What the maps didn’t provide was the likelihood or probability of the occurrence of a certain type of hazard in a certain area. This is crucial information to assess if and how often of a certain hazard might happen in a certain area. GIZ addressed this need by developing a map that integrated different hazards and the probability of their occurrence. With this map land use planners are able to quickly assess the risks for normal residential buildings anywhere in Leyte as well as to assess risks for future projects and structures. For example, the map shows that some areas have 5% or more expected annual damage. This means statistically the value of a residential building is wiped out in 20 or less years by the accumulated damages it sustains.

The production of the map included a survey of available hazard and vulnerability related information and data. The most reliable and appropriate sources were chosen and processed in a Geographic Information System. The first version of the map was provided to Local Government Units in Leyte in the middle of 2014. This second version includes a lot of improvements, such as one more hazard and more details.

The map reveals big differences in the risk level of different areas. The flat coastal areas in the east of the island are more exposed to severe coastal hazards (storm surge and tsunami) than other coasts and with this they are the most dangerous spots in Leyte. Contributing to this is also the earthquake and the storm hazard. Both are more severe in the north east than the south west of the island. Some areas are facing relatively low risk levels. This applies to some spots with only ground shaking and storm as possible hazards.
Acknowledgement

GIZ’s work on risk maps for Leyte started in 2008 and was inspired by University of Twente (ITC) Associate Professor Norman Kerle, who introduced the concept back then to the author.

A number of German geographers contributed their skills and knowledge to the development of various approaches over the years, namely Katharina Wilkin, Benedikt Hahn, Hannah Fuchs, and Henning Goetz. However, the bulk of the GIS-related work for the building suitability map was done by Bastian Schneider, partly in night shifts because of the slow computers. GIS and other data were kindly provided by PHIVOLCS (Dr. Leonida Bautista), Project NOAH (Prof. Dr. Mahar Lagmay), and Weihua Fang (Beijing Normal University).

Preparing the map was a team effort and without the contributions of each member the final result would not have been possible.

Last but not least Dolores Nuevas needs to be mentioned. She is a tireless promoter of the map in the Local Government Units of Leyte and Soutern Leyte.
Top reasons to use building suitability maps

- One map combines all important hazards and there is no need to consult many hazard maps for planning settlements.

- The suitability map includes the different probabilities of different hazards and thus weighs the hazards by their impact.

- The most detailed and reliable sources of information were chosen from many available sources.

- The suitability map shows quantitative data (percent damage per year). This is a sound foundation for judging the acceptability of the risk.
Land use planners have to take into account many factors when they consider future spatial developments. One of them is the threat posed by natural disasters. The standard method of assessing the danger level of locations is consulting hazard maps. In the Philippines, a relatively large number of hazard maps exist in various scales.

But for one, these maps often come in formats not suitable for spatial analysis (printed maps or pixel files) and it is extremely cumbersome to overlay the different hazards in GIS used by planners. Even if the hazard maps exist in GIS ready vector files, overlaying them results in a confusing multitude of hazards in most places.

Second, these maps do not weigh the hazards by importance. The current hazard maps rarely provide information needed to assess the relative importance of one hazard compared to another. They mostly show categories like “low, medium, high susceptibility” to a hazard, but it is often unclear what “low, medium, high” really mean.

GIZ addressed this issue by considering the frequency and intensity of major hazards in Leyte Island. This revealed that some hazards are much more important than others because they occur often with dangerous severity while others are rare and/or not very intense.

One of the main features land use planners are concerned with is where people shall reside and live. Typical residential houses in the Philippines in rural areas have one or two floors, are made of steel reinforced concrete columns and bricks (hollow blocks) as walls. Such houses have typical sensitivities to the forces of extreme natural events. Certain hazard intensities cause specific damages to buildings. Combining such vulnerabilities with the frequency and intensity of various hazards gives a good picture of the danger normal residential buildings are facing. The impact on the buildings can be expressed as the expected percent average damage per year (calculated in % of the value of the building?). These data are easily comparable and one can add the expected damages from different hazards easily.

The building suitability map shows the multi hazard impact on residential buildings and thus reduces the many hazard maps to one single map. Furthermore the suitability map displays quantitative data (percent annual damage) and thus gives concrete indications on the danger level in specific locations. In a GIS, the land use planner can also see the composition of the different risks. This helps to identify hazard specific counter measures (e.g. building elevated in flood prone areas). Furthermore, in GIS it is easy to display areas above and below user defined risk levels. The economic feasibility of such activities may be assessed with a cost-benefit-analysis.
One Single Map for Multiple Hazards

Obviously it is much easier consulting one map than many. GIZ did this by considering the severity and return period of major hazards. As landslides and ground rupture are hazards which, strictly speaking, do not return at the same place in the same manner, they are marked on the map but they are not part of the calculations. In total the risks for residential buildings caused by seven hazards are displayed on one single map.

Risk from seven hazards displayed in one map.

The risk is displayed as expected annual damage in percent of the value of the building.
Quantitative Data Display of Danger Level

The exposure to different natural hazards differs a lot. There are hazards expected only in specific locations (floods usually in planes or near rivers, tsunamis and storm surges in coastal areas and landslides in mountainous landscape) but other hazards cover large areas (storm, ground shaking...
caused by earthquakes). However, hazards also show strong local variations as valleys are to some degree protected from strong winds while mountain top edges experience higher wind speeds. The same is true for earthquakes. The actual ground shaking depends a lot on soil characteristics.

The resulting map enables house owners to see how dangerous a specific place is. This applies to plans for future settlements as well as to existing houses. This might be of interest for the insurance industry to determine premiums based on the level of exposure to risk.
User Defined Risk Levels

Risks caused by natural hazards can never be reduced to zero as no place on earth is absolutely free from all hazards, but what level of risk is acceptable, depends largely on individual perception. In some places in Leyte the value of a residential house may be completely gone by extreme events within 20 years (5% annual damage), while in other locations this may take more than 100 years (<1% annual damage). Local or national political decision-makers may define acceptable risk levels and produce maps showing areas below and above such risk threshold. The private sector may also find such maps helpful. Investors looking for relatively safe locations for a new subdivision (or a factory) can define a risk level and have all suitable areas displayed in one color and the too dangerous areas in another color.

