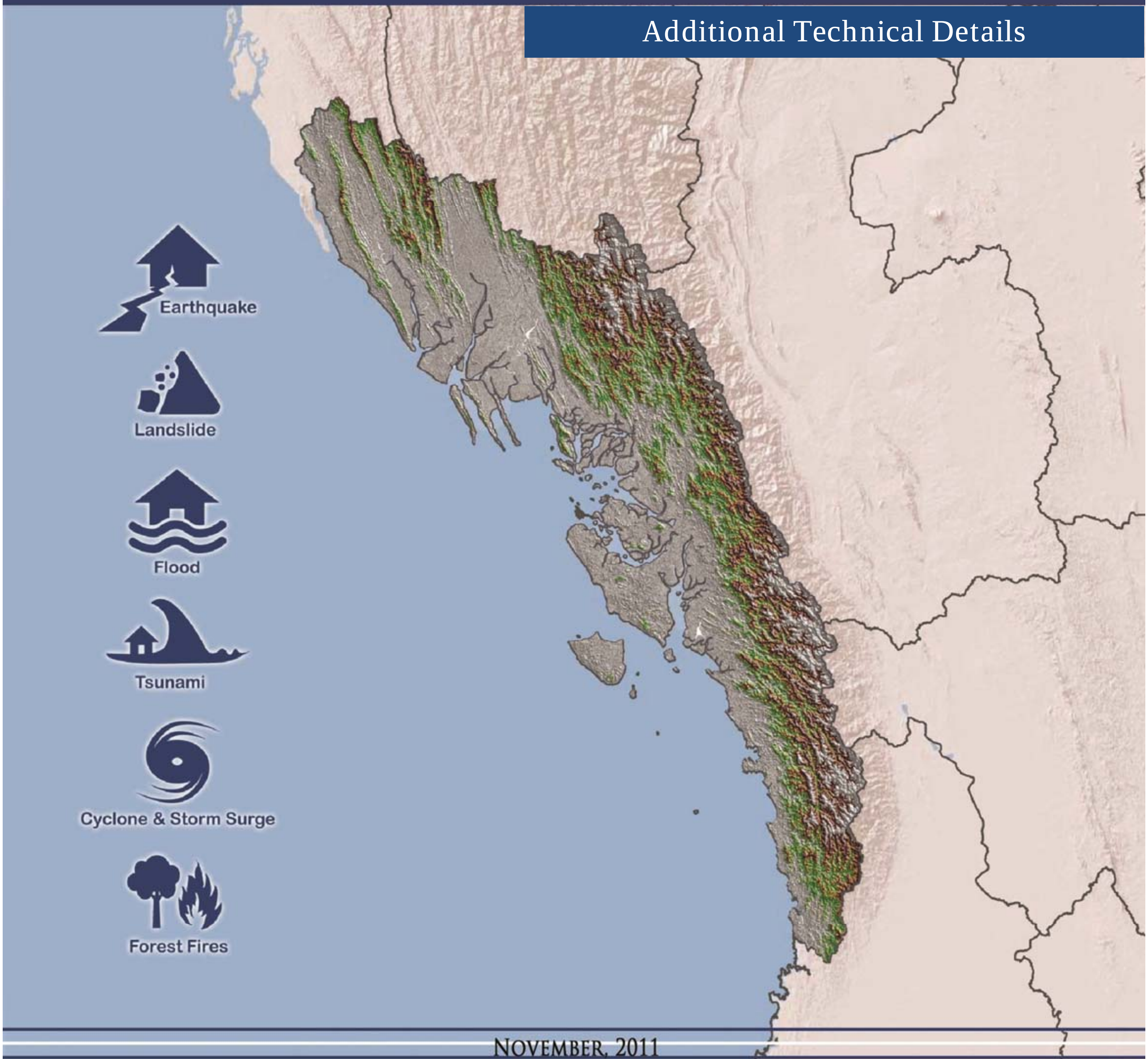
MULTI HAZARD RISK ASSESSMENT IN RAKHINE STATE OF MYANMAR

Additional Technical Details



NOVEMBER, 2011

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CHAPTER A: DETAILED HAZARD CALCULATION

Cyclone Hazard Assessment

The cyclone hazard map is derived from statistical analysis of the wind speed simulated from the Weather Research and Forecasting (WRF) Model. The WRF model is used to produce the wind speed maps over Myanmar and the Bay of Bengal. Thirteen recent storm events, which developed over the Bay of Bengal, during the 2000-2010 period are selected and the wind speeds at landfall time (when the center of the storm moves across the coast) are simulated for each storm events in form of gridded data over the study domain.

The Gumbel Distribution (Gumbel, 1958) is used to fit the wind speed data from the 13 storm events at each grid point, allowing for frequency analyses of the storms. Different return periods (2, 5, 10, 100 and 200 years) are considered and the two selected scenarios (5 and 100-year return periods) representing frequent and extreme cases are finally selected and presented in this study.

Data Availability and Sources

Selected past events of tropical cyclones which affected to Rakhine State of Myanmar and neighborhood were simulated using Advance Research WRF (ARW) model developed by National Centre for Atmospheric Research (NCAR) of USA. ARW Modeling System is one of the most popular meso-scale models because of its continuous development and the status of a community model (Pattanaik et al, 2009).

National Centre for Environment Prediction (NCEP) Final Analysis (FNL) data which is available at http://dss.ucar.edu/dsszone/ds083.2/index.html?g=1 were used as input data for simulating the past events. These NCEP FNL Operational Global Analysis data are on 1.0x1.0 degree grids (~100 km x 100 km) prepared operationally every six hours. This product is from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources, for many analyses.

The NCEP FNL data is the data in binary format which consists most of the atmospheric variables (wind, pressure, temperature, etc.) at each and every grid point (at 1.0x1.0 degree-horizontal and at pressure levels - vertically) to cover the whole globe. These data are constructed into grid mesh based on observed data (surface observations, upper air observations (raidosonde), satellite imageries such as TRMM, radar imageries, and etc.). The topography (GTOPO30) and land use (GLCC) data used in this study for wind field simulations are obtained from U.S. Geological Survey (USGS).

GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30 was derived from several raster and vector sources of topographic information and is available at

http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/e060n40

Global Land Cover Characterization (GLCC) is a series of global land cover classification datasets that are based primarily on the unsupervised classification of 1-km AVHRR (Advanced Very High Resolution Radiometer) 10-day NDVI (Normalized Difference Vegetation Index) composites available at

http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/GLCC

These topography and land use data are needed to represent and simulate local forcing (land-sea interactions and etc.), meso-scale phenomena (heating and cooling, land and sea breeze, anabatic and katabatic features and etc.).

As per the availability of necessary NCEP FNL data for simulating the behavior of winds over Rakhine State, 13 cyclonic events which were formed over the Bay of Bengal and caused widespread influence for Rakhine and its neighboring states were selected. Table 1 summarizes the 13 storm events with landfall times utilized in this analysis. Storm tracks of 13 events hitting neighborhood of Myanmar during the period of 2000 -2010 are displayed in Figure 1.

Table 1: Thirteen storm events used in this cyclone analysis during the period of 2000-2010

No	Name of the Cyclone	Affected Period	Landfall date and Time (UTC)	Maximum Sustained Wind Speed (km/h)
1	02B	2000/10/25-29	2000/10/27	35
2	02B	2002/05/11-12	2002/05/12	45
3	01B	2003/05/10-19	2003/05/19	65
4	NA	2004/05/16-19	2004/05/19	NA
5	Mala	2006/04/25-29	2006/04/29	115
6	NA	2007/05/03-04	2007/05/04	NA
7	AKASH	2007/05/13-15	2007/05/15	65
8	Sidr	2007/11/11-16	2007/11/15	135
9	Nargis	2008/04/27-05/03	2008/05/02 (1200)	115
10	Rashmi	2008/10/26-27	2008/10/26	45
11	Bijli	2009/04/15-18	2009/04/17 (0600)	50
12	Aila	2009/05/24-26	2009/05/25 (0900)	65
13	Giri	2010/10/21-23	2010/10/22 (1400)	135

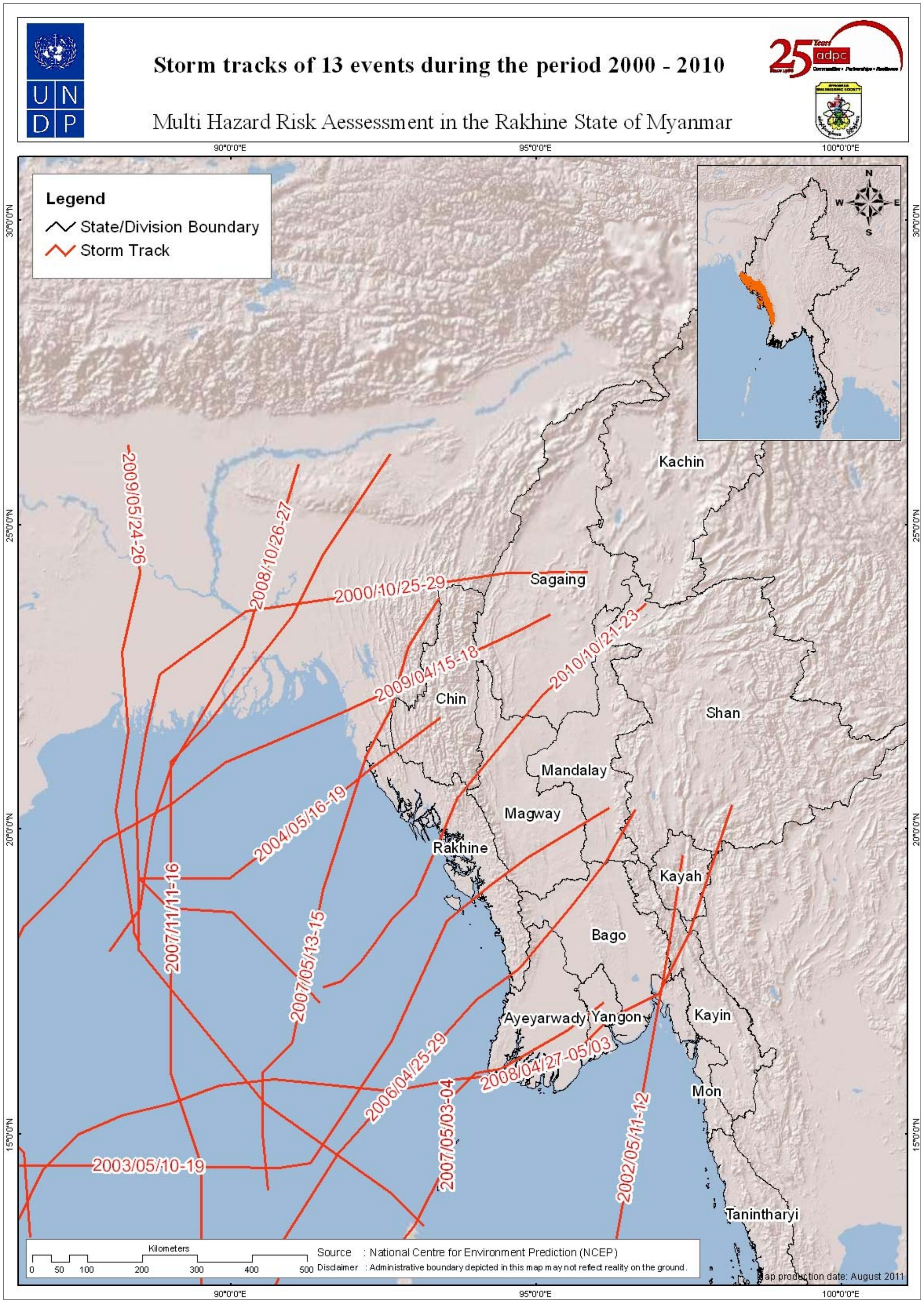

Figure 1: Storm tracks of 13 events over Myanmar during the period of 2000-2010

Hazard Assessment Methodology

The methodology used in this study is the combination of the numerical simulation (WRF model) of wind speed and the probabilistic approach.

The Weather Research and Forecasting (WRF) Model is a next-generation meso-scale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. NCEP FNL data are used as input and boundary conditions for the WRF model to produce the wind field at finer grid resolution. As mentioned in above section, high resolution advanced version Weather Research and Forecasting (ARW) model was used to simulate the wind fields over study area for each cyclonic event. The study is carried out based on the assumption that the storm has the most severe impacts at landfall time, i.e. when the storm eye moves off from the sea to the land.

The selected model domain covers 2° S to 26° N and 75° E to 101° E with a horizontal resolution of 9 km and 28 vertical pressure levels. The initial conditions for the events were preprocessed through the WRF Preprocessing System (WPS), which generates initial and lateral boundary conditions as input to ARW for each case. As the input data for WPS, NCEP FNL one degree resolution 6 hourly data were used. The WPS is set of programs that takes terrestrial and meteorological data and transforms them for input to ARW. The summary of technical information and parameters used in the ARW is shown in Table 2.

Table 2: Summary of technical information in ARW model

Initial input data	• *NCEP Final analysis (FNL) one degree resolution(around 100km) 6 hourly data* • *Topography from USGS (GTOPO30)* • *land use data from USGS (GLCC)*
Dynamics	*Non hydrostatic Model*
Domain	*2° S to 26° N and 75° E to 101° E*
Horizontal grid distance of output	*9 km*
Output frequency	*1 hour*
Integration time step	*150 seconds*
Map projection	*Mercator*
Vertical coordinate	*Sigma co-ordinates (28σ levels)*

The ARW (9 km resolution) model was executed 48-hour duration for generating the possible ground wind field with hourly frequency of outputs for each case with IBM power 755 high performance computer facilities. The generated results were validated with best track data (maximum wind speed) and observed wind data obtained from http://weather.unisys.com/hurricane/.

Maximum wind field influenced Rakhine State was calculated in the post processing stage of the model simulation using the ARWpost and Grid Analysis and Display System (GrADS) and data converted to a GIS compatible GEOTIFF format for further analysis.

ARW model is run to get maximum wind speed at the landfall time for each storm in total of 13 storm events producing 13 wind speed gridded maps with the spatial resolution of 9 km and temporal resolution of 1 hour. It is noted that winds derived from numerical models need to be correctly assimilated into the framework of mean and turbulent components and should be regarded as mean wind estimates over space and time (Harper et al., 2010)

The outputs from ARW model in term of wind speed at 10m above the surface are extracted and analyzed by the probabilistic approach.

The Gumbel (Extreme Value Type I) Distribution is utilized in the probabilistic approach. Only wind speed dataset from these 13 simulated storm events are fit to the Gumbel Distribution. The location and shape parameters of Gumbel Distribution are estimated (Bedient and Huber, 1992) from the 13 wind speeds in each grid. Finally wind speeds corresponding to various return periods can be calculated based on the fitted Gumbel Distributions. In this study, low-frequency event (100-year return period or 99th percentile) and high frequent event (5-year return period or 80th percentile) are considered. The example of histogram and cumulative distribution function (CDF) plots of the fitted Gumbel Distribution with the simulated wind speed at the grid near Manaung Island are shown in Figure 2.

The overall approach of the cyclone hazard analysis is shown in Figure 3. Figure 4and Figure 5 show the wind speed at 5 and 100-year return periods respectively.

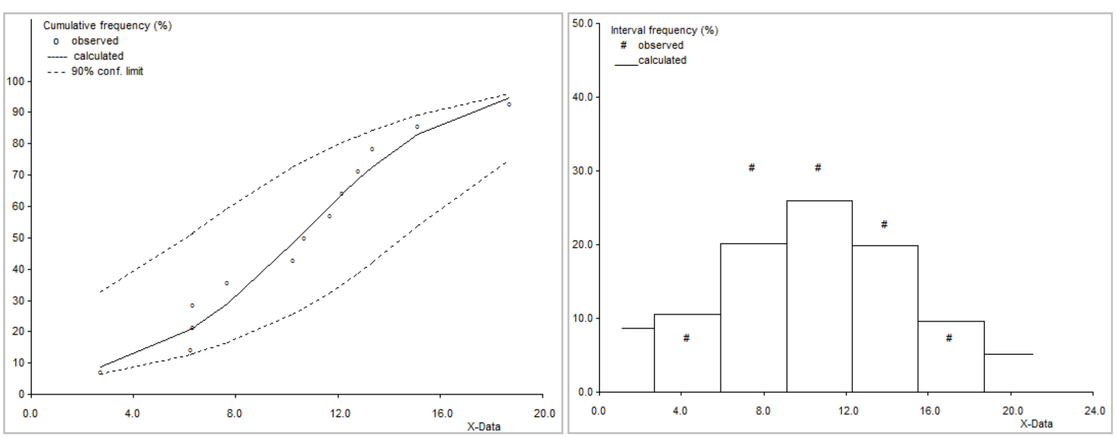

Figure 2: Histogram plot and cumulative distribution function (CDF) plot of the fitted Gumbel Distribution with the simulated wind speed at the grid near Manaung Island

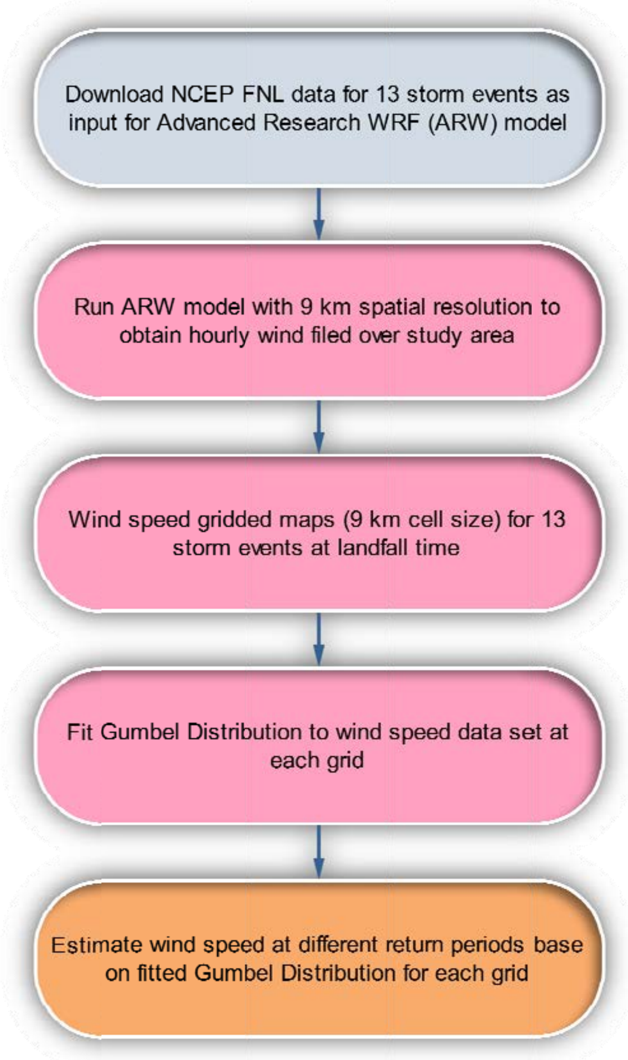

Figure 3: Flowchart of overall approach in cyclone hazard assessment

Hazard Maps and their Interpretation

The cyclone hazard map displays the spatial distribution of the wind speed over Myanmar and the Bay of Bengal. The cyclone categories from the India Meteorological Department (IMD) which monitors tropical cyclone that forms between longitude 45°E and 100°E in the Northern Hemisphere are used in for the classification in this study. Six different categories were defined to measure the wind speed of a tropical cyclone based on the maximum sustained winds over a 3-minute averaging period (WMO, 2008). Figure 6 depicts the tropical cyclone intensity scale by IMD.

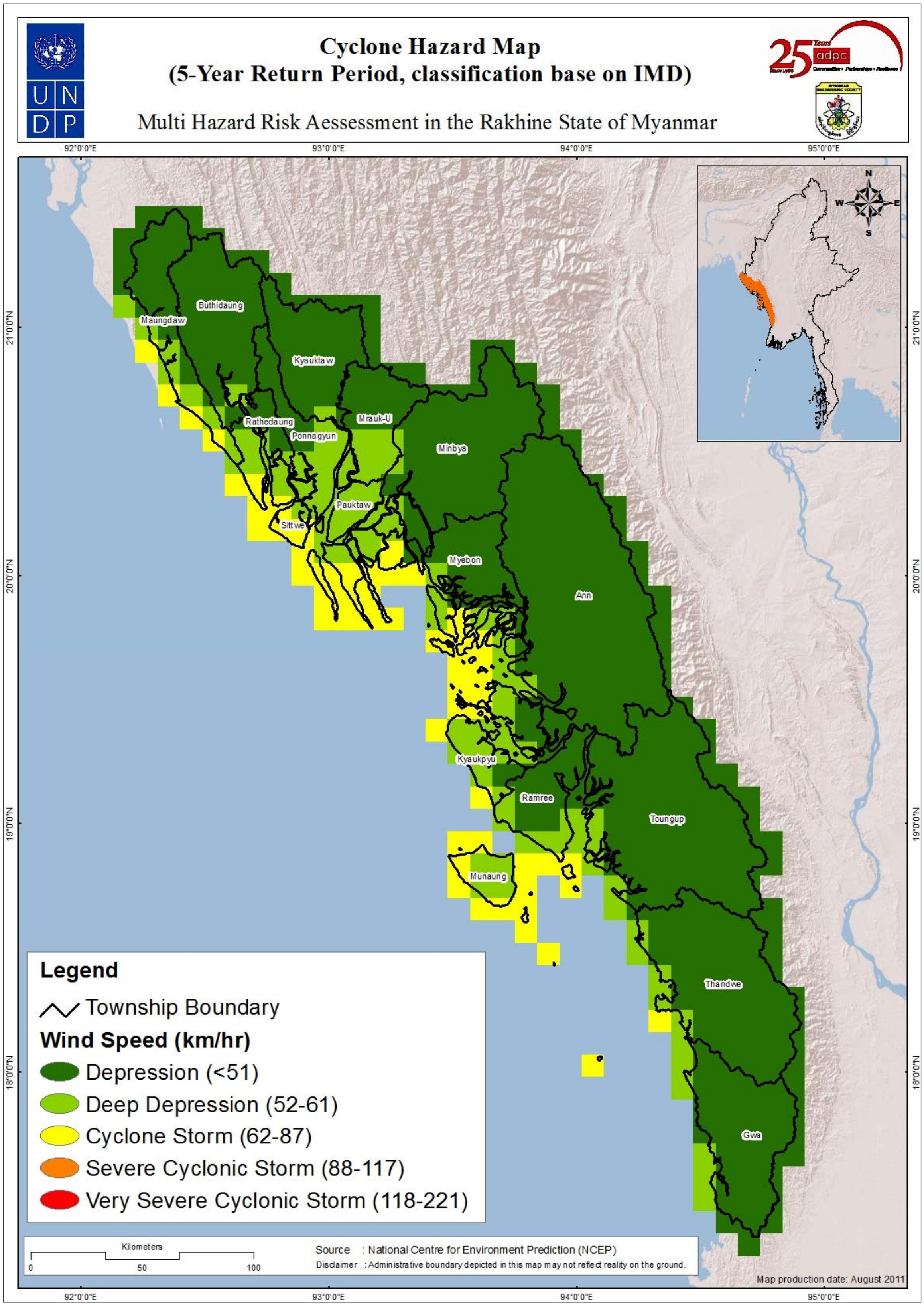

Figure 4: Cyclone hazard map for 5-year return period

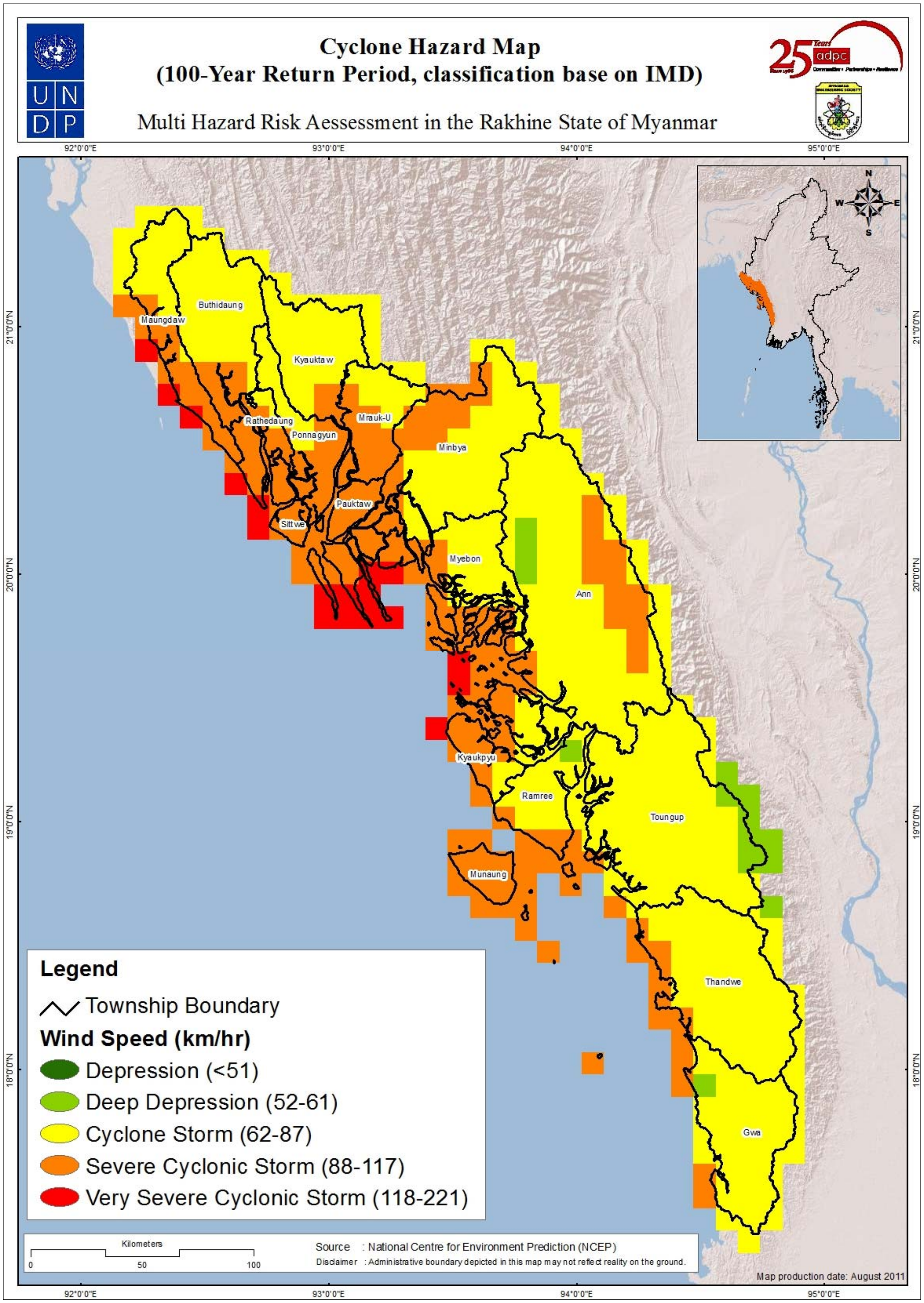

Figure 5: Cyclone hazard map for 100-year return period

The high wind speed with the category of Severe Cyclonic Storm (88-117 km/hr) is found in the inland area (eastern part of Ann Township) from 100-year return period cyclone hazard map (Figure 5). As the maximum wind moves inland, the increased friction due to increased surface roughness acts to reduce the sustained wind. This effect can be seen in the Ann Township. High wind speed is shown in the coastal area and the wind speed reduces when wind moves inland. The wind speed becomes higher again at the eastern part of Ann Township. This is due to the interaction between wind and terrain. Because of surface friction, the over-land winds increase with height from the surface to about 3,000 feet (Guard and Lander, 1999). The eastern part of Ann Township is mountainous area with higher altitude compared to the central area. As a result, winds at the eastern part (higher elevation) are stronger than winds at lower elevations.

India Meteorological Department
Tropical Cyclone Intensity Scale

Category	Sustained winds (3-min average)
Super Cyclonic Storm	>120 knots >222 km/h
Very Severe Cyclonic Storm	64–119 knots 118–221 km/h
Severe Cyclonic Storm	48–63 knots 88–117 km/h
Cyclonic Storm	34–47 knots 62–87 km/h
Deep Depression	28–33 knots 52–61 km/h
Depression	≤27 knots ≤51 km/h

Figure 6: Tropical Cyclone Intensity Scale by India Meteorological Department (IMD)

Wind speed range for 5-year return period varies from approximately 33 to 72 km/hr. According to IMD classification, this range will fall into three classes which are Depression (<51 km/hr), Deep Depression (52-61km/hr) and Cyclone Storm (62-87 km/hr). The histogram in Figure 7 represents the range of the 5-year return period wind speed over Rakhine.

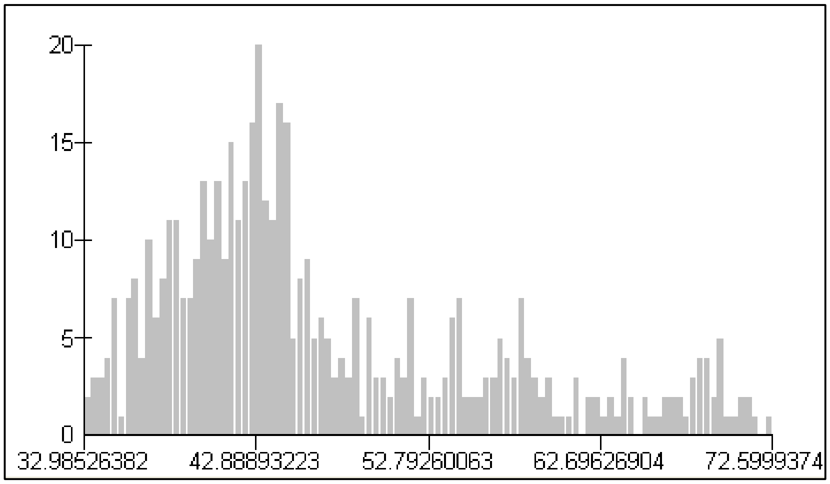

Figure 7: Wind speed histogram of 5-year return period over Rakhine

Wind speed range for 100-year return period varies from approximately 54 to 131 km/hr. According to IMD classification, this range will fall into 3 classes which are Cyclonic Storm (62-87 km/hr), Severe Cyclonic Storm (88-117 km/hr) and Very Severe Cyclonic Storm (118-221 km/hr). Figure 8 represent the range of the 100-year return period wind speed.

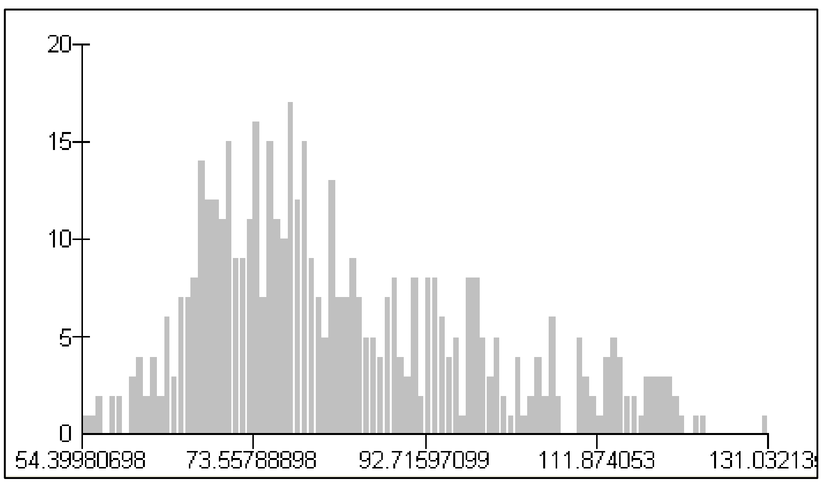

Figure 8: Wind speed histogram of 100-year return period over Rakhine

Recommendation for improving the Hazard Maps

The cyclone hazard maps could be improved by increasing the number of storm events used in the probabilistic analysis. More storm events (at least 30-40 events) should be included in the analysis to represent the population of the storm. In addition, it is important to validate the WRF simulated wind speed with the observed wind speed to check how good the numerical simulated outputs are. Once the discrepancy is estimated then the bias correction can be carried out to improve the simulated wind speed. Model tuning by changing some model physics, such as microphysics, radiation schemes and etc., could also improve the simulated storm simulation results, for instance storm track, wind speed, pressure and etc. However, time constraint should be taken into consideration. Carrying out model physics tuning is extremely time-consuming and could take up to several months to finish the simulations.

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Storm Surge Hazard Assessment

Storm surge inundation shown on the map is based on a static projection of surge levels near the shoreline derived from a computer model of tropical cyclone induced forcing on the sea-surface. The simulated storm surges correspond to probable cyclones of maximum wind speed 270 km/h and 200 km/h originating in the Bay of Bengal; the mean recurrence interval for these cyclone scenarios are expected to be of the order of 40 years and 10 years, respectively. Given the considerable uncertainty on the probable track of the cyclone including its location of landfall, storm surge simulations have been carried out for a large set of synthetic tracks that are in statistical agreement with the historical database in order to derive a composite of the maxima of surge levels. A numerical model which solves the vertically integrated, non-linear equations of conservation of mass and momentum using finite difference numerical schemes has been employed to simulate the hydrodynamics of the cyclone-induced surge. A supplementary parametric module has been utilized to compute the space- and time-varying wind and pressure fields corresponding to these cyclone scenarios. The bathymetric and topographic grids have been adjusted to "Mean High Water", representing a conservative sea level for the intended use of the storm surge hazard mapping. The computed storm surge inundation is in general shown on the map in six color-coded depth ranges corresponding to low, moderate, high and very high levels of the hazard.