IN THE AREA OF TANAUAN, TABON TABON AND TOLOSA IN LEYTE

These three maps show that places with less than 1% risk are very rare and relatively few locations have less than 2% risk, but most locations are exposed to less than 3% expected annual damage to residential buildings.

It is a political decision what level of risk is perceived to be acceptable with respect to land use planning. “No build zones” may be declared or “safe” areas for new settlements can be identified based on a certain risk threshold. Ordinances may also include mitigation and preparedness measures for zones. This could be ground shaking resistant design and construction obligations or higher and sturdier buildings in coastal areas faced by big ocean waves.

It is also an individual decision what type and level of danger is acceptable to a house owner and the value of property might be influenced by the exposure of a lot to different hazards.
Residential Building Suitability Map for Leyte Island, Philippines

2% Expected Annual Damage

3% Expected Annual Damage

NOTICE TO THE PUBLIC
3.0 METER EASEMENT ALONG WATERWAYS IS A "NO BUILD ZONE"
PD 1067
Display of the Contribution of Different Hazards to the Total Risk

Though the risk to damages is displayed as a single value for a particular spot or area, it is possible to see the contribution of different hazards to the total hazard. In the example shown below two small areas are displayed with the composition of their risk data. The point on the east is a the coast and typical coastal hazards contribute most of the risk, while further to the west, tsunami and storm surge are less important. With GIS software the values for any point may be retrieved.
Cost Benefit Analysis

The building suitability map provides an easy way of calculating counter measures to reduce the impact of hazards.

EXAMPLE

A house will be located in an area where the expected annual damage from floods is 0.9%. The cost of elevating the building above the maximum flood level is estimated at 15% of the value of the residential building. The costs for building elevated (e.g. on stilts) will be recovered by savings from avoided damages after almost 17 years (15% / 0.9%/year = 16.7 years).

EXAMPLE OF A COST BENEFIT ANALYSIS OF FLOOD PROTECTION MEASURE

0.9% flood damage per year based on the value of the house.

0.0% flood damage per year based on the value of the house.

0.9% in 17 years accumulates to 15.3% of the value of the house.

In 17 years break even is reached and the costs for the elevation are recovered.
In November 2013 typhoon Yolanda (international name Haiyan) crossed the Philippines, killed thousands, and damaged and destroyed countless buildings. This disaster highlighted the need to “build back better”, which, among other considerations, also means building in better or safer places. Political decision makers, land use planners and last not least the affected population recognized the importance of risk information for decisions on where future settlements should be located. So, people were looking for simple maps and the building suitability maps developed by GIZ provided the needed information.

In the aftermath of the Yolanda disaster, planners wanted to identify relocation sites for families displaced by the storm. With the destruction of homes fresh in their minds one major consideration was the safety of the resettlement areas. In this situation, the risk awareness and the openness to use new methods to provide information on the danger level in potential new settlement sites was high.

Most LGUs in Leyte are familiar with using GIS software and have them installed on their computers. This enables the municipal planners using the building suitability map with any overlay the planners may find interesting. For example a layer displaying the land ownership might contribute to the decision on the location of a new resettlement site.
Although the suitability map displays more and less hazardous places and gives a composite of hazards to be expected in these places, some limitations and considerations have to be kept in mind. It is essential to use common sense while working with the maps, no map is perfect and one should never blindly rely on a map only.

The final building suitability map is only as good as the input data. Hazard mapping in Leyte is still ongoing and improving, as new methods are developed and more and more data are available. However, currently there is still a lack of some datasets and it is expected that the building suitability map can be improved at a later stage when more and better data are available.

The suitability map is a simplified and generalized model. It is a great tool and helps in land use planning, but it will never be a perfect display of reality. Continuous work on hazard mapping, vulnerability data and the resulting risk maps will ensure that the maps are improved and kept up to date.

Generally, the documentation of historic disasters and extreme natural events in Leyte is far from perfect and this lack of detailed data of past events is a limitation in predicting the intensity and frequency of future events. This applies especially to infrequent hazards with very limited written accounts of the few events which happened within the last centuries.

Landslides and ground ruptures lack proper return periods and were not included in the probabilistic calculations of the risk. They are displayed on the map without a corresponding risk value.

The building suitability map includes the major hazards important for risk estimations, but other unlikely hazards were not included at all. This applies, among others, to volcanic eruptions, liquefaction, and forest fires.

The standard residential building used for vulnerability estimations is not clearly defined in technical terms. This means that the vulnerability curves used are not perfectly applying to the standard building. Available data may be based on global building categories and thus the curves apply to slightly different buildings. The most suitable model was chosen for all hazards.

As of now, the suitability map focusses on the standard building. This is just a simplified approach, as it excludes other building types such as wooden huts or multi-story reinforced concrete buildings. They will show significantly other annual damage characteristics due to different vulnerabilities towards hazards. By implementing different hazard curves, maps for other buildings can be easily created.

It is important to keep the map updated regularly and include new insights and methods in future versions. This will ensure the best possible accuracy and will help to keep the building suitability map as an easy to use and useful tool in many spatial planning disciplines.

This report explains how the building suitability map was produced and how it may utilized. It does not recommend where to build or not and it does not aim to list options on how to prevent or mitigate damages for buildings.
Development of suitability maps

The Philippines is one of the countries most prone to natural hazards worldwide. Natural hazards including typhoons, storm surges, earthquakes, floods, landslides, active volcanism, tsunamis and others afflict the country regularly. Furthermore, the Philippines is a country with a dynamic and fast growing population and economy. The country’s geography however, limited by steep mountains ranges and flood-prone low lands, restricts settlement in many places as they are located in hazardous areas. Settlements often occur uncontrolled and spontaneous and land use planning is still underdeveloped in many areas. The building suitability map aims to integrate hazard and vulnerability information and display the result on a simple and easily understandable map.

For some hazards and vulnerabilities a spectrum of different data sources is available and an assessment of the data quality and to what extent they may be used was needed. For some hazards it was difficult to find quantitative data at all.

Different hazards impact buildings in different ways and it is obvious that qualitative hazard data are difficult to compare. A “medium” landslide hazard does not mean the same damage to a house as a “medium” flood hazard. A scale is needed that is able to compare different hazards. The degree of damage to buildings caused by a hazard event of a specific severity is a good way of making hazards comparable. If return periods (or probabilities) of hazards with certain severities are considered one can calculate the expected damage to a building. The temporal reference used is a year. This means the risk is expressed in expected annual damage in percent of the value of the building.

The final building suitability map displays the aggregated average annual damage which can be expected at each site and how it is composed from the numerous hazards.

The concept of multi-hazard suitability mapping is based on the classical risk equation:

\[
\text{Risk} = \text{Hazard} \times \text{Vulnerability}
\]

This implies knowledge about the extent of hazards and the vulnerability of assets towards these hazards. In order to calculate expected annual damage of a building, it is important to know how many and how strong hazard events are to be expected in a certain period of time.

Weak events are usually much more frequent than devastating events (compare figure 1). For example:

- Storms occur in Leyte every year, while a super typhoon is a much rarer event
- Small (and often for humans insensible) earthquakes are very common, while strong earthquakes leading to wide-spread damage have long return periods

It is therefore important to know the return periods of a natural hazard event of a certain magnitude.
RELATION BETWEEN THE FREQUENCY AND SEVERITY OF A NATURAL HAZARD
In order to be able to calculate the expected effects of hazards they were divided into five categories ranging from frequent/low severity to rare/high intensity.

CATEGORIES OF HAZARD SEVERITY
Most of the utilized hazard maps differed slightly in spatial extend. This is especially evident at the coastline. One of the most up to date coastlines is provided by the Project NOAH in 2015. Other hazard maps were adjusted to this coastline by either cutting or extrapolating the respective spatial extent.

Depending on the magnitude of a natural hazard event the expected damages on assets (such as buildings) vary widely. While weak events can lead to no or small damage, strong events can lead to a complete loss or destruction of an asset. Vulnerability curves are used to model the relation between the severity of an event and the expected damage on a certain type of building. Depending on the quality of the building, the curves vary significantly.
EXAMPLE OF A VULNERABILITY CURVE

Combining the concepts of frequency and severity of natural hazards with the concept of vulnerability curves allows the calculation of expected annual damage for buildings. The expected damage caused by a certain hazard usually shows that medium severities are causing the bulk of damages.

CALCULATION OF THE EXPECTED ANNUAL BUILDING DAMAGE

The expected annual damage was calculated using a typical but simplified standard building:
- residential house
- concrete columns
- bricks walls
- maximum two floors

This characterizes a typical, stable residential building in Leyte. The resulting maps give indicative values for the standard building and cannot directly be transferred to completely different building types as wooden nipa huts or multi-story reinforced concrete buildings.

By summing up the annual damage of all hazards, a multi-hazard suitability map is created.
**PRINCIPLE COMPOSITION OF A MULTI HAZARD RISK MAP**

Numbers are expected annual damage in percent of the value of the building.

In this graph only three layers of hazards are added, while the building suitability map is composed of 26 layers. The risks of many hazards are composed of sets of five layers.

**LAYERS OF THE MULTI HAZARD BUILDING SUITABILITY MAP**

The resulting multi hazard building suitability map shows significant differences in the risk level in different locations. The minimum risk is caused by ground shaking and storm and in many areas other hazards add to the risk. The highest risk is found in some coastal areas where storm surge and tsunami contribute much to the overall risk.
MULTI-HAZARD BUILDING SUITABILITY MAP FOR LEYTE

The composite risk is the sum of the risk of five different hazards and the respective vulnerabilities of residential buildings to these hazards. The risks are described in the following chapter.
5.1 Typhoon (Wind hazard)

Almost all storms in the Philippines belong to the category of tropical cyclones (locally called Typhoon in the western part of the Northern Pacific Ocean). They are rotating, and strong low-pressure storm systems formed over tropical sea surfaces. Their energy is derived from evaporation of warm water from the ocean surface. After landfall a tropical cyclone usually weakens. Tropical cyclones are connected to very high wind-speeds, as well to secondary effects as storm surges and extensive rainfall causing floods and landslides.

Future climate change and associated sea level rise is believed to result in stronger but not in more frequent typhoons.

Typhoons have a center (the “eye”) with relatively low wind speeds and a surrounding area with very high air velocity. In the northern hemisphere tropical cyclones rotate counter clockwise and they move predominantly in westerly directions. This means that the wind is stronger north of the center. GIZ calculated historical wind speeds in Region VIII based on known tracks. The result shows that stronger winds occur more often in the north east of the Philippines than in the south west. This is consistent with two sources of global wind hazard accessible in GIS format. They were developed by Weihua Fang of the Beijing Normal University and by the Probabilistic Risk Assessment (CAPRA) Program. The CAPRA data display maximum wind speeds during 3 seconds and Fang’s data include the same. The data display the same trend but Fang’s data have a much higher resolution (1 km) than the data from CAPRA (30 km) and Fang’s data show lower wind speeds. In order to be on the safe side the higher wind speed data from CAPRA were chosen for further processing. Transformation of the regional wind speed (30 km pixel size) to a site specific wind speed (<90m pixel size) was done based on Monteverde (2014). The three factors were multiplied to get a site specific wind speed correction factor for the regional wind speed data.

**Site specific wind speed**

\[
\text{Site specific wind speed} = \text{Regional wind speed} \times M_z (\text{Land cover}) \times M_h (\text{Topography}) \times MA (\text{Aspect})
\]

The regional wind speed was obtained from CARPA (see Appendix Data Sources). Highest wind speeds can be expected in north-eastern Leyte, while south-western Leyte is likely to experience lower wind speeds.