Data Availability and Sources

The primary data required for the storm surge hazard assessment include topographic and bathymetric data pertinent to Rakhine State as well as historical data relating to past cyclone impacts along the western coast of Myanmar. Moreover, field measurements of surge heights due to past events of severe cyclonic events, preferably along Rakhine coastline or in adjacent areas, are also required for model validation. Table 3 summarizes the data requirements, possible sources and whether or not such data were available for the present study.

The accuracy of inundation modeling depends to a large extent on the resolution of topographic data used; however, owing to non-availability of high-resolution LIDAR or land-based survey maps, coarse resolution satellite based elevation data (ASTER) had to be used. Moreover, due to the same reason, the zero line/land line of Rakhine State had to be digitized from that given in the navigation charts.

Table 3: Required data and Sources

Type of Data	Source	Spatial Resolution	Availability
Bathymetric Data			
• **Entire Indian Ocean Basin**	GEBCO	30 arc-seconds	Available
• **Seaboard off Western Myanmar**	Navigation charts	1:150,000 or 1:300,000	Available (1:350,000)
• **Local bathymetry at some nearshore locations**	Myanmar Oceanographic	Varying	Not available
Elevation data Coastal zone of Rakhine State			
• **LIDAR**		Horizontal < 1 m Vertical < 0.3 m	Not available
• **Land based surveys**	Myanmar Survey Department	1:1000, 1:5000, 1:10,000 (at least 1 m contour interval)	Not available
• **ASTER**	JPL, Caltec	Horizontal = 30 m Vertical resolution not known	Available
Past cyclone events			
• **Best track data**	UNISYS, JTWC, IMD, SMRC, DMH	N/A	Available (pre-1945 data availability sparse)
Miscellaneous base data			
• **Administrative boundaries in vector format**	Myanmar Survey Department	1:10,000 or better	Not available
• **Vector data depicting land use types, drainage network, road network, etc**	ditto-	ditto-	ditto-
Hydrological data			
• **Rainfall and river discharges**	DMH, Myanmar	N/A	Not available
Data on past events of storm surges in Western Myanmar			
• **Surge heights**	Scientific Publications	Varying	Available (limited in extent)
• **Extent of inundation**	Scientific Publications	-ditto-	Not available

Hazard Assessment Methodology

The main steps involved in the methodology adopted for the assessment of tropical cyclone induced storm surge hazard for Rakhine State of Myanmar are given in the following.

Statistical analysis of past cyclone events

A database of historical tropical cyclone events was compiled for the North Indian Ocean (NIO) region for the period 1900-todate using 'best-track' data from several sources including Joint Typhoon Warning Centre (JTWC, US Navy) and SMRC (1998). However, maximum wind speeds in the portion of data prior to satellite observations (i.e., 1945) were found to be distinctly less reliable and were thus excluded. From the remaining portion of the database (i.e., 1945-todate), the cyclones that made landfall in Rakhine State and adjacent areas of the western coast of Myanmar were collated to statistically analyse the annual maxima of wind speeds using Gumbel's (1958) method (Holmes, 2007), following Rupp and Lander (1996) for tropical cyclones in Guam, and several others. Figure 9 shows the resulting plot of wind speed against the reduced variate: the intercept and the slope of the linear regression line give the mode (u = 68.46) and slope (a = 55.3) of the fitted Type-I extreme value distribution. The recurrence interval for different wind speeds could thus be predicted, and accordingly, the following scenarios were selected for the storm surge hazard assessment: Wind speed of 270 km/h with an estimated recurrence interval of 40 years (Scenario-1) and a wind speed of 200 km/h with an estimated recurrence interval of 10 years (Scenario-2).

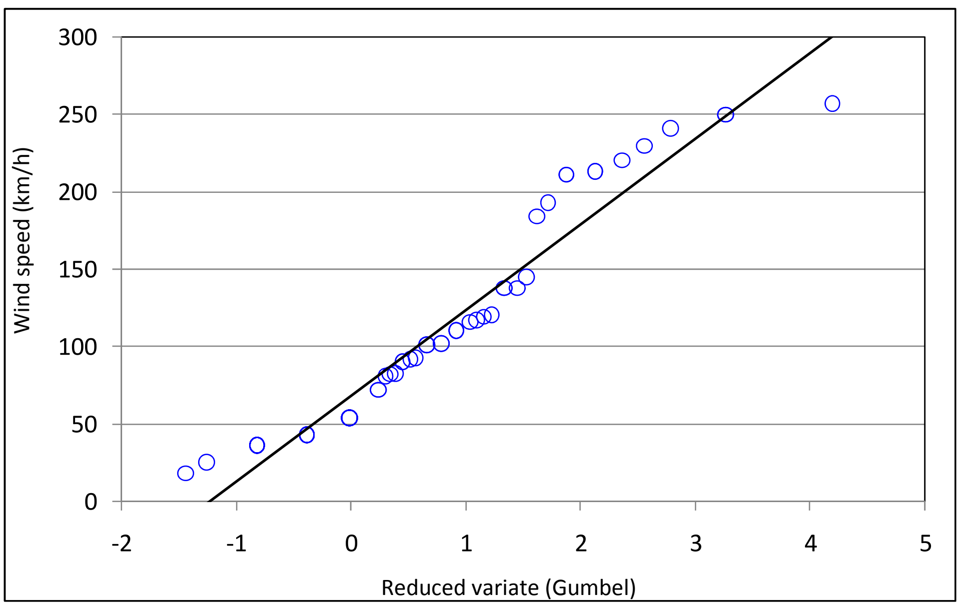

Figure 9: Analysis of annual maximum wind speeds for Rakhine State and adjacent areas using the Gumbel method

Numerical simulations

The space- and time-varying wind and pressure fields for selected cyclone events and scenarios were generated using a parametric model. These wind and pressure fields (Figure 10) forced a depth-averaged, two-dimensional hydrodynamic model (*Delft3D Flow*), which employs the quadratic wind friction formulation and vertically integrated, non-linear equations of conservation of mass and momentum, to compute the resulting storm surge off the coastline of Rakhine State. The primary input parameters required for the cyclone model include the maximum sustained wind speed (V_m), the radius to maximum wind (R), the central pressure (p_c), the neutral pressure (p_n), the cyclone track (longitude and latitude) and the forward velocity.

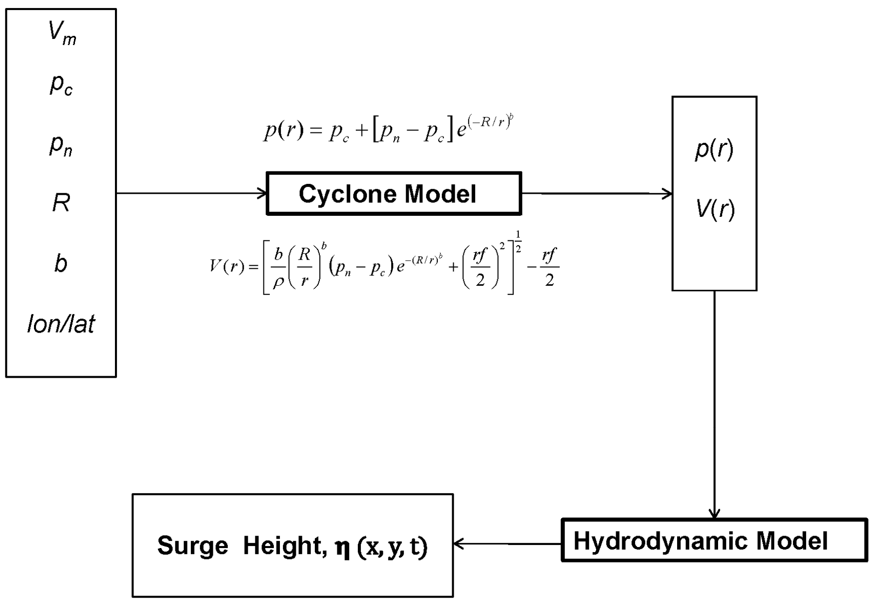

Figure 10: Cyclone and storm surge modelling procedure (notation shown has usual meaning)

The bathymetry for the model was derived from Navigation Charts (Chart Nos. 817 and 818) and from 30 arc-second GEBCO (2010) grid. The extent of the rectangular grid for scenario simulations is 89.6°E-94.6°E and 16°N-21°N with a grid spacing of 2 km. The grid spacing of 2 km for the surge simulations was determined based on a sensitivity analysis whilst the time step of 60 s was chosen so as to satisfy the Courant numerical stability criterion. The conventional impermeable vertical wall assumption was made along the coastal boundary.

First, the cyclone and hydrodynamic models were run for two past events, namely Gwa in 1982 and Mala in 2006 in order to calibrate and validate the model formulation by extending the above computational domain further south to accommodate the track of these cyclones. Accordingly, it was decided to use a wind friction factor of 0.026 and a Manning's roughness coefficient of n = 0.03.

As there is considerable uncertainty on the probable cyclone tracks including the landfall location, the storm surge simulations for each scenario was carried out for a large set of synthetic tracks that are in statistical agreement with the historical database (e.g., as in Emanuel et al., 2008 and Hallegatte, 2007). Accordingly, for each scenario, the landfall location on the coastline was varied at 0.186^{o} (~20 km) intervals along the latitude and an array of separate model simulations was carried out for each hypothetical track. The model for cyclone scenario-1 was integrated with a maximum pressure drop of 70 hPa and a radius of maximum wind of 40 km whilst these parameters for scenario-2 were 55 hPa and 30 km, respectively.

The computed maximum surge heights at every grid point from each of the above hypothetical scenarios was collated to form a composite map of peak surges corresponding to respective hazard scenarios over the entire model domain (Figure 11). Note that the surge levels shown in Figure 11 for wind speeds, (a) 270 km/h, and (b) 200 km/h, are exclusive of tidal effects. For a conservative, worst-case estimate of storm tide, an additional 1.2 m may be added to the surge levels shown in Figure 11 (as explained in the following section).

Incorporation of tidal effects

The tide-surge interaction is non-linear. However, given the uncertainties involved in predicting the time of landfall of tropical cyclones and in keeping with the objective of present hazard mapping, we superimpose the maximum tide on the surge for a conservative estimate of probable flood distribution. Accordingly, the computed surge levels near the shoreline were adjusted to “Mean High Water” sea-level condition at spring tide prior to inundation computations, thus representing a conservative sea level for the intended use of the storm surge hazard mapping. An average value of the maximum tidal range (2.4 m) corresponding to spring tide was obtained based on data from several tidal stations along the seaboard off Rakhine State (Table 4). Accordingly, the computed maximum surge levels near the shoreline were superimposed with a further rise in water level of 1.2 m to take into account the worst-case tidal effect.

Table 4: Tidal range along seaboard off Rakhine State based on Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) conditions. (Source: Admiralty Chart Nos. 817 and 818)

Tidal Station			Max. tidal range based on MHWS and MLWS (m)
Location	**Latitude (N)**	**Longitude (E)**	
Chaungtha Kyun	16° 57'	94° 26'	2.0
Gwa Bay	17° 35'	94° 34'	2.1
Andrew Bay	18° 21'	94° 21'	2.2
Sagu Kyun	18° 48'	93° 59'	2.3
Searle Point	18° 54'	93° 37'	2.5
Kyaukpyu	19° 26'	93° 33'	2.8
Sittwe	20° 08'	92° 54'	2.3
S. Martin's Island	20° 37'	92° 19'	2.7
Average max. tidal range along seaboard off Rakhine State			**2.4**

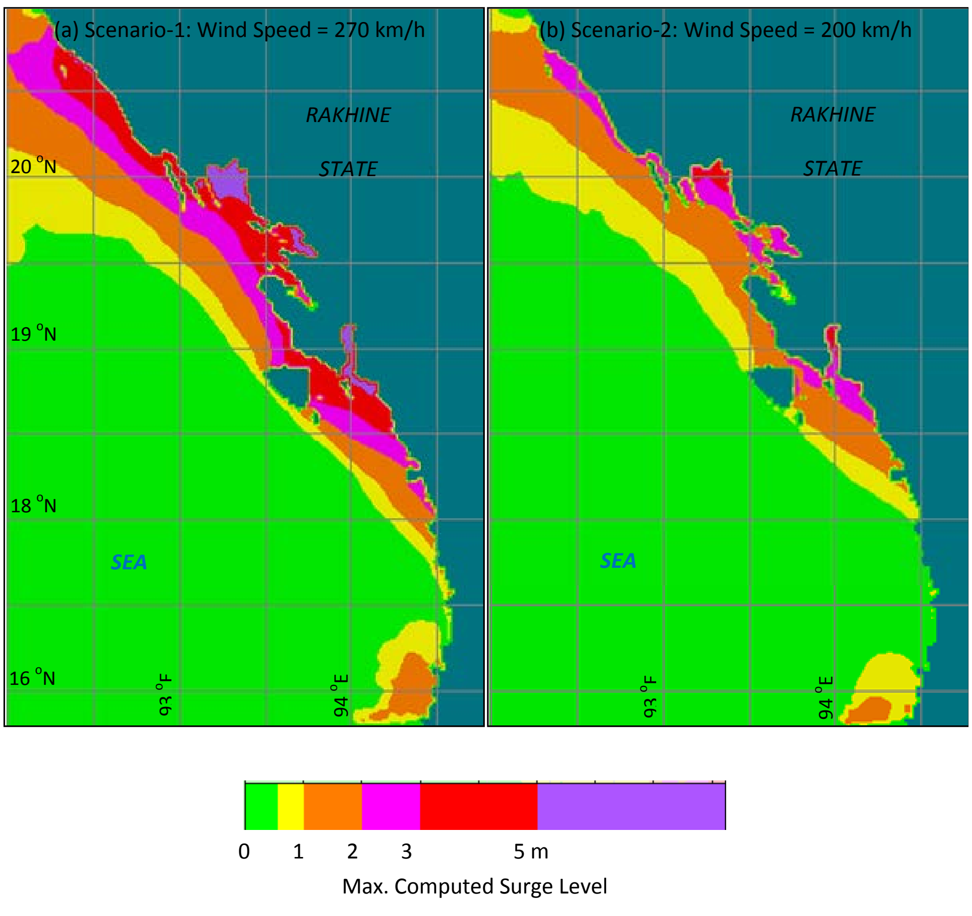

Figure 11: Composite of computed maximum storm surge levels corresponding to: a) Scenario-1 (Wind speed = 270 km/h), and b) Scenario-2 (Wind speed = 200 km/h)

Inundation simulations

GIS based modeling tools and supplementary software were used to obtain the likely inundation distribution onshore based on the computed surge heights at the coastline. The inundation distribution computed in this way is essentially static; however, a constant rate of decay of surge heights was allowed in the absence of land use maps depicting ground roughness. The inundation computations were carried out for the two cyclone-induced storm surge scenarios at a horizontal resolution of 100 m with elevation data obtained from ASTER DEM.

Limitations

One limitation is that the resolution of the modeling is no greater or more accurate than the bathymetric and topographic data used. The resolution of the model also constrains its ability to resolve some small-scale features of the onshore terrain including narrow waterways. Moreover, the tide has been linearly superimposed on the computed storm surge levels on a conservative basis although the tide-surge interaction is non-linear. It must also be added that set-up due to wave breaking, storm rainfall, riverine flooding, ground cover and surface roughness have not been incorporated in the present model simulations.

Hazard Maps and their Interpretation

The storm surge hazard maps depicting the spatial distribution of onshore inundation at high tide for Rakhine State of Myanmar are shown in Figure 12 to

Figure 17 for scenarios-1 and -2, respectively. The depth of probable inundation shown on these maps is classified as given in Table 5. (Note: The classification to be adopted finally ought to be discussed with the end users, and this may be revised accordingly.)

Whilst this tsunami hazard map has been compiled with the currently available scientific information and base data, users are invited to notify the developers of any map discrepancies.