Maximum wind speed (sustained for 3 seconds) for 50 years return period (from CAPRA) Numbers: wind speed in km/h
Land Cover
The land cover pattern of an area influences the local wind speed. Rough surfaces as dense cities or forests can slow down wind, whereas surfaces like water or short grass have almost no lessening effect on wind speed.

In 2008 GIZ generated a land cover map of Leyte using a supervised classification on high resolution satellite images (Neussner, Wilkin). This map includes 11 types of land cover taken from the Philippines National Forest Inventory Manual (Branthomme et al.). Monteverde et al (2014) use a slightly different classification of land cover for their study. The categories used by GIZ were adjusted accordingly.

RECLASSIFICATION OF LAND COVER CLASSES AND THEIR MULTIPLIER

<table>
<thead>
<tr>
<th>Class</th>
<th>Description in Monteverde et al (2014)</th>
<th>Philippines National Forest Inventory Manual</th>
<th>Mz</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Forests</td>
<td>Closed Forest, Mangrove Forest</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>Residential subdivisions</td>
<td>Settlement</td>
<td>0.77</td>
</tr>
<tr>
<td>8</td>
<td>Few trees with long grass</td>
<td>Perennial Crops (Coco), Shrubs</td>
<td>0.82</td>
</tr>
<tr>
<td>9</td>
<td>Crops</td>
<td>Annual Crops</td>
<td>0.84</td>
</tr>
<tr>
<td>10</td>
<td>Rough open water surfaces, uncut grass, airfields</td>
<td>Barren Land, Pastures</td>
<td>0.89</td>
</tr>
<tr>
<td>11</td>
<td>Cut grass, rice paddies, enclosed waters</td>
<td>Roads, Rivers, Fishponds</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Topography
The STRM90 digital elevation model (DEM) was used to create a slope model of Leyte using ArcGIS 10.2.

SLOPE MULTIPLIER (STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND)

<table>
<thead>
<tr>
<th>Slope in %</th>
<th>Mz</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>1.00</td>
</tr>
<tr>
<td>5-10</td>
<td>1.08</td>
</tr>
<tr>
<td>10-20</td>
<td>1.16</td>
</tr>
<tr>
<td>20-30</td>
<td>1.32</td>
</tr>
<tr>
<td>30-45</td>
<td>1.48</td>
</tr>
<tr>
<td>&gt;45</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Wind direction
The average track direction of the typhoons in the Philippines is towards North-West (Joint Typhoon Warning Center, 1991). Slopes with a South-East aspect are therefore exposed to the strongest winds, whereas slopes with a North-West aspect are shielded by mountains and ridges. Other wind directions face values in between those of SE and NW. Only areas with a slope of more than 5% were considered in this factor. Flatter areas were assigned with a $M_A$ of 1.0. The SRTM90 DEM served as base data to create the aspect data of Leyte.

UTILIZED SHIELDING (OR EXPOSITION) MULTIPLIERS FOR LEYTE

<table>
<thead>
<tr>
<th>Aspect</th>
<th>$M_A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>1.1</td>
</tr>
<tr>
<td>NE</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>0.9</td>
</tr>
<tr>
<td>NW</td>
<td>0.8</td>
</tr>
<tr>
<td>W</td>
<td>0.9</td>
</tr>
<tr>
<td>SW</td>
<td>1</td>
</tr>
<tr>
<td>S</td>
<td>1.1</td>
</tr>
<tr>
<td>SE</td>
<td>1.2</td>
</tr>
<tr>
<td>Flat</td>
<td>1</td>
</tr>
</tbody>
</table>
Localized of Storm Hazard Map

Typhoon Vulnerability

The resulting local wind speed is then transferred into expected averaged annual damage. The vulnerability data are estimations by GIZ based on observations mostly from typhoon Yolanda.

Wind speeds were categorized according to the Saffir Simpson Scale. This scale has five categories, but we added more categories for finer steps in damages. We calculated annual damage for five return periods (50y, 100y, 250y, 500y and 1000y) based on the return periods provided by CAPRA. To obtain the total annual damage, all five values have to be added.

Wind Speed – Damage Relation

<table>
<thead>
<tr>
<th>WS in km/h</th>
<th>SS1</th>
<th>SS2</th>
<th>SS3</th>
<th>SS4</th>
<th>SS5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage in %</td>
<td>5</td>
<td>7.5</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

Two Examples of Calculating the Total Annual Damage

The values highlighted in the table were taken from two sample points on the maps for the five different return periods.
Strong storms constitute a major part of the risk for residential buildings in some places. This applies especially to exposed slopes and ridges while some valleys in mountainous areas are more protected from storm. Overall the danger of high wind speeds is higher in the north east and lower in the south west of the island.
5.2 Storm Surge

Storm surges are usually secondary hazards of tropical cyclones. They are caused by a tropical cyclone’s low air pressure-induced water dome and are intensified by winds pushing the water surface. The severity of a storm surge is furthermore affected by the tides and the depth and orientation of the water body relative to the storm path.

Storm surges are responsible for most casualties during tropical cyclones. Climate change related sea level rise will lead to increased magnitude of storm surges. An increase in strong typhoons may also increase the number of storm surges.

There are different sources of data concerning storm surges in Leyte. PAGASA issued a storm surge hazard map for the island in 2007 (see appendix data sources). It indicates possible water heights of 1 to 4m, but only in this bracket and not up to 1m and not more than 4m. This map does not indicate probabilities. Because of these limitations it was not considered further.

Storm surge height (m) at the shore in Southern Samar and in Leyte Island for a 10 year return period (from CAPRA, see appendix Data sources)
WARNING

40 METERS EASEMENT FROM SEA SHORE IS A

"NO BUILD ZONE AREA"
The history of storm surges in Leyte reported by local people does not validate the frequency of 10 years of storm surges of 1 to 3m in many parts of Leyte. Therefore this source of data was not considered further.