Table 5: Classification of storm surge inundation depth

Depth of Inundation (m)	Color code
< 0.5 m	
0.5 – 1 m	
1 – 2 m	
2 – 3 m	
3 – 5 m	
> 5 m	

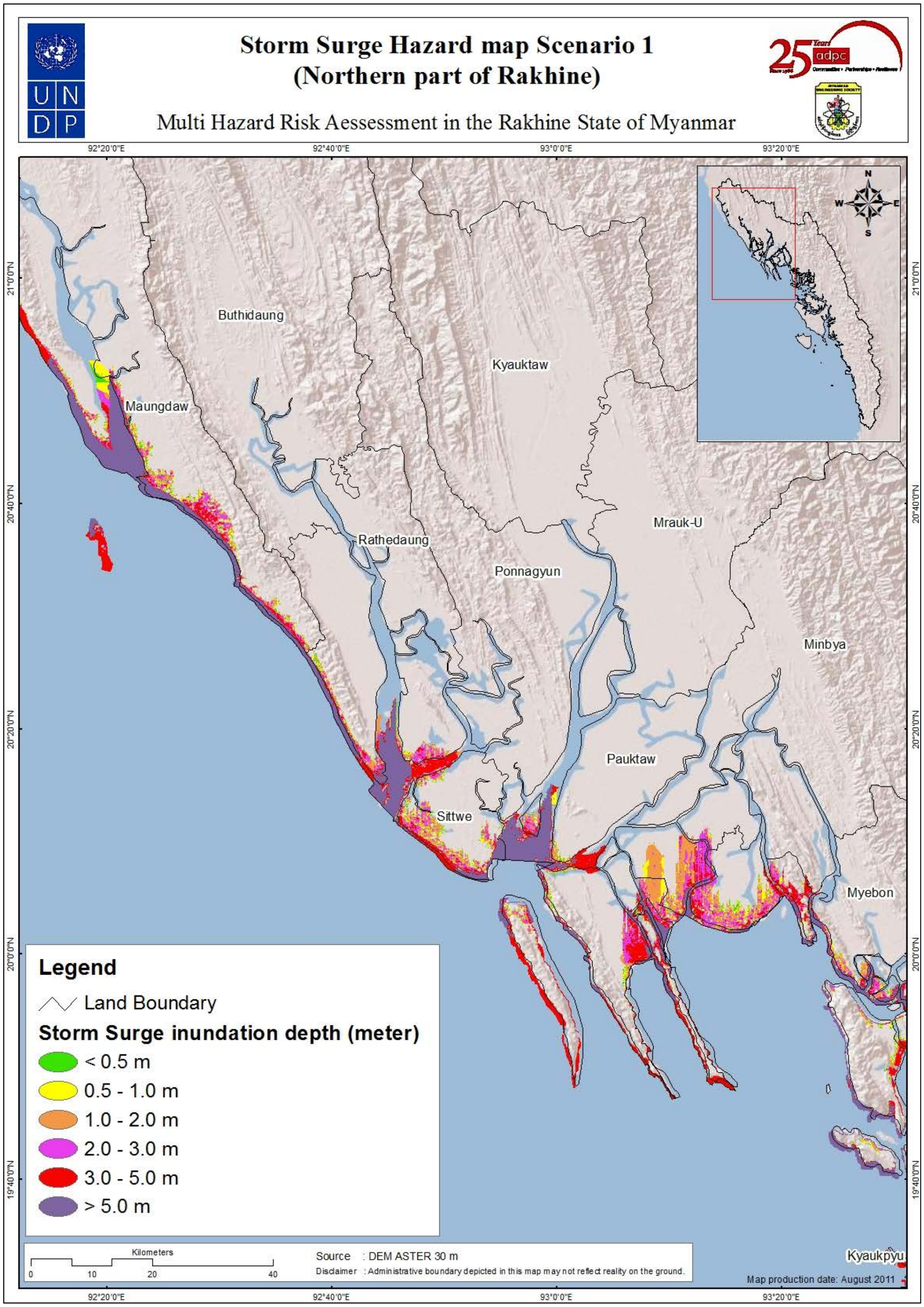

Figure 12: Storm surge hazard map for Rakhine State of Myanmar (Northern part) corresponding to a tropical cyclone event of maximum wind speed 270 km/h.

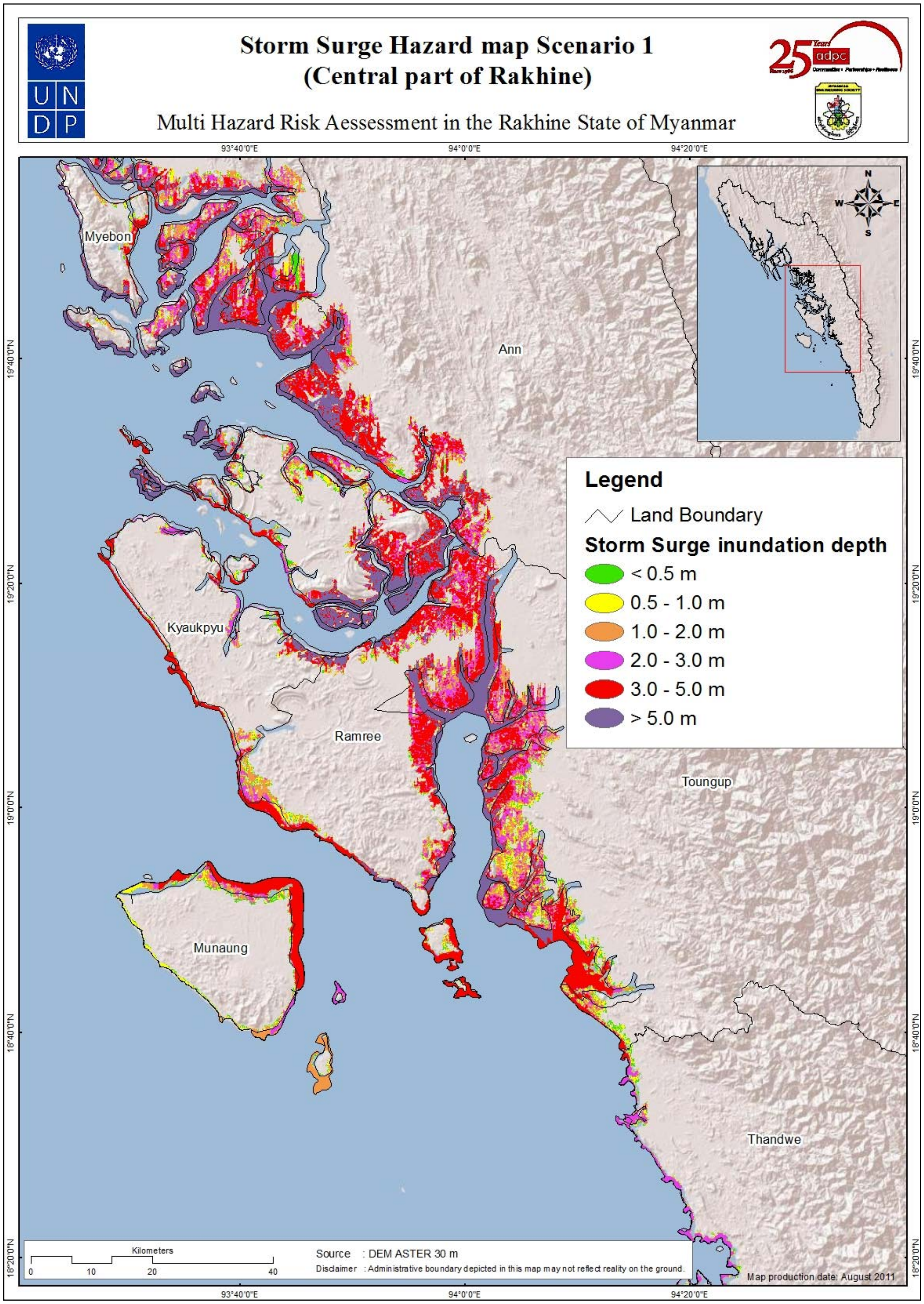

Figure 13: Storm surge hazard map for Rakhine State of Myanmar (Central part) corresponding to a tropical cyclone event of maximum wind speed 270 km/h.

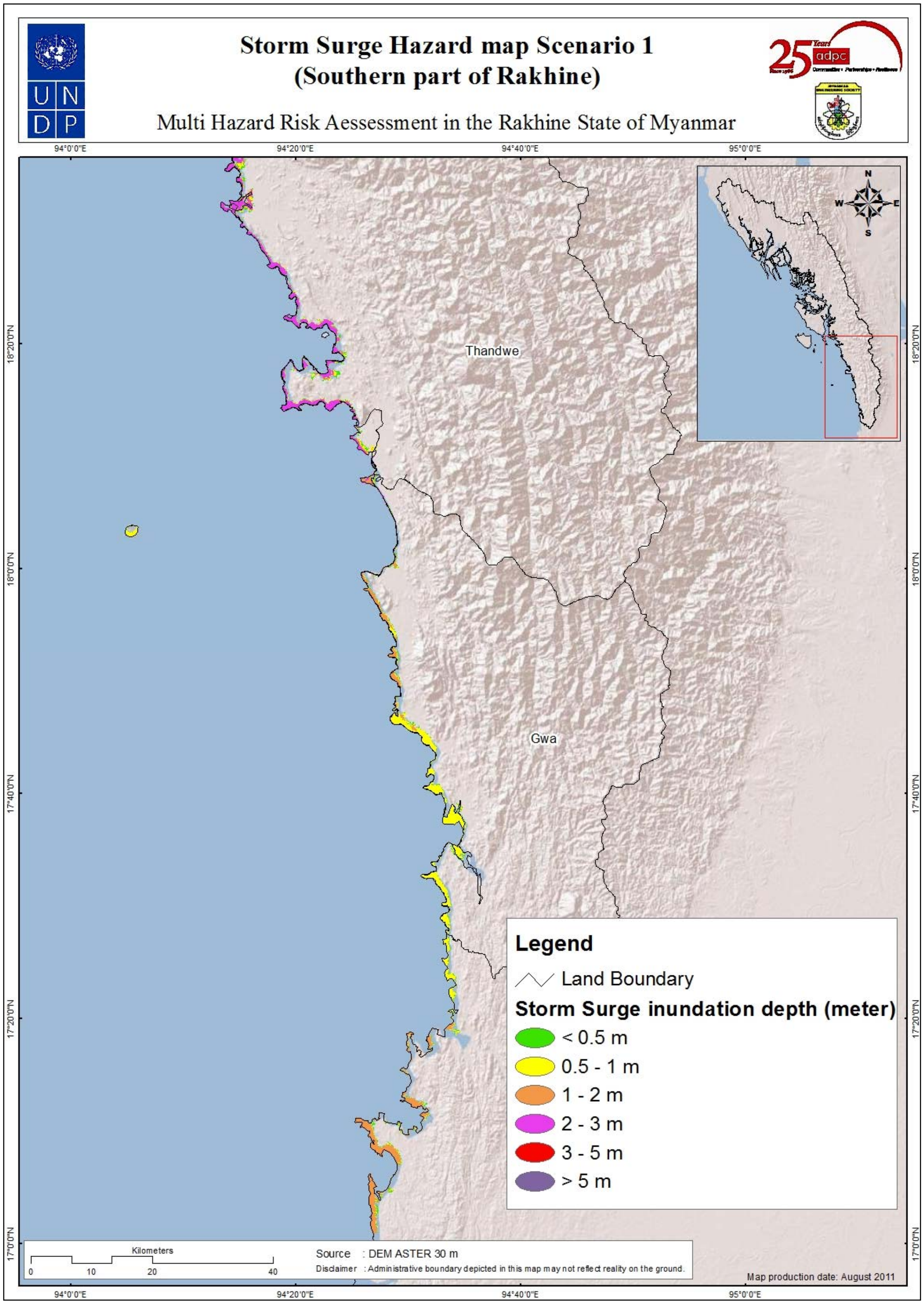

Figure 14: Storm surge hazard map for Rakhine State of Myanmar (Southern part) corresponding to a tropical cyclone event of maximum wind speed 270 km/h.

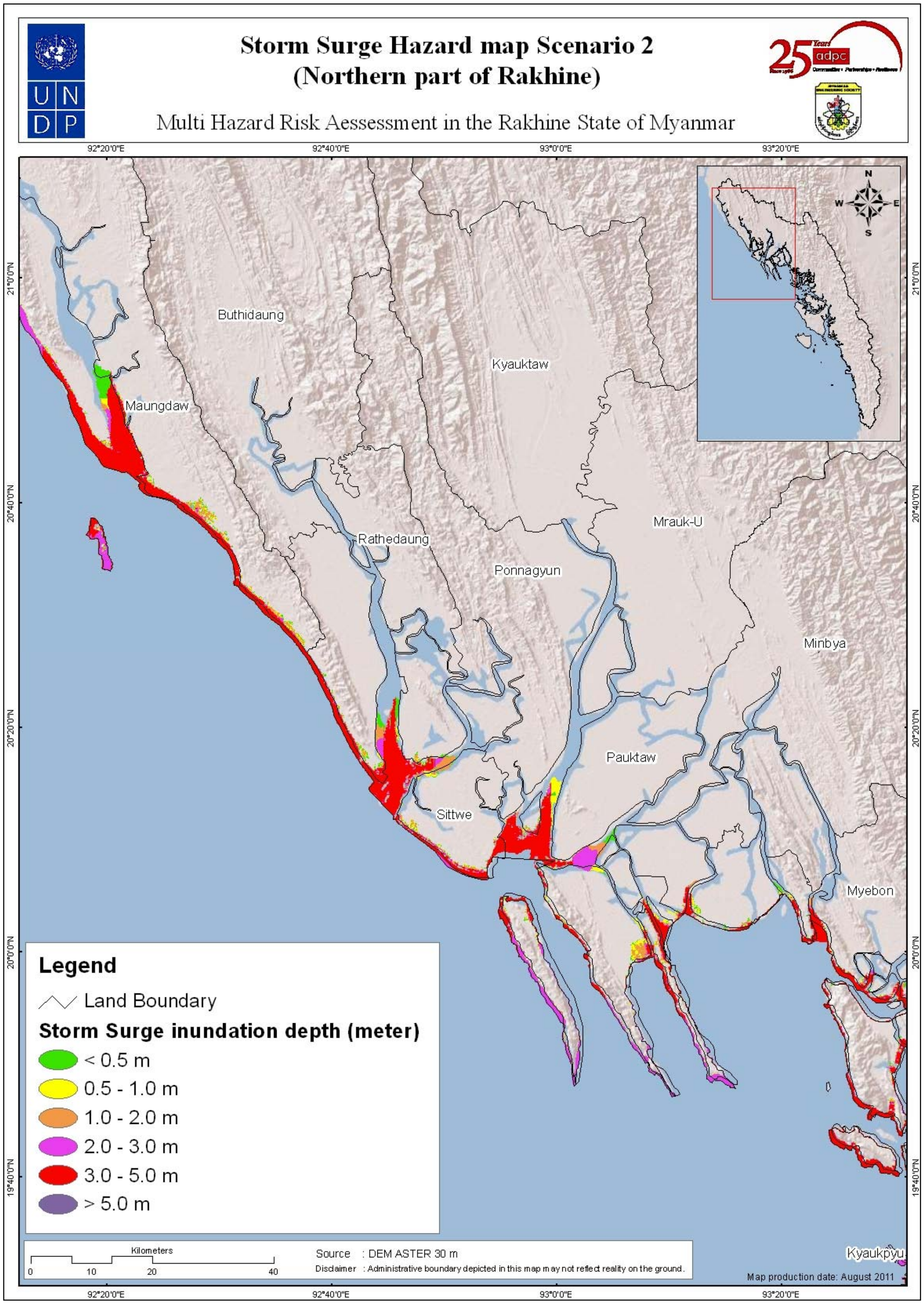

Figure 15: Storm surge hazard map for Rakhine State of Myanmar (Northern part) corresponding to a tropical cyclone event of maximum wind speed 200 km/h.