JICA provided storm surge hazard maps for the eastern coast of Leyte province in November 2014. The calculated inundation area is a bit smaller than the one from Project NOAH (see below). To be on the safe side the larger inundation area was considered for further calculations.

Project NOAH published storm surge hazard data for Leyte. The data are consistent with reports about the inundation extent and height of tropical cyclone Haiyan. Furthermore the data have a high spatial resolution and are available in GIS format. No information on the probability of the inundation is available from NOAH, but as probabilities of storms are available it is possible to assign probabilities to NOAH’s storm surge hazard data.

NOAH’s data are distinguish between storm surges water heights from 2m (called SSA1) to 5m (called SSA4). Each scenario is furthermore divided in three sub-division, designated to a flood height below 0.5m, 0.5m to 1.5m and higher than 1.5m.

By subtracting the individual scenarios from each other, a higher resolution inundation model can be created. As the four available scenarios include a maximum water level of 2-5m, a gradation in 1m steps is possible. All scenarios also include 0.5m and 1.5m steps.

As there are no return periods published for each scenario, GIZ calculated the necessary wind speed to create a storm surge of each extend and used the return periods for the respective typhoons. Calculations according to Irish (2008).

### RELATION BETWEEN WIND SPEED AND STORM SURGE HEIGHT

<table>
<thead>
<tr>
<th>Saffir-Simpson scale</th>
<th>Wind speed in km/h</th>
<th>Storm surge in m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>119-153</td>
<td>1.2-1.5</td>
</tr>
<tr>
<td>2</td>
<td>154-177</td>
<td>1.8-2.4</td>
</tr>
<tr>
<td>3</td>
<td>178-209</td>
<td>2.7-3.7</td>
</tr>
<tr>
<td>4</td>
<td>210-249</td>
<td>4.0-5.5</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 250</td>
<td>&gt; 5.5</td>
</tr>
</tbody>
</table>

The return periods for the maximum regional wind speed (see chapter Typhoon [wind hazard]) were used to determine return periods for storm surges in Leyte.

### RETURN PERIODS OF DIFFERENT STORM SURGE WAVE HEIGHTS

<table>
<thead>
<tr>
<th>Water height (m)</th>
<th>Return period (years)</th>
<th>NOAA nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>SSA1</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>SSA2</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>SSA3</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>SSA4</td>
</tr>
</tbody>
</table>

SSA: Storm Surge Advisory
**Storm Surge vulnerability**

Not many data are available describing the relation between storm surge heights and building damages, but some are reported for tsunamis and GIZ used such vulnerability values as compiled by Scheer (2011).

**COASTAL WAVE VULNERABILITY CURVES OF BUILDINGS (ACCORDING TO SCHEER)**

The building type closest to residential buildings in Leyte is class B and the respective vulnerability data were used for risk calculations.

Combining the inundation, return periods and vulnerabilities for each scenario leads to a number of expected annual damage in %:
ANNUAL DAMAGE FOR EACH POLYGON FOR ALL SCENARIOS (IN PERCENT OF BUILDING VALUE)

<table>
<thead>
<tr>
<th>Inundation in m</th>
<th>SSA1</th>
<th>SSA2</th>
<th>SSA3</th>
<th>SSA4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.2</td>
<td>0.125</td>
<td>0.083</td>
<td>0.056</td>
</tr>
<tr>
<td>1.5</td>
<td>0.8</td>
<td>0.375</td>
<td>0.25</td>
<td>0.167</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>0.5</td>
<td>0.333</td>
<td>0.222</td>
</tr>
<tr>
<td>3</td>
<td>---</td>
<td>1</td>
<td>0.667</td>
<td>0.444</td>
</tr>
<tr>
<td>4</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>0.667</td>
</tr>
<tr>
<td>5</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.889</td>
</tr>
</tbody>
</table>

SSA: Storm Surge Advisory

The expected annual damages of each scenario were summed up to obtain the expected total annual damage from the storm surge hazard.

STORM SURGE RISK FOR RESIDENTIAL BUILDINGS

Some flat coastal areas of Leyte island are seriously exposed to storm surges. As storms (and with them the surges) are usually coming from the east, the eastern coast is more dangerous in this respect. Storm surges are expected to be be more frequent than tsunamis and with this storm surges are the main contributing hazard in flat coastal areas in Leyte.
5.3 Earthquakes

An earthquake is a shaking of the earth’s surface. Most earthquakes are tectonically induced, when accumulated stress and friction on subduction, collision or fault zones is suddenly released. The released energy is transmitted in seismic waves which are felt as ground motion. Earthquakes can range from imperceptible to extremely violent. Furthermore, earthquakes can trigger tsunamis, landslides, liquefaction and ground ruptures.

**HISTORIC NUMBER OF GROUND SHAKING EVENTS IN REGION VIII**

It appears that there are two different schools of thought concerning the earthquake hazard in Leyte Island. Some experts believe that the Central Philippine Fault Line is the main source for major earthquakes, while others think that the Philippine Trench located east of Mindanao and Samar is constituting more danger to Leyte.
The top part of the Philippine Trench is approximately 150km east of the center of Leyte and the slab under Leyte is in a depth of about 150km too (USGS, 2011). The Central Philippine Fault Line supporters (Thenhaus, 1990; Punongbayan, no date; Munich Re, 2014) apparently argue that this fault passes right through Leyte and is therefore the prime source of strong ground motions, while the supporters of the Philippine Trench (CAPRA [see Data Sources: Various global hazards], Torregosa, 2001; Manila Observatory et al., 2005) appear to base their conclusion mostly on historical data. There are reliable historic records of earthquakes for the Eastern Visayas available for the last 100 years. GIZ took the records of USGS and PHIVOLCS and calculated the resulting ground shaking intensities with the methods of Tanaka and Fukushima as well as Allen and Wald.