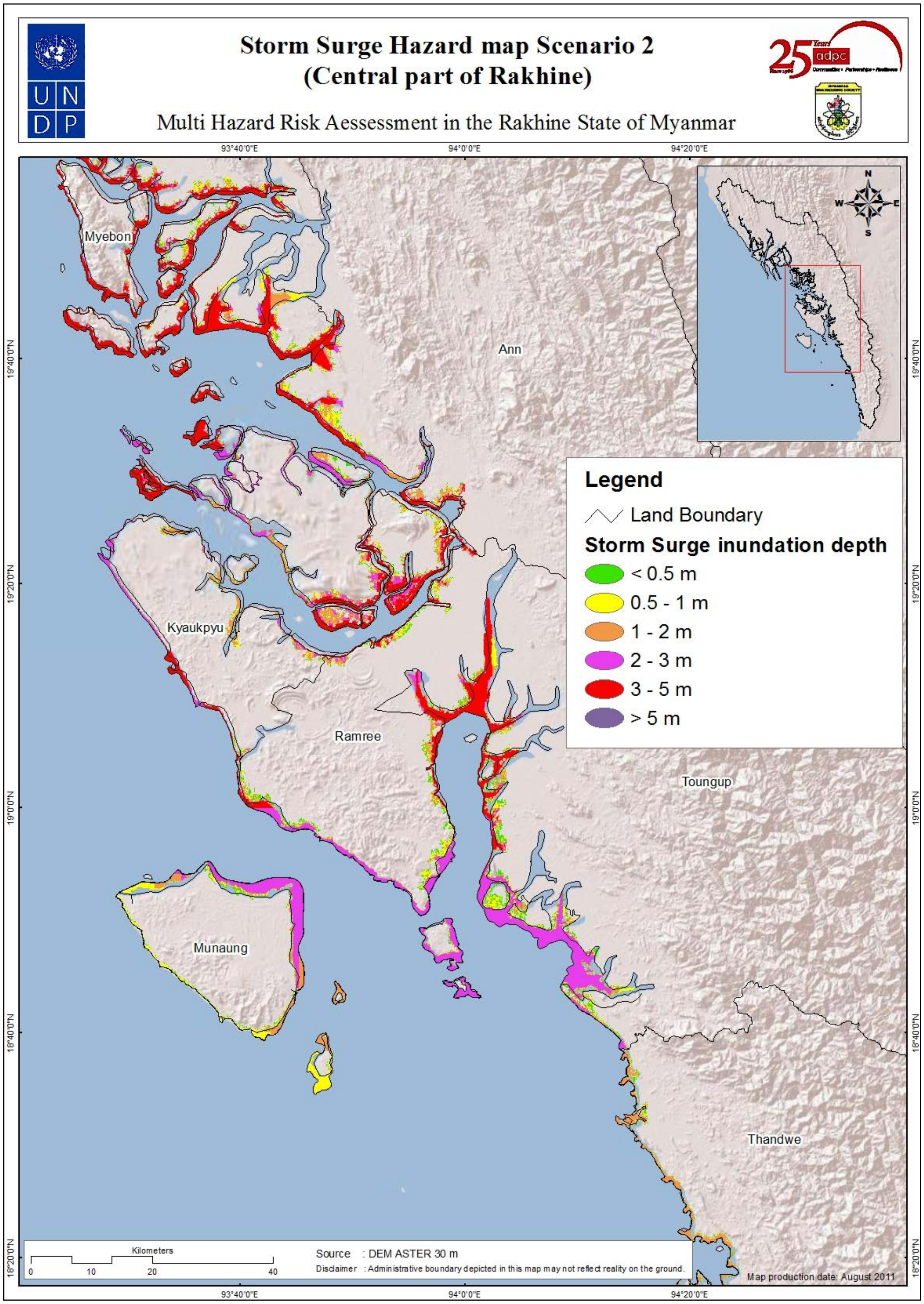

Figure 16: Storm surge hazard map for Rakhine State of Myanmar (Central part) corresponding to a tropical cyclone event of maximum wind speed 200 km/h.

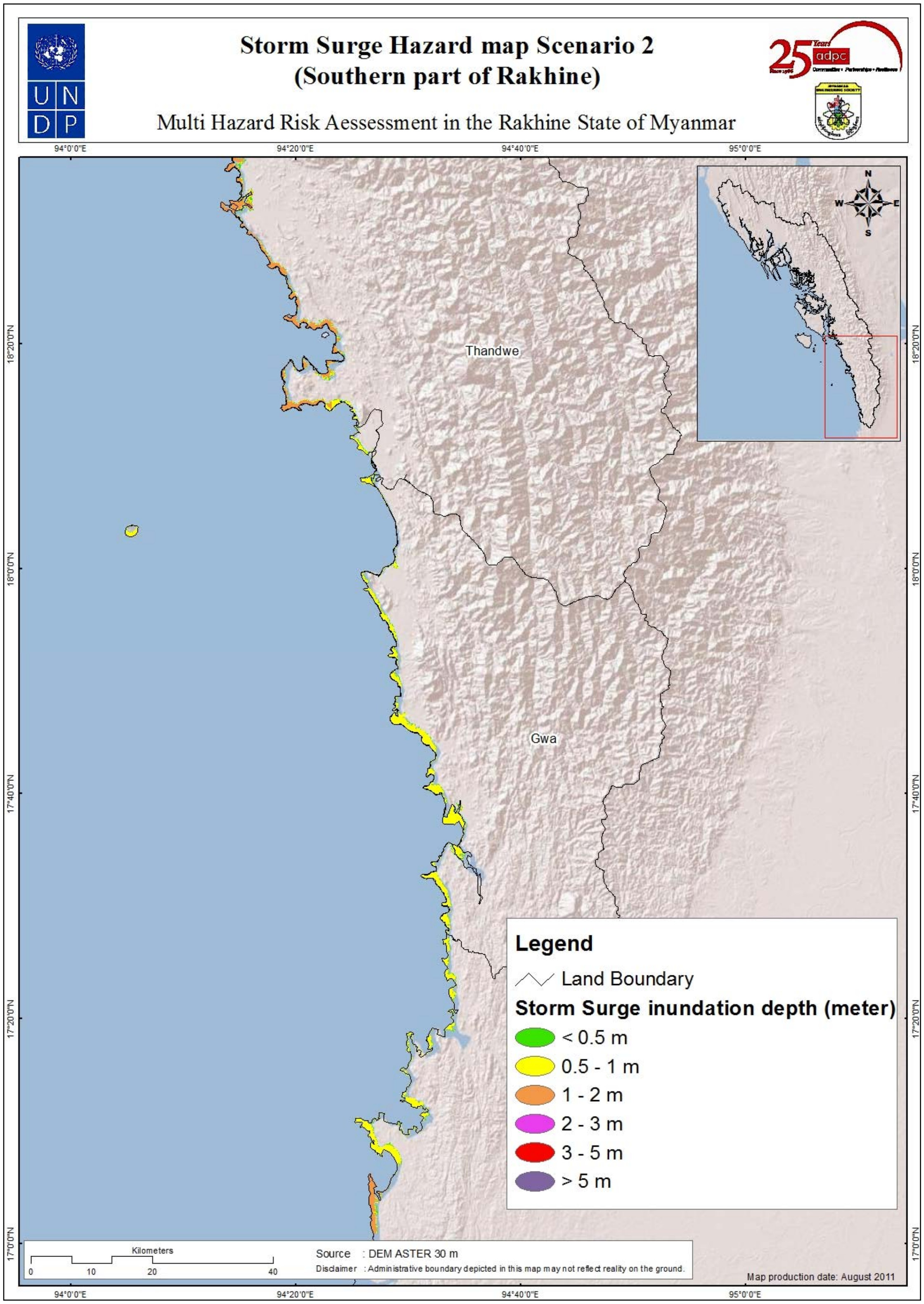

Figure 17: Storm surge hazard map for Rakhine State of Myanmar (Southern part) corresponding to a tropical cyclone event of maximum wind speed 200 km/h.

Recommendation for improving the Hazard Maps

The accuracy of inundation simulations could be improved by utilizing higher resolution topographic data such as those acquired through the LIDAR system. It is also desirable to carry out field verifications to detect any discrepancies, particularly since the vertical resolution of elevation data (ASTER) utilized in the present inundation simulations is coarse. The present version of the map could be further enhanced by incorporating more information relating to the storm surge hazard as well as mitigation measures.

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Riverine Flood Hazard Assessment

Flood hazard maps were developed for the most flood prone river basins. Five rivers have been identified and determined for flood hazard and risk assessments in accordance with the past history of flooding as well as in consultation with flood-related agencies. These rivers are Naf, (Ka La Pan Zin+Ma Yu), Kala Dan, (Le Myo+Ya Maung+Thin Ganet), (Sin Gon Daing+Ye De). The flood hazard maps showing the flood inundation and flood water depth with various return period scenarios were developed. These return periods are 10 years and 100 years. It is noted that the larger the return period is, the worst the flood scenario will be. The flood inundation area for a particular scenario has been indicated in square kilometers. The results of the flood hazard maps are shown in Figure 20.

Data Availability and Sources

For extensive flood hazard mapping, detailed hydrological, meteorological, demographic and geomorphological data are required. It is also imperative to understand the scale of the flood hazard assessment. More precise and detailed data are required for site specific flood studies. The objective of the current project is to develop flood hazard maps at state level scale. The current hazard maps have been developed based on data available with focal departments and established authentic sources. The parameters are classified into following categories with their sources.

(1) Hydrological data: Daily rainfall data for the period from 2001 to 2010 at 10 gauging stations within Rakhine State were collected from the Department of Meteorology and Hydrology, Myanmar (DMH)

(2) Elevation: ASTER, resolution 30 meters (source: http://asterweb.jpl.nasa.gov/gdem.asp)

(3) River network: Google Map

Software required for Flood Hazard Assessment

The flood hazard assessment has been developed using several software like ArcGIS 9.3, HEC-GeoHMS (USACE, 2009a), HEC-HMS (USACE, 2008), HEC-GeoRAS (USACE, 2009b) and HEC-RAS (USACE, 2009c).

The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a geospatial hydrology toolkit, which uses ArcView and the Spatial Analyst extension to develop a number of hydrologic modeling inputs for the Hydrologic Engineering Center's Hydrologic Modeling System, HEC-HMS. ArcView GIS and its Spatial Analyst extension are available from the Environmental Systems Research Institute, Inc. (ESRI). Analyzing digital terrain data, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the drainage network. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, and delineate sub-basins and streams.

HEC-HMS is a numerical model which is used mainly to simulate precipitation-runoff processes of dendritic watershed systems. The model offers different methods to simulate infiltration losses, transform excess precipitation into surface runoff, open-channel routing and compute base flows.

HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI). The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. To create the import file, the user must have an existing digital terrain model (DTM) of the river system in the ArcInfo TIN format. The user creates a series of line themes pertinent to developing geometric data for HEC-RAS. The themes created are the Stream Centerline, Flow Path Centerlines (optional), Main Channel Banks (optional), and Cross Section Cut Lines referred to as the RAS Themes.

HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS system contains four one-dimensional river analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines.

Hazard Assessment Methodology

Figure 18 and Figure 19 show the methodology for mapping the flood inundation area and depth for various return periods. The methodology largely used software Hec-GeoRAS, Hec-GoHMS, Hec-RAS and ArcGIS 9.3 as stated above. The creation of river basin and river profile has been validated using Google-map images of the river basin. The following are the steps used in the development of flood inundation maps.

- Extraction and profiling of river and basin from ASTER data using HEC-GeoHMS
- Creation of river center lines, bank lines, flow path lines, and cross sections in GIS platform by using HEC-GeoRAS
- Estimation of floods at different return periods (this analysis uses five different return periods; 10 and 100 years) for each river using Extreme Type I distribution (Gumbel distribution).
- Computation of flood levels using HEC-RAS.
- Export of the result from HEC-RAS into GIS platform for mapping of flood inundation areas.
- Development of flood inundation maps (area and depth).

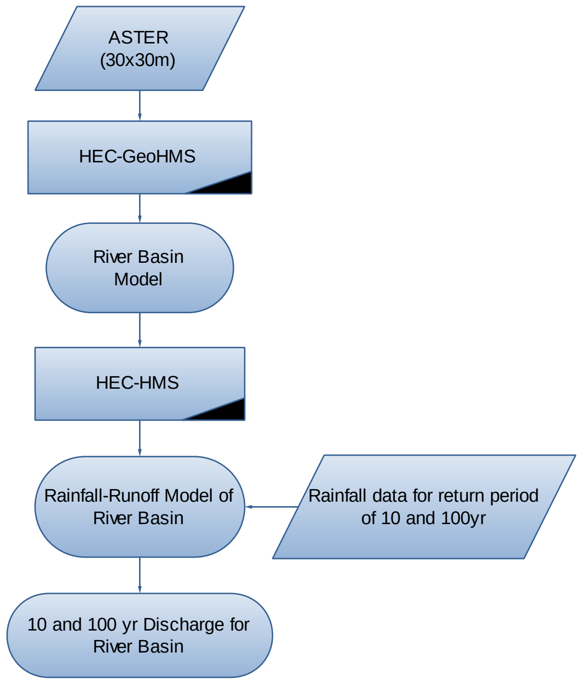

Figure 18: Flow Chart : Rainfall runoff model

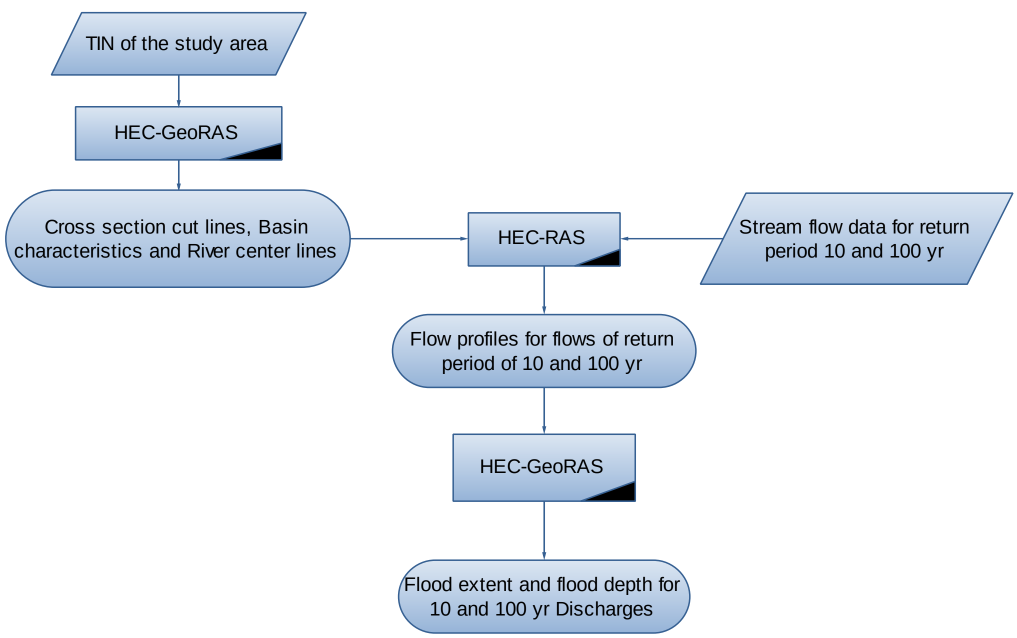

Figure 19: Flow Chart : Inundation model

Based on the proposed methodology, the flood hazard maps for specified rivers have been developed and presented in Figure 20 to Figure 21.

Hazard Maps and their Interpretation

The flood hazard maps will be overlaid on administrative boundary maps (townships, etc.) and impacts will be discussed.

The current flood hazard maps have been developed for five important river basins in Rakhine state of Myanmar. These river basins are frequently reported to have flooding that affects lives and properties. The flood hazard map shows the following:

- State and township boundaries
- Main river network
- Each color of flood inundation area represents different levels of flood depth

Color		Flood Depth
	Dark Green	Less than 0.5 meter
	Light Green	Between 0.5 and 1.0 meter
	Light Blue	Between 1.0 and 2.0 meters
	Dark Blue	More than 2.0 meters

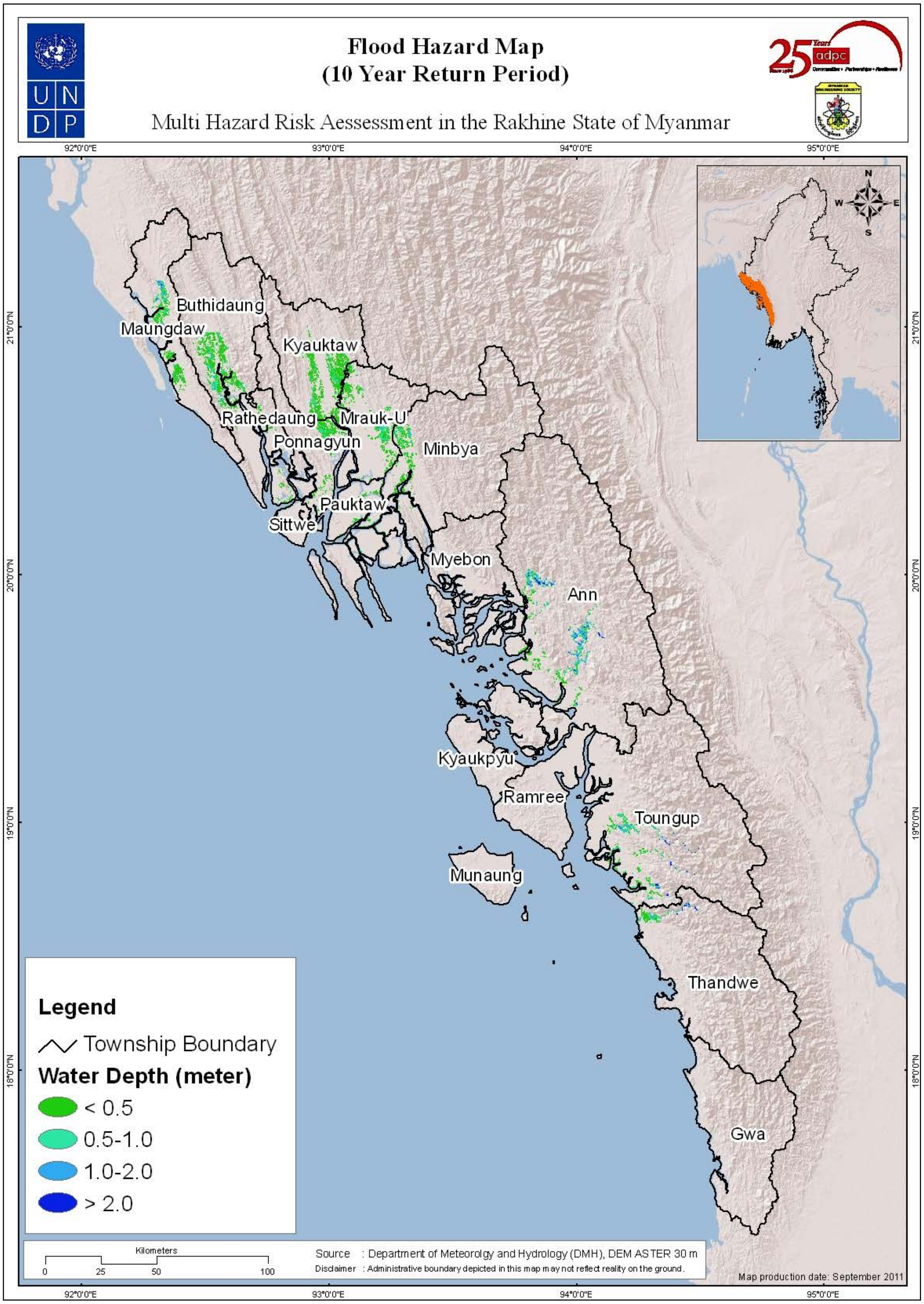

Figure 20: Flood hazard map showing flood inundation area several main river basins located in Rakhine State for 10 year return period