The result shows basically that by far most ground shaking in the Region is caused by earthquakes from the subduction zone of the Philippine Trench. There are also some shallow, small magnitude earthquakes from the vicinity of the Cabalian volcano and a few earthquakes which may be related to the Central Philippine Fault Line. Visual observations of the Central Philippine Fault Line in Leyte reveal ground rupture movements of 1-3cm per year at the fault line. The eastern side is moving northwards relative to the western side. This strike/slip fault line appears to be moving smoothly and this might be an explanation for the few observed earthquakes in this area.
The maximum expected magnitude for an earthquake from the Central Philippine Fault Line is estimated to be 6.0 – 6.3 while 8.3 is expected for the Philippine Trench (Torregosa, 2001). However, PHIVOLCS estimated the maximum magnitude for the Central Philippine Fault Line to be 7.2 in the area between Baybay and Abuyog (Punongbayan, no date).

In view of the historic records and estimated maximum magnitudes GIZ decided to use the Philippine Trench as the main earthquake threat in the Leyte area. The respective GIS ready data were available from CAPRA (see Data Sources: Various global hazards).

The CAPRA data are calculated on a global scale and come with a pixel size of about 39km. This is quite broad and therefore GIZ used a method to calculate more localized ground shaking intensities. It was assumed that the ground shaking hazard has the same spatial distribution as historic ground shaking during the last one hundred years. This map (see maps above: Historic number of ground shaking events in Region VIII) had a spatial resolution of 90m, which is derived from the slope calculated with data from SRTM. The historic data cover only one century while the shortest return period in the CAPRA calculations is 250 years. This makes comparison of the data difficult. The authors decided to use one of the CAPRA pixels in the center of Region VIII as the link. This pixel covers the city of Tacloban.

### Expected Peak Ground Acceleration in Tacloban (from CAPRA)

<table>
<thead>
<tr>
<th>Return period (years)</th>
<th>PGA (cm/s²)</th>
<th>Intensity (MMI)</th>
<th>Intensity (PEIS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>488</td>
<td>VIII</td>
<td>VIII</td>
</tr>
<tr>
<td>475</td>
<td>597</td>
<td>VIII</td>
<td>VIII</td>
</tr>
<tr>
<td>1000</td>
<td>748</td>
<td>IX</td>
<td>IX</td>
</tr>
<tr>
<td>1500</td>
<td>847</td>
<td>IX</td>
<td>X</td>
</tr>
<tr>
<td>2500</td>
<td>951</td>
<td>IX</td>
<td>X</td>
</tr>
</tbody>
</table>

### Maximum PGA vs. Return Period

[Graph showing maximum PGA vs. return period]
The data from Tacloban are compared with two other places in Leyte (Ormoc and Abuyog). Tacloban has higher PGA than the other places and therefore the selection of the CAPRA pixel for Tacloban appears to be a conservative choice. The curve of the PGA for Tacloban indicates a PGA of approximately 350 cm/s² for a return period of 100 years. The highest count of Intensity VI ground shaking in Tacloban pixel was 29 events in approximately 100 years. 29 events are taken as equivalent to 350cm/s². With this we get approximately the following distribution:

<table>
<thead>
<tr>
<th>Return Period (years)</th>
<th>PGA (cm/s²)</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>350</td>
<td>1.00</td>
</tr>
<tr>
<td>250</td>
<td>488</td>
<td>1.39</td>
</tr>
<tr>
<td>475</td>
<td>597</td>
<td>1.78</td>
</tr>
<tr>
<td>1000</td>
<td>748</td>
<td>2.14</td>
</tr>
<tr>
<td>1500</td>
<td>847</td>
<td>2.42</td>
</tr>
<tr>
<td>2500</td>
<td>951</td>
<td>2.72</td>
</tr>
</tbody>
</table>

By using the indicated factors it is possible to calculate a localized distribution of PGA for five different return periods.

The PGA distribution for the other return periods (475, 1000, 1500, 2500 years) was calculated by using the same factors.
Earthquake vulnerability

There are a number of ground shaking vulnerability curves available for buildings. Many of them are adjusted to specific countries or areas and some work was done on typical Philippine buildings but the data were not yet available to GIZ. The utilized data came from the Global Quake Model.

MS-T1: unreinforced clay brick masonry, 1 to 2 story high, lime/cement mortar, timber floors/roof

MS-T2: unreinforced clay brick masonry, 1 to 2 story high, lime/cement mortar, concrete floors/roof

MS-T3: unreinforced concrete block masonry, 1 to 2 story high, lime/cement mortar, reinforced concrete floors/roof

MS-T4: unreinforced rubble stony masonry, 1 to 2 story high, lime/cement mortar, timber floors/roof

MS-T5: reinforced concrete block or clay brick masonry, 1 to 3 story high, lime/cement mortar, concrete floors/roof

MS-T6: confined clay-brick masonry, 1 to 3 story high, lime/cement mortar, concrete floors/roof
Vulnerability curves for various building types depending on the PGA. GIZ used building type MS-T3 (from Global Quake Model, see Data sources). By multiplying the expected percent of damage with the return period a table with annual damages was calculated.

<table>
<thead>
<tr>
<th>PGA (cm/s²)</th>
<th>≤90</th>
<th>91&lt;177</th>
<th>178&lt;334</th>
<th>335&lt;634</th>
<th>&gt;634</th>
</tr>
</thead>
<tbody>
<tr>
<td>% damage</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>30</td>
<td>60</td>
</tr>
</tbody>
</table>

**TABLE CALCULATION OF ANNUAL DAMAGES FROM GROUND SHAKING FOR RESIDENTIAL BUILDINGS**

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Annual % damage per intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 years</td>
<td>0.0040 0.0200 0.1200 0.2400</td>
</tr>
<tr>
<td>475 years</td>
<td>0.0021 0.0105 0.0632 0.1263</td>
</tr>
<tr>
<td>1000 years</td>
<td>0.0010 0.0050 0.0300 0.0600</td>
</tr>
<tr>
<td>1500 years</td>
<td>0.0007 0.0033 0.0200 0.0400</td>
</tr>
<tr>
<td>2500 years</td>
<td>0.0004 0.0002 0.0120 0.0240</td>
</tr>
</tbody>
</table>

**EARTHQUAKE (GROUND SHAKING) RISK FOR RESIDENTIAL BUILDINGS IN LEYTE**

The lowland areas towards the north and east of the island exhibit the highest expected annual damages (0.5% annually). Overall the risk from ground shaking in Leyte Island is relatively small compared to risks caused by some other hazards.
5.4 Tsunami

Tsunamis are a series of waves in a water body (mostly in oceans) caused by the displacement of a large volume of water. Tsunamis can be caused by earthquakes, volcanic eruptions, landslides and other factors. Different from “normal” waves, tsunamis can travel whole ocean basins and have damaging effects in all bordering coasts. Most tsunamis hitting the Philippines are triggered by earthquakes.

Tsunamis and storm surges have similar characteristics, but with the same water height at the shore a storm surge normally would travel further inland because strong winds push the water further than in tsunamis (unless there is an on shore storm at the same time). The storm surge map regarded to be most reliable by GIZ (Project NOAH) show in most locations inundation areas slightly smaller than the tsunami area according to the maps of PHIVOLCS for the same water height at the shore (5m).

PHIVOLCS published a set of tsunami hazard maps, indicating potential tsunami inundation areas. GIZ modified the data by calculating the wave height per distance from the shore line using a proportional wave height decrease approach.

Return rates of tsunamis were estimated after Thio (2007).

**RETURN PERIODS AND WATER HEIGHTS FOR TSUNAMIS IN LEYTE**

<table>
<thead>
<tr>
<th>Water height at the shore in m</th>
<th>Return period in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
</tr>
</tbody>
</table>

**Tsunami vulnerability**

GIZ used vulnerability values as suggested by Scheer (2011). For details see chapter Storm Surge. The following table shows how the composite tsunami risk was calculated. The column on the right (max. 5m) represents the shore at the water. Once in 500 years a 5m tsunami is expected, but the contribution to the total tsunami risk is relatively small (0.02%). A tsunami with a wave height of 1m may happen every 50 years. Though the damages are not massive they contribute relatively more to the total tsunami risk because of their high frequency. The values of the other waves heights are in between the two mentioned extremes (1 to 5m).

**COMPOSITION OF THE ANNUAL DAMAGE IN PERCENT FOR RESIDENTIAL BUILDINGS CAUSED BY TSUNAMIS IN LEYTE**

<table>
<thead>
<tr>
<th>Inundation in m</th>
<th>max 1m</th>
<th>max 2m</th>
<th>max 3m</th>
<th>max 4m</th>
<th>max 5m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200</td>
<td></td>
<td>0.050</td>
<td>0.033</td>
<td>0.020</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.200</td>
<td>0.100</td>
<td>0.067</td>
<td>0.040</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>0.200</td>
<td>0.133</td>
<td>0.080</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>0.200</td>
<td>0.120</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.160</td>
</tr>
</tbody>
</table>

**ACCUMULATED TSUNAMI RISK IN PERCENT PER ANNUM**

<table>
<thead>
<tr>
<th></th>
<th>Shore</th>
<th>0.960</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.453</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.197</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.020</td>
</tr>
</tbody>
</table>

Inland

Data for a maximum water height of 5m.
The tsunami risk for residential buildings in Leyte is limited to some flat coastal areas in the east of the island. Tsunamis are not expected at the western coast.
5.5 Flood

A flood is an overflow of water that submerges land which is usually dry. Floods are mostly caused when rivers or lakes are overflowing or water accumulates on saturated ground after intense or long lasting rainfalls. Some flood events occurring in steeper slopes have a rapid, flash-flood character, whereas floods in flat areas are usually slow-rising but long-lasting.

Climate change is believed to lead to intensified rainfall events in many places. In the Philippines the wet season may expect more rain while there could be less rain. Sea level rise leads to a higher discharge base level and can cause intensified low-land flooding in coastal areas as well.

There is only one complete set of flood hazard maps available covering all of Leyte Island. It is a map of MGB (2007), scale 1:50,000, which shows only flood-prone and not flood-prone areas. There are no indications of expected water height or probabilities. A 2014 set of MGB maps covers the province of Leyte in 1:10,000 but not Southern Leyte. These maps give indications of maximum water heights but not on probabilities. The maps are not yet available in GIS format. JICA issued a flood hazard map for some coastal areas of eastern Leyte in 2014 and GIZ derived detailed flood hazard maps (including probabilities) for four rivers (Pagsangaan, Marabong/Daguitan, Bito, Cadac-an) and Project NOAH produced a flood hazard map for a 100 year return flooding event for Leyte province and part of Southern Leyte. The NOAH map seems to reflect historical flooding reasonably well and therefore this map was used for calculations. As no probabilistic flood hazard data for most of Southern Leyte are available future updates of this building suitability map shall include those data as soon as they are available.

The NOAH data are divided in 3 subdivisions of flood height: below 0.5m, 0.5-1.5m and 1.5-3m with a return period of 100 years. No data on other return periods were available. GIZ estimated water levels of 67% for a 50 year scenario and 33% for a 25 year scenario respectively. This estimation is based on experiences from other regions.

<table>
<thead>
<tr>
<th>Return period in years</th>
<th>Water height in percent</th>
<th>Water height in m</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100%</td>
<td>Data (NOAH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5-3</td>
</tr>
<tr>
<td>50</td>
<td>67%</td>
<td>Estimated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.35-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-2</td>
</tr>
<tr>
<td>25</td>
<td>33%</td>
<td>Estimated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.2-0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1</td>
</tr>
</tbody>
</table>

Flood vulnerability
GIZ used vulnerability estimations derived from experiences of recent flood events in Leyte.