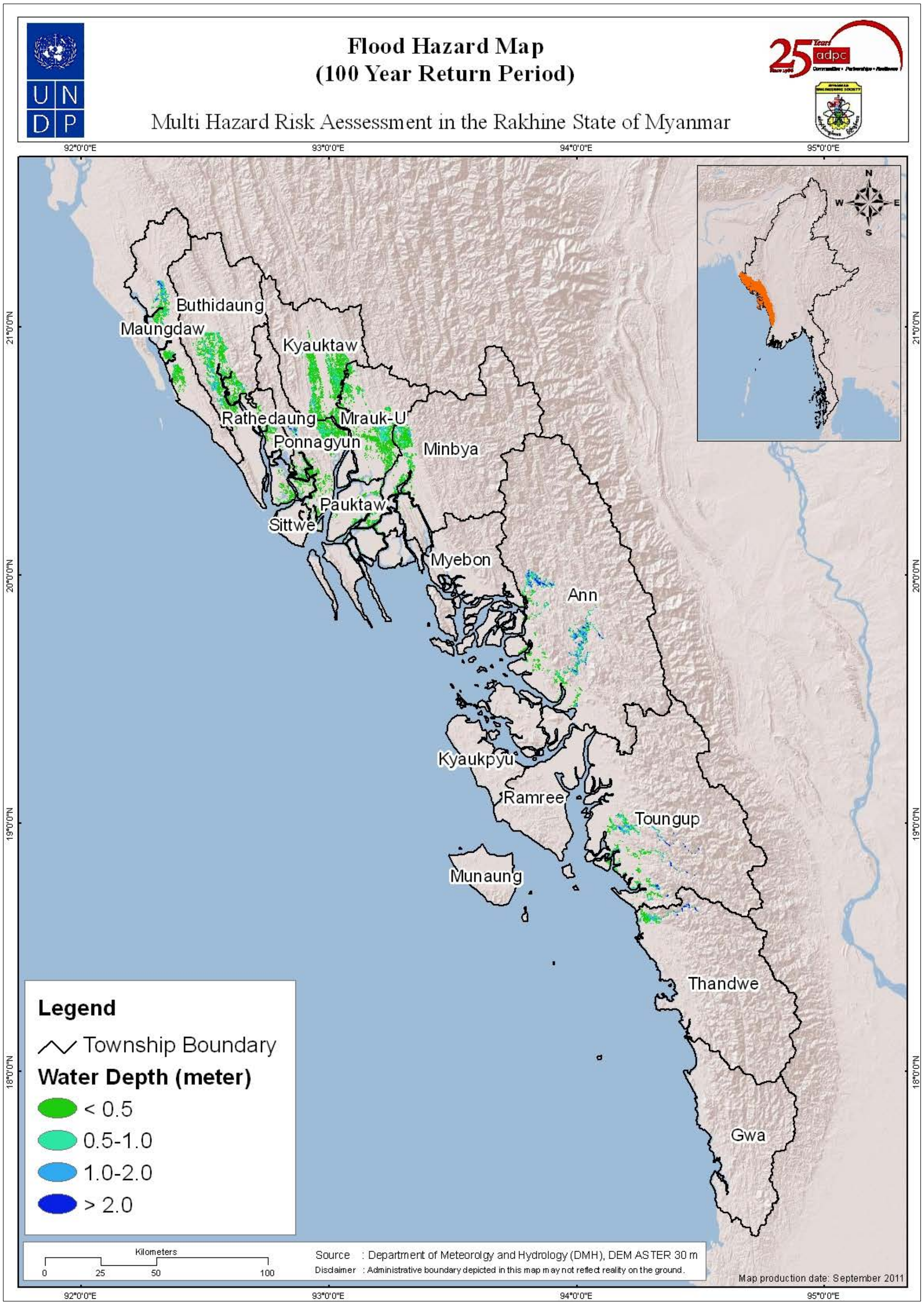

Figure 21: Flood hazard map showing flood inundation area several main river basins located in Rakhine State for 100 year return period

Recommendation for improving the Hazard Maps

- Use of better digital elevation data will improve the results. Also, continuously recorded rainfall data will be useful.
- The study has used secondary data primarily from the Department of Meteorology and Hydrology. Due to the limited access to detailed data and field visits, the results of the flood hazard assessment are limited to the state level. It is recommended that site-specific flood hazard mapping is carried out for local-level analysis and more detailed planning.

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Landslide Hazard Assessment

The map is a simplified representation of landslide hazard susceptibility zones in Rakhine State of Myanmar.

Figure 24 and

Figure 25 show the spatial distribution of landslide hazard susceptibility zones induced by rainfall and earthquake at state level. Townships boundaries are marked as overlay layers for more detailed spatial distribution. Because of the absence of reliable landslide inventory, which would allow the use of a statistical method and the fact that running physical models at state scale is not feasible, weights were selected based on the expert opinion. Although the method is subjective, it allows the incorporation of expert opinion and the use of group decision making and therefore is leading to reliable results, given the scale. Semi-quantitative indicators has been used and found to be more suitable with the indicators and resulting landslide susceptibility expressed in a scale from 0 to 1, to allow better representation of the spatial variability in the data. Only the final susceptibility was classified into qualitative classes of negligible, low, medium, high, and very high.

Data Availability and Sources

Conditioning factors:

- Slope and lithology maps; The slope map used for the landslide susceptibility mapping of Rakhine State has been derived from Global Digital Elevation Model dataset called ASTER DEM , 30 meter resolution released by NASA for assigning grid of slope angles (http://asterweb.jpl.nasa.gov/),geological descriptions or lithological characteristics for assigning the lithology factor (rock strength)
- Geological map used for this study has been derived from a geological map of Myanmar scale 1 : 500,000 developed by Myanmar Geo-science Society (MGS).
- Land use map : Myanmar Information Management Unit (MIMU, 2000) with updated from Google map (Year 2003-2010)
- Soil type map; soil map has been resulted in from the combination of using the agricultural soil map from FAO (2006) and Landsat ETM imagery using “clay ratio”.
- Geomorphological map; geomorphological information has been derived from Landsat ETM imagery.

Triggering factors:

- Rainfall data ; Daily rainfall data from several stations covering Rakhine State (10 stations) for 10 years period have been collected from the Department of Meteorological and Hydrology (DMH) of Myanmar and used to create rainfall map.

- Earthquake hazard map; the earthquake hazard map which is built around existing and on-going related works, namely National Seismic Hazard Maps of Myanmar by the Myanmar Earthquake Committee and Myanmar Earthquake Risk Assessment by ADPC and the Department of Meteorology and Hydrology, Myanmar has been used to assess the Earthquake-induced landslide.

Hazard Assessment Methodology

The generation of landslide hazard susceptibility maps at state level in Rakhine, has been designed using semi-quantitative model with seven indicator maps. A spatial-criteria evaluation technique has been implemented in GIS system. Each indicator was processed, analyzed and standardized according to its contribution to hazard. The indicators were weighed using direct, comparison and rank-ordering weighing methods, and weights were combined to obtain the final landslide susceptibility maps.

Seven thematic layers comprising from five conditioning factors and two triggering factors were created: geomorphology, slope gradient, land use, rock condition (lithology), soil, PGA and rainfall. Each of the thematic layers was ranked into several classes from safe condition to the most prone condition for landslide hazard. Those layers are then combined with different values of weighting. Table 6 shows the overview of indicators with their corresponding ranking and weight value Geomorphology influences 12% of landslide occurrence, slope contributes 24%, land use to 16%, lithology to 20%, soil to 8% ; and for triggering factor (PGA and rainfall) each contributes 20% to the landslide occurrence. The approach results are illustrated in a susceptibility map with ranks of 1 to 5 which define the landslide susceptibility from safe (negligible) to very susceptible (very high). The overall methodology of landslide hazard susceptibility in Rakhine State can be seen in Figure 22

Table 6: Overview of indicators with their corresponding ranking and weight value

Conditioning Factors				
Factors	**Class**		**Ranking**	**Weight**
Slope (degree)	**from**	**to**		0.24
	0	1	0	
	1	6	0.2	
	6	12	0.4	
	12	18	0.6	
	18	24	0.8	
	24	40	0.95	
	40	45	0.6	
	45	90	0.6	
Soil	Residual, sandy silt		0.7	0.08
	Residual, sandy-silty clay		0.6	
	Transported soil, silty clay		0.2	

Conditioning Factors				
Factors	**Class**		**Ranking**	**Weight**
	Transported and residual soil, silty clay		0.3	
Land use	Evergreen forest		0.1	0.16
	Deciduous forest		0.2	
	Scrubland		0.26	
	Agriculture		0.4	
	Settlement		0.9	
Lithology	Flysch type sediments and Globotruncana Limestone		0.3	0.2
	Flysch (Mawdin Fm and Equivalent)		0.7	
	Irrawady group and equivalents		0.5	
	Recent alluvium		0.25	
	Ultrabasic and basic intrusive		0.8	
	Upper Pegu Group and marine, brackish and terrestric equivalent		0.6	
	Western range		0.6	
Geomorphology	Structural-Ridges Mountains		0.5	0.12
	Denudated Structural Ridge Hills		0.7	
	Alluvium		0.1	
Triggering Factors				
Factors	**Class**		**Ranking**	**Weight**
Rainfall	1170	1310	0.45	0.2
	1310	1410	0.6	
	1410	1560	0.75	
	1560	1620	0.85	
	1620	1650	0.9	
PGA	39	51.7	0.05	0.2
	51.8	56.2	0.2	
	56.3	63.4	0.4	
	63.4	84	0.6	

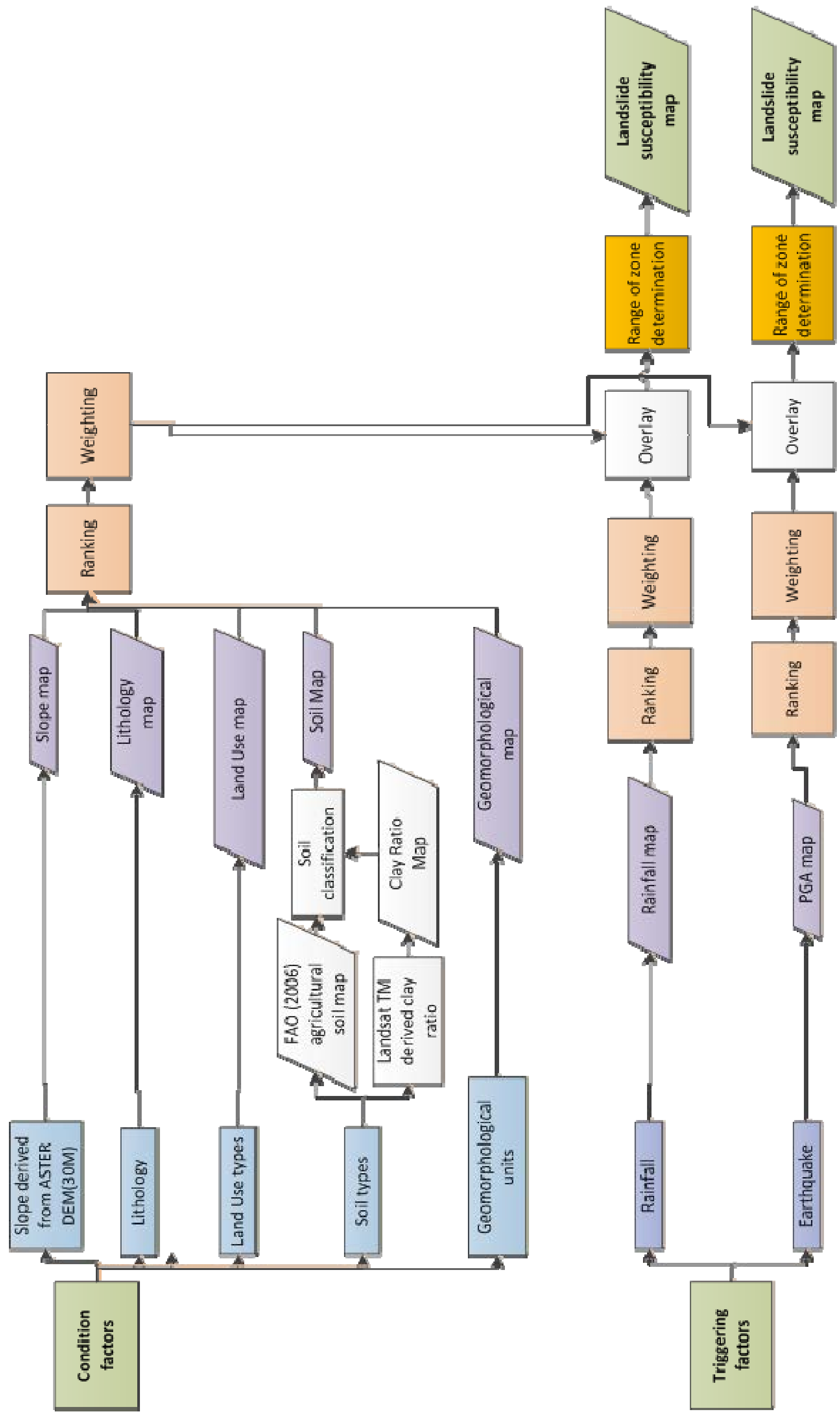

Figure 22: Flowchart showing methodology for landslide hazard susceptibility mapping

Hazard Maps and their Interpretation

The hazard map shows spatial distribution of several landslide susceptibility classes in Rakhine State. Townships boundaries are demarcated for detailed susceptibility in specific regions. Landslide hazard susceptibility in Rakhine State is classified into five zones as stated above. There are two types of landslide hazard susceptibility maps developed in this project, namely, those that are triggered by rainfall during the peak monsoon and those that are triggered by earthquakes.

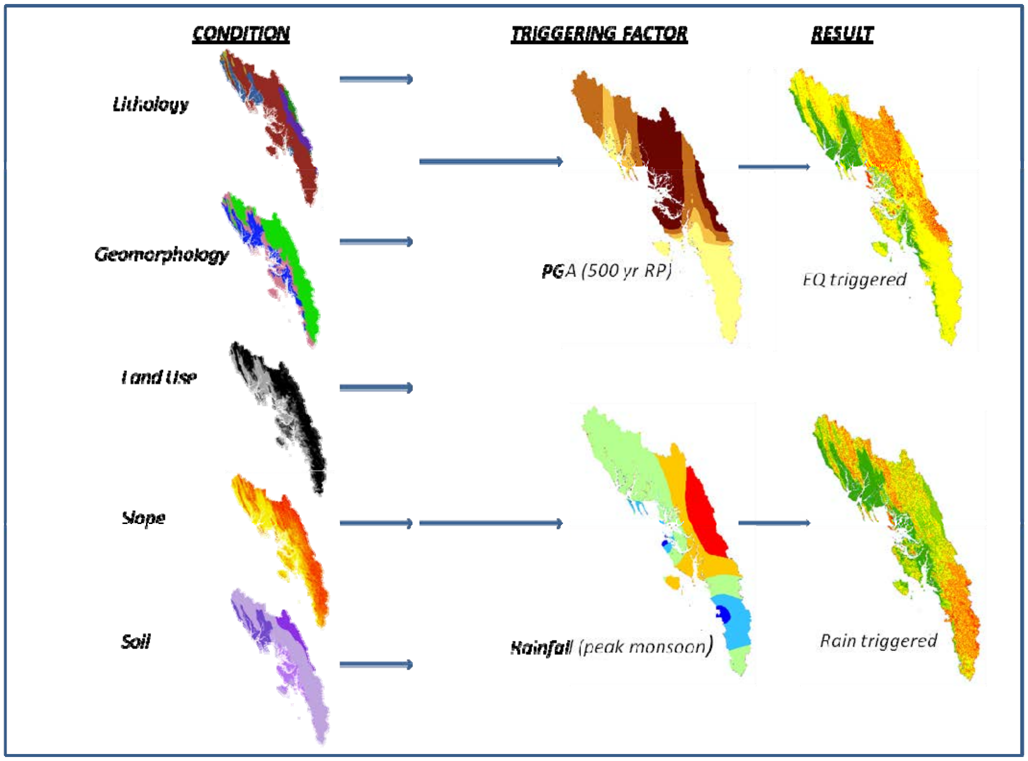

Figure 23: Flowchart showing the model for landslide risk assessment at state level in Rakhine, Myanmar

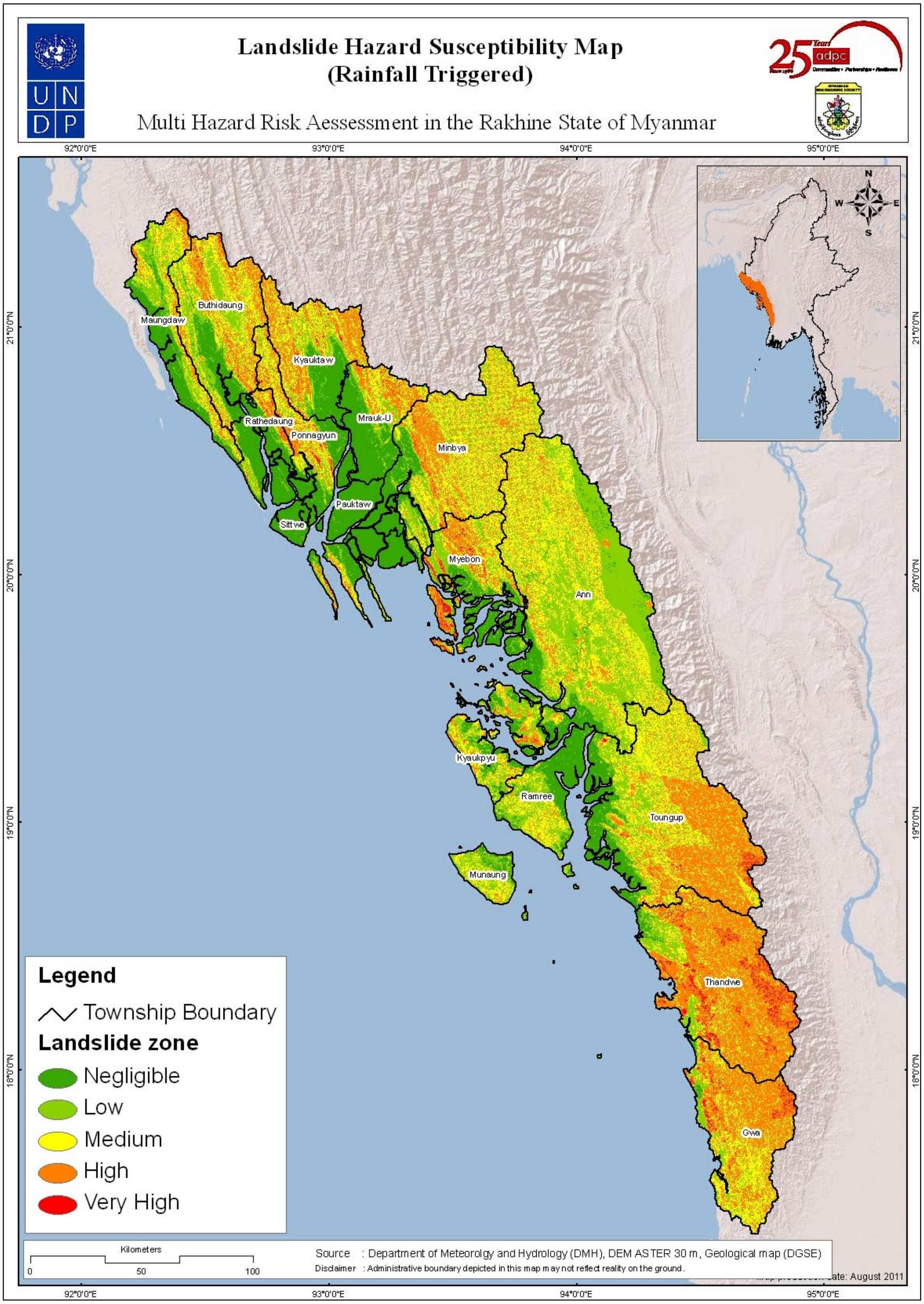

Figure 24: Landslide hazard susceptibility map (induced by rainfall)

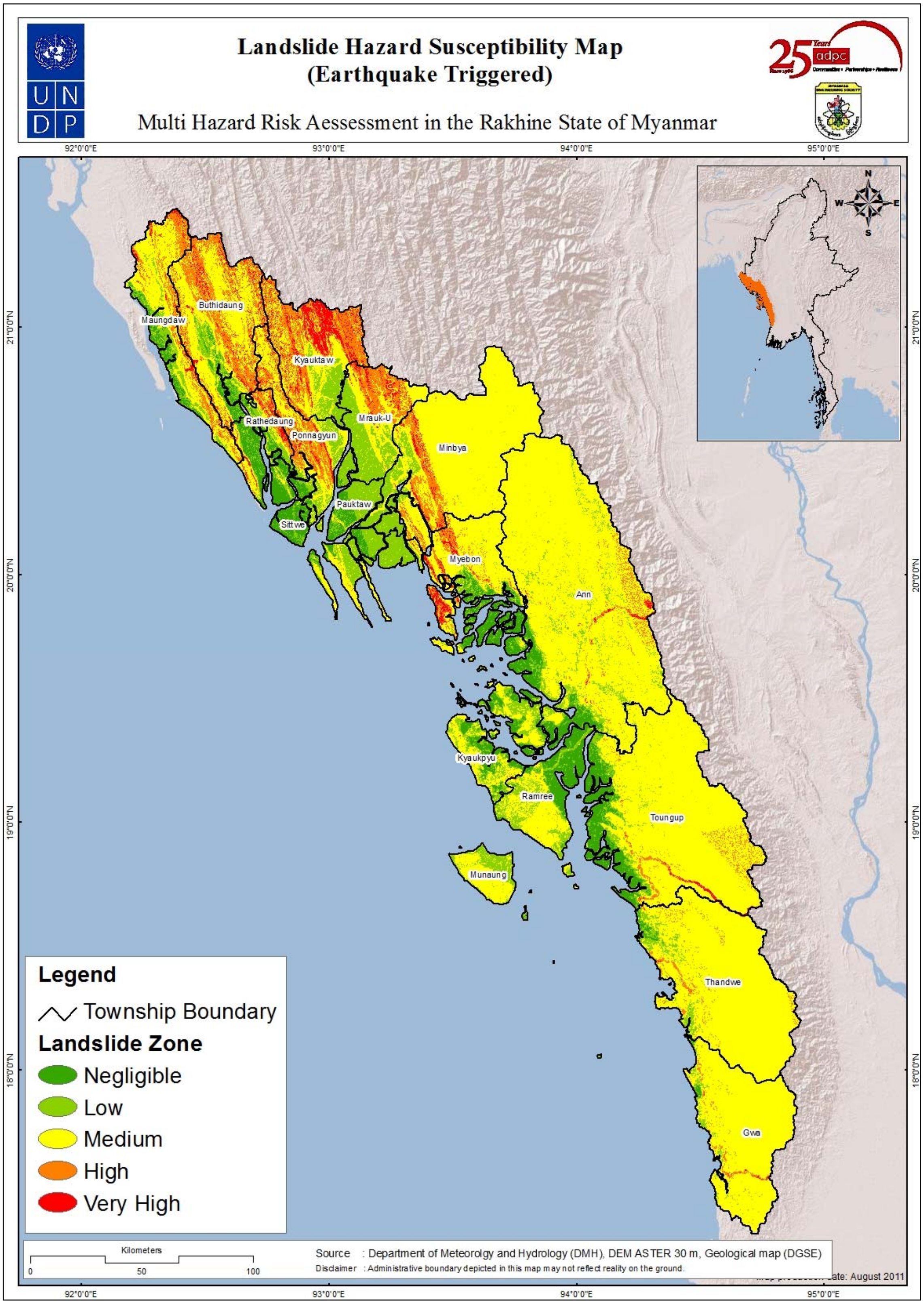

Figure 25: Landslide hazard susceptibility map (induced by earthquake/seismic)

Recommendation for improving the Hazard Maps

- A landslide inventory database does not exist for Rakhine State. A specific rating system for landslide susceptibility in Myanmar country and in Rakhine particularly, also has not been developed. Therefore this assessment used a rating system (semi-quantitative approach) for landslide susceptibility assessment. More detail data for analysis of parameters related to landslide susceptibility are needed to create a rating system by Myanmar landslide experts, either qualitative or quantitative. This rating system can be used for analyzing susceptibility for the whole country, particularly for Rakhine State.

- More detailed analysis on high and very high susceptibility zones are recommended in the context of transportation infrastructure.

- In relation to precipitation and flood, a dynamic model for landslides should be developed for Rakhine State. Due to landslide occurrence that is closely related with specific rainfall periods, the threshold of a precipitation-triggered landslide can be a vital help in disaster risk management.

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Forest/Rural Fire Hazard Assessment

Forest/rural fire hazard map of Rakhine Region, western Myanmar, was prepared by using spatial data, remotely sensed imagery and others data such as road network, settlements and forest inventory data from the Forest Department.

The final map product is a scenario-based forest/rural fire hazard map. It shows the hazard classification based on several components. Forest/rural fire hazard map requires integration of natural (fuel and topography) and anthropogenic factors (roads, farmlands and settlements).

Forest/rural fire hazard zones are locations where a fire is likely to start and from where it can be easily spread to other areas. In this hazard map of Rakhine State contains forest types, topographic data (slope, aspect and altitude), transportation network, settlements data and records of fire occurrences. Because of the absence of reliable forest/rural fire ground data would allow the use of the past fire occurrences detected using MODIS and weights were selected based on the expert opinion.

Data Availability and Sources

The following data were used for the analyses.

- Global Digital Elevation Model dataset called ASTER 30m released by NASA for assigning grid of slope angles
- Global vegetation cover data from the Joint Research Centre (JRC, Ispra, Italy) of land cover for the year 2005 at 300 m resolution for assigning the vegetation cover index
- Primary and secondary data from Forest Department.
- Fire inventory from 1996 to 2011 from Fire Department for Rakhine Region
- The image from the Moderate Resolution Imaging Spectro-radiometer (MODIS) on NASA's Aqua satellite (for historical fire occurrences between 2006 to 2010)
- Primary and secondary data from Department of Meteorology and Hydrology (DMH)
- Transportation network, settlement data, township boundary and maps (MIMU)

Attempt was made to convert all available data into digital format using 1:250,000 scale data layers so that forest/rural fire hazard zone map could be produced in the scale of 1:250,000.

The historical records (ground data) from State Fire Department were emphasized only for urban and rural events, and no record of forest/rural fire for detailed studies. Therefore, the past five years (2006 – 2010) MODIS fire hotspots data from NASA were used as past records.

Hazard Assessment Methodology

The methodology for fire hazard mapping will be developed based on available secondary data from various authentic sources such as DMH as mentioned above. The methodology largely uses software such as Remote sensing software and ArcView GIS 3.3.

Forest/rural fire hazard is related with fuel, topography and anthropogenic factors. The fuel factor includes forest type and land use, topographical factor includes 3 variables: slope, aspect and altitude, anthropogenic factor includes settlement area, road density, distance to roads or residential areas and distance to farmlands.

The methodology adopted was visual, digital and hybrid method for Remote Sensing data analysis. The primary and secondary data related to the fire were integrated using GIS to derive the fire risk zone maps.

Global vegetation cover data from the Joint Research Centre (JRC, Ispra, Italy) and secondary data from Forest Department were applied for analysis. The classified raster layers converted to vector layers for further analysis in GIS. ASTER GDEM of 30 meter resolution used to generate topographic information with ArcView GIS 3.3 using spatial analyst function.

The parameters used for modeling the fire hazard map were –

- fire occurrence map (past five years data)
- classified vegetation map
- road network
- topography (slope, aspect)
- settlement (township) map
- reserve forest map

All these parameters have direct/indirect influence on the occurrence of fire and were integrated using GIS and a multi parametric weighted index model has been adopted to derive the forest/rural fire hazard zone map.

Like in other tropical regions of the northern hemisphere, forest fires in Rakhine State occur between December to end of April when the weather is hot and dry. The flowchart for the analysis is presented in Figure 26

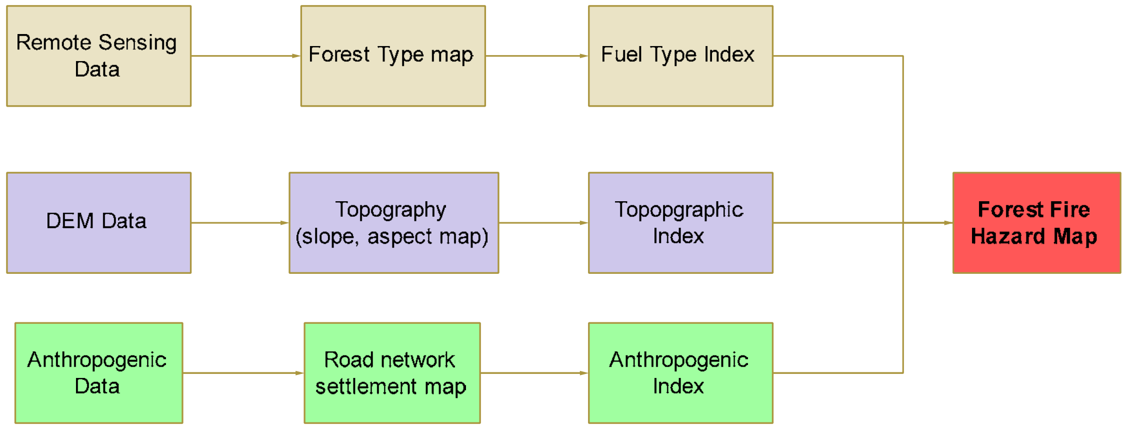

Figure 26: Fire hazard zonation model

According to fire data in the last 15 years, frequency of fires in rural areas where 70 % of the population dwelled, account about 25% (as one fourth) of the total incidences of fires all over the region i.e. a total of 444 events (Figure 27). But fire losses in rural area arise about 40% of the total losses surprisingly. Fire cases mainly happen in rural areas where usually big fires occur by spreading through the whole village. Average numbers of rural fire especially occur in Rakhine State accounts 40 % of the total cases while the losses arise more than 50% of the total losses. Because of above mentioned data, the challenge of rural fires in Rakhine State reflects to focus (or) to consider as a big issue of risk. The rural fire intensity of townships in Rakhine State is shown in the following graph (Figure 28).