<table>
<thead>
<tr>
<th>Flood height (m)</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>&gt;3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Damage</td>
<td>3</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>

Return periods and damage were then used to compile an expected average annual damage for each area.

<table>
<thead>
<tr>
<th>Return period in years</th>
<th>0.5m</th>
<th>1.5m</th>
<th>3.0m</th>
<th>0.5m</th>
<th>1.5m</th>
<th>3.0m</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3</td>
<td>10</td>
<td>30</td>
<td>0.03</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>50</td>
<td>3</td>
<td>5</td>
<td>20</td>
<td>0.06</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>0.08</td>
<td>0.12</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Sum: 0.17 0.32 0.9
Fresh water floods are a frequent phenomenon in many flat areas near rivers in Leyte and are a major part of the risk for residential buildings to many areas near river banks.
5.6 Landslide

Landslides are gravitational ground movements on slopes. The term landslide includes various phenomena such as rock falls or wet debris flows as well. Landslides occur when the slope stability is reduced and reaches an unstable condition. The main reasons for reduced slope stability are an oversaturation of the soil after intense rainfalls and seismic events. Human activities such as deforestation, construction, earthworks or agriculture usually amplify the landslide hazard.

Project NOAH published a hazard map for rain-induced landslides the Philippines. It is divided into 3 subdivisions (called “No dwelling zone”, “Build only with slope protection and intervention; and continuous monitoring” and “Build only with continuous monitoring”). With this specification it is actually no hazard but a suitability map, though without probabilities.

Data for earthquake-induced landslides were published by PHIVOLCS. PHIVOLCS uses “High Susceptibility”, “Medium Susceptibility” and “Low Susceptibility” as well as areas which are under risk of landslide deposits.

The Mines and Geoscience Bureau published a 1:10,000 landslide hazard map, which does not distinguish between rain or earthquake induced triggers in 2014 for Leyte province. This set of maps is not available in GIS format yet and therefore GIZ was not able to utilize these data.

There are only few data on historic landslides recorded in Leyte island. They normally only cover events that caused damages to man-made structures or agricultural areas, but most landslides happen in mountainous, forested areas. Without reliable historic data it is extremely difficult to quantify the hazard likelihood. Therefore landslides were not included in the calculation of the overall risk and building suitability.

However, areas which are under a possible landslide risk are marked in the map. This includes rain-induced as well as earthquake-induced landslides. Stakeholders should consult a specialist in case a project should be implemented in a landslide hazard zone.
Most of Leyte island is to some degree a landslide hazard area. In Southern Leyte only few places are not prone to landslides. The actual probability of landslides is not included in the map.
5.7 Ground Rupture

Ground ruptures are usually secondary effects of differential seismic movements, when a fault rupture reaches the surface. The resulting offset is capable of tearing apart structures built on or near the fault line. Ground ruptures are not confined to the fault itself but affect nearby areas as well. Ground rupture movements can be constantly slowly creeping or be sudden and intense. The ground rupture observed in Leyte along the Central Philippine Fault Line appears to be slow and more or less constant movement of 1 – 3cm per year.

There are some maps from different sources showing fault lines in Leyte. The most detailed one was published PHIVOLCS (scale: 1:50,000). This map was digitized by GIZ.

There are various limitations to the Ground Rupture Hazard at this stage. In many areas the exact location of the fault system is unclear, and based on estimations. The remote location in steep, densely vegetated areas hampers a precise mapping of the fault so far.

The second limitation is the scale of the source maps. It makes it difficult to digitize the location of the faults. Even minor mistake in digitizing can cause a relocation error of many meters. The combination of these limitations with the hazard buffer zone of just a few dozens of meters make a precise hazard assessment for Ground Rupture on Leyte difficult at the moment. The buffer zones are therefore generously and conservatively estimated. Buffer distances were calculated with 500m on each side of the assumed fault line. It is suggested to consult an expert for individual building project near a fault line to estimate the site-specific hazard and possible countermeasures.
Residential Building Suitability Map for Leyte Island, Philippines

© GIZ/ Olaf Neussner
The active fault line is marked on the map. It is not possible to calculate a probability for the slow moving plates.
Various hazard maps for the Philippines (country scale):
http://vm.observatory.ph/hazard.html
http://philgis.org/freegisdata.htm

Various hazard maps for the Philippines (provincial scale):
http://www.namria.gov.ph/readyMapsResultFrame.htm

Flood, storm surge and severe wind hazard from PAGASA:

Flood and rain induced landslide hazard maps from MGB (1:50,000)
Viewer: http://gdis.deni.gov.ph/mgbviewer/

Flood, rain induced landslide, storm surge hazard maps from project NOAH:
http://beta.noah.dost.gov.ph/
KML and shape files:

Tsunami, earthquake induced landslide, liquefaction and ground shaking hazard maps from PHIVOLCS:

Various global hazards (shape and grid files)
http://risk.preventionweb.net/capraviewer/download.jsp?tab=11&mapcenter=0,2965169.792775&mapzoom=1

Global earthquake archives:
http://earthquake.usgs.gov/earthquakes/search/
http://earthquake.usgs.gov/data/slab/models/phi_slab1.0.pdf,
http://www.globalquakemodel.org/what/seismic-hazard/

Various hazard and disaster maps from the UN
http://reliefweb.int/country/phl/thumb#content
https://data.hdx.rwlabs.org/dataset/storm-surge-hazard-10-years
Manila Observatory; Department of Natural Resources. (2005): map: Earthquake-prone areas (vm.observatory.ph/images/Geophys_hires/eq_prone_areas.jpg),
Munich Re, 2014, quoted as a source in OCHA: Asia-Pacific: Earthquake Risk – Modified Mercalli Scale, (reliefweb.int/sites/reliefweb.int/files/resources/map_613.pdf)
Punongbayan, J.T.; Lasala, M.P.; Bautista, B.C. (no date): Ground shaking hazard mapping, Province of Leyte, PDF power point presentation, 38 pages