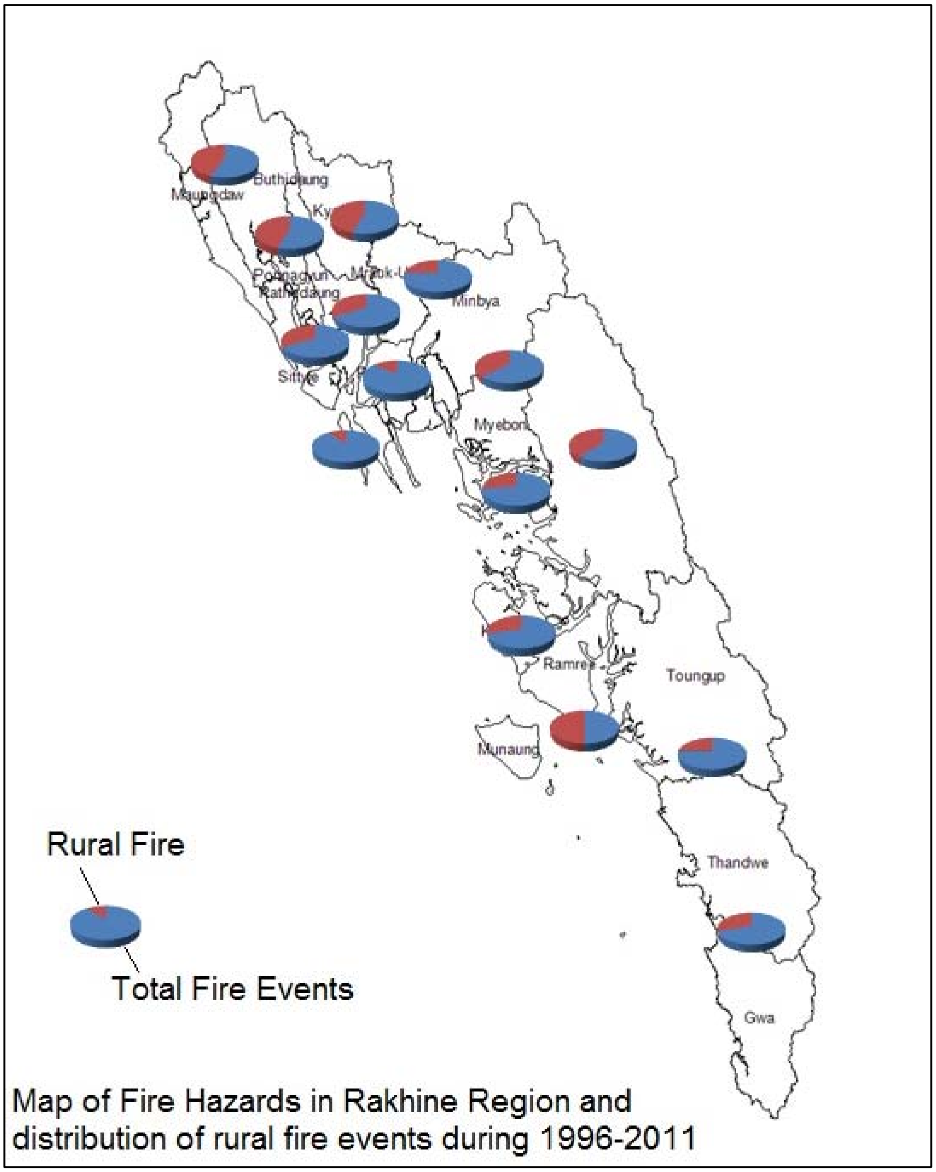

Figure 27: Map of fire hazards in Rakhine State and distribution of rural fire events over each townships during 1996-2011

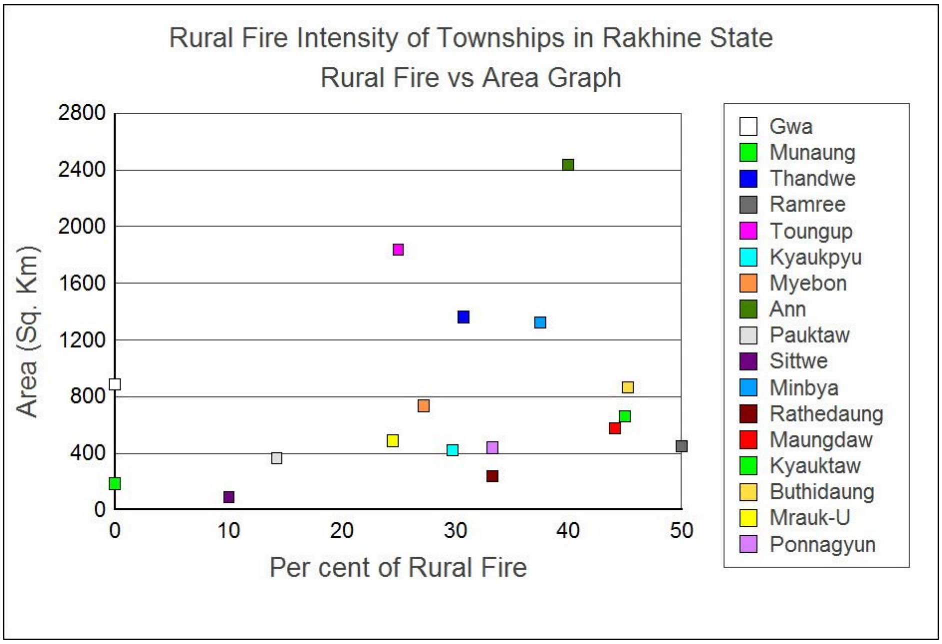

Figure 28: Rural fire intensity of Townships in Rakhine State

Hazard Maps and their Interpretation

The scenario-based analysis was applied to classify this map into four fire hazard zones. There are low, moderate, high and very high. The color chart showing the four classes of forest/rural fire hazard susceptibility zone is given in

Figure 29.

The low zone is characterized by the areas with agriculture and less forest, low ignition value, low to moderate slope with east and north facing. It also shows lack of past fire occurrence.

The moderate zone is characterized by areas with sparse vegetation, moderate ignition value on moderate and high slope with facing northwest and west direction.

The high zone is typified by areas with a forest type dominated by bamboo, high ignition value on slopes with west and southwest direction.

The very high zone is occupied by the areas with bamboo and dry mix type of forest: high and very high ignition value on high and very high slope with west and southwest facing. The past fire occurrences were also high in this zone.

Forest/rural fire risk is mainly influenced by fuel and environment factors including natural environment factors (topography) and social environment factors (anthropogenic factors). The three category factors were analyzed separately so that high-risk area influenced by each factor can be sorted out and the most important factor contributing to forest/rural fires can be determined.

The method has some advantages, which integrates the GIS and remote sensing for Rakhine State forest/rural fire hazard zone mapping in this study: (1) detailed data can be gotten by integrating inventory data with remotely sensed data; (2) local authority can access to high fire risk locations easily and manage effectively because that sub-compartments are the basic units of analysis; and (3) each factor influencing forest/rural fires risk was analyzed, so local authority can find out why forest/rural fires risks of some sub-compartments are high and then can manage these areas effectively.

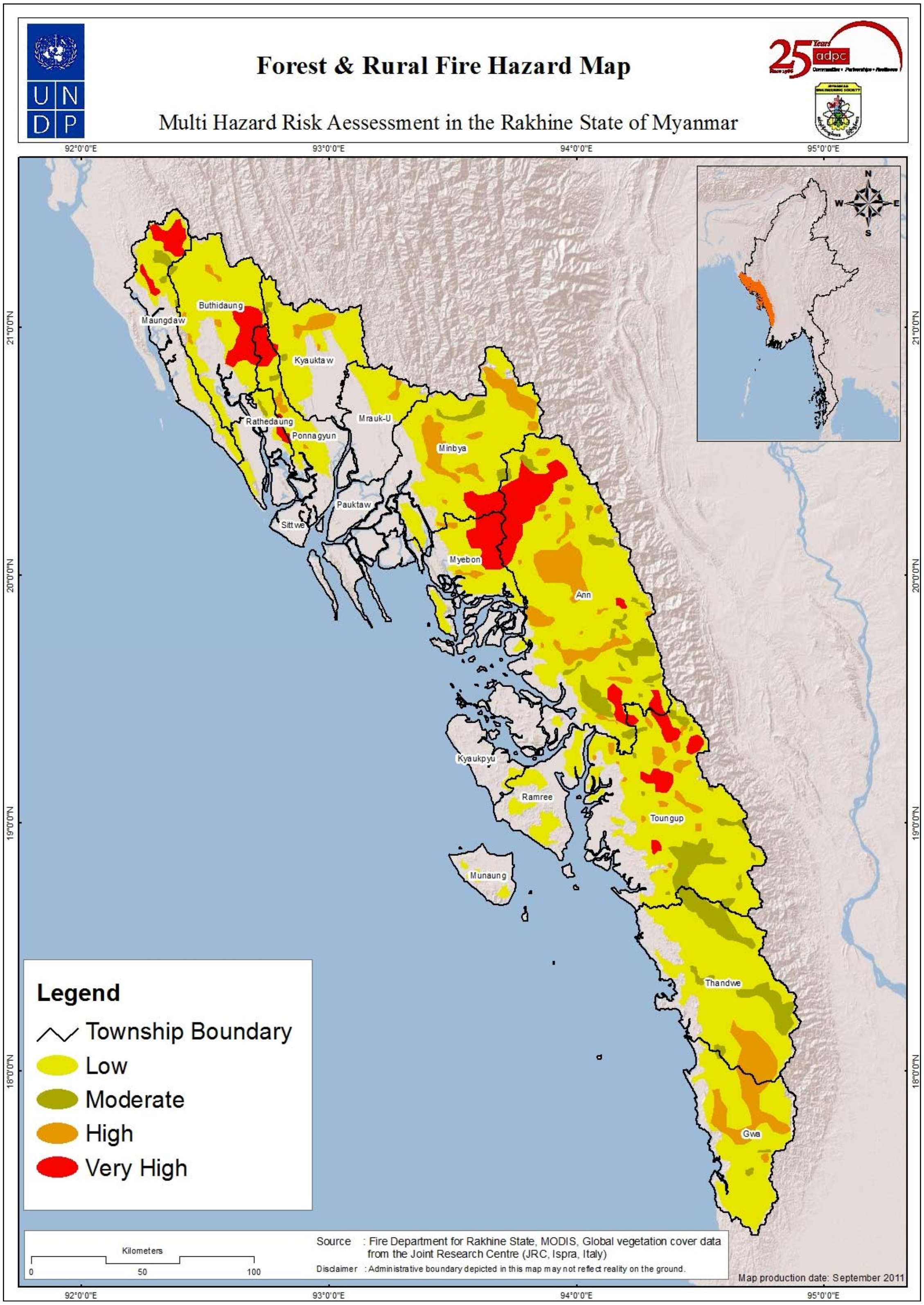

Figure 29: Forest and Rural Fire hazard map of Rakhine State

Recommendation for improving the Hazard Maps

There occurred no forest fire, specifically crown fire in the forest, recorded in Rakhine region. Present study applied only the thermal sensor of satellite imagery and potential factors like slope, sun angle, type of forest and fuel so true historical records and field observation may help improve the hazard map to be more effective.

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Earthquake Hazard Assessment

The earthquake hazard assessment methodology for this assignment was built around existing and on-going related works, namely National Seismic Hazard Maps of Myanmar by MEC and Myanmar Earthquake Risk Assessment by ADPC and DMH. The earthquake hazard maps produced under this project include the following maps.

(1) Peak Ground Acceleration (PGA) map with a 2% probability of exceedance in 50 years (equivalent to an Annual Exceedance Probability of 0.04%)

(2) Peak Ground Acceleration (PGA) map with a 10% probability of exceedance in 50 years (equivalent to an Annual Exceedance Probability of 0.2%)

(3) Suggested earthquake hazard zonation maps associated with 2% and 10% probabilities of exceedance in 50 years

Data Availability and Sources

The data that was utilized in deriving the earthquake hazard maps under this project is the following.

Data	Source
Gridded PGA values	Dr. Myo Thant (MEC) – personal communication
30m Digital Elevation	NASA, U.S.A.
Topographic data	U.S. Geological Survey's EROS Data Center
Geological map	Myanmar Geoscience Society (MGS)

Hazard Assessment Methodology

The earthquake hazard assessment methodology for this assignment is built around existing and on-going related works, namely National Seismic Hazard Maps of Myanmar by the Myanmar Earthquake Committee and Myanmar Earthquake Risk Assessment by ADPC and the Department of Meteorology and Hydrology, Myanmar.

Calculation of the Earthquake Hazard for Bedrock Condition

Maps of the bedrock ground motion parameter such as Peak Ground Acceleration (PGA) associated with the 0.04% and 0.2% Annual Exceedance Probabilities (representing rare and occasional earthquakes for the region, respectively) are produced. Components that are required in deducing the earthquake hazard maps are the following.

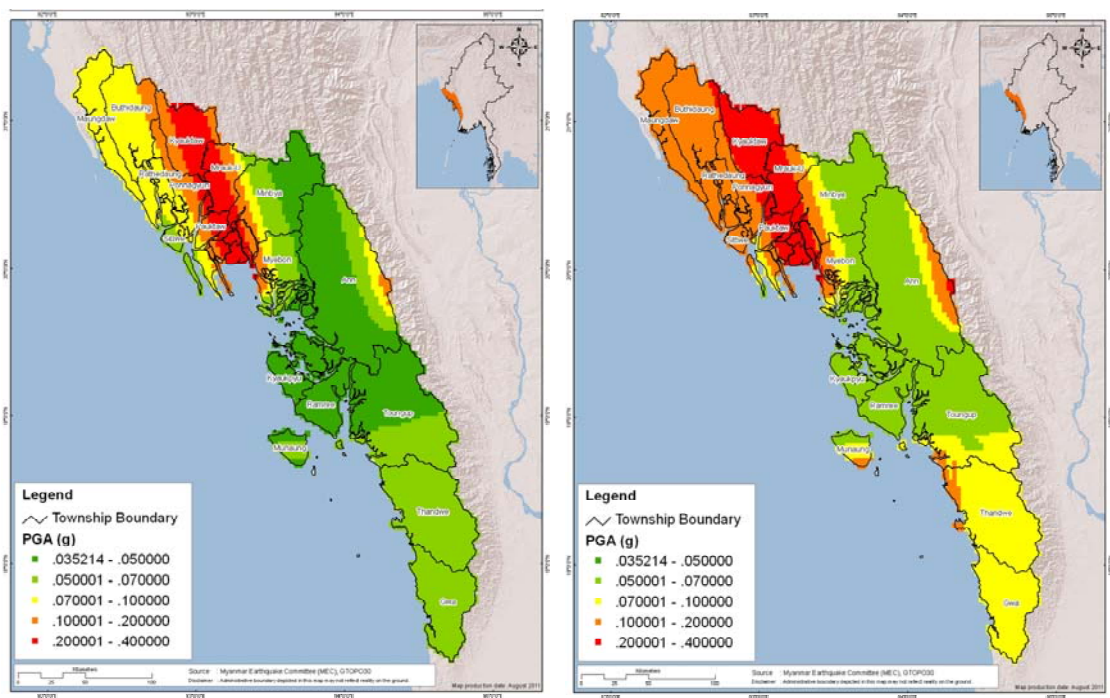
(1) Earthquake catalogue

(2) Earthquake source modeling

(3) Ground motion prediction equation

(4) Probabilistic seismic hazard assessment

The calculation of the earthquake hazards under this project is taken directly from an on-going effort to update the seismic hazard map of the whole Myanmar by the Myanmar Earthquake Committee (Myo Thant, 2011). More details of the overall procedure and each of the components listed above will be provided in the final report. Figure 30 shows the estimated Peak Ground Acceleration values at bedrock, for 0.2% and 0.04% Annual Exceedance Probabilities, respectively.



(a) (b)

Figure 30: Estimated Peak Ground Acceleration (PGA) at bedrock level: (a) with 0.2% Annual Exceedance Probability (475-year return period). (b) with 0.04% Annual Exceedance Probability (2,475-year return period)

It is important to mention that the earthquake hazard maps shown subsequently in this report should be treated as a working version. They will undergo serious evaluation by the research team, along with Myanmar experts, in the next few weeks to ensure that the earthquake hazard in Rakhine State is accurately portrayed.

Estimation of Soil Amplification Factors

The seismic hazard assessment described in the previous section produces ground motion parameters, such as the Peak Ground Acceleration, estimated at the bedrock condition. However, the actual earth surface always comprises of layers of soils of various types and various thickness. The soil condition at any site dictates the intensity of the ground motion at the surface level, which is the actual ground shaking that the people and buildings feel. Most often than not, the soil does amplify intensity of the earthquake shaking.

The ground motion soil amplification factors, which indicate how much the ground shaking intensity is amplified (or sometimes reduced), due to the underlying soil layers, need to be estimated at locations throughout the entire state. The soil type at any site usually is characterized by a parameter called "average shear-wave velocity for the top 30 meters of the soil or Vs30". The United States' National Earthquake Hazards Reduction Program (NEHRP) classified the soil types using English alphabets and defined a range of Vs30 for each site class (BSSC, 2001), as shown in Table 7.

Table 7: NEHRP Site Class and corresponding Vs30

Site Class	Soil Profile Name	Vs30 Range (meter/second)
E	Soft soil	< 180
D	Stiff soil	180 – 360
C	Very dense soil / soft	360 – 760
B	Rock	> 760

Actual determination of the Vs30 at a site requires geophysical field exploration, which is technically difficult and costly. However, it has been scientifically verified that the topographic variation is an acceptable indicator of near-surface geomorphology and lithology (e.g., steep mountain indicates rock, while flat basin indicates soil). Recent studies have confirmed good correlations between the topographic slope and Vs30 in both intra-plate and active tectonic regions around the world (Allen and Wald, 2007).

For Rakhine State, the topographic slope at every 30 arc-seconds or approximately 1-km interval was calculated from the GTOPO30 - Global Topographic Data Digital Elevation Model[1]. Figure 31 illustrates the elevation map, the calculated slope throughout the state, and the site-class derived from the relationships suggested by Allen and Wald (2007).

[1] U.S. Geological Survey's EROS Data Center (EDC) : http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info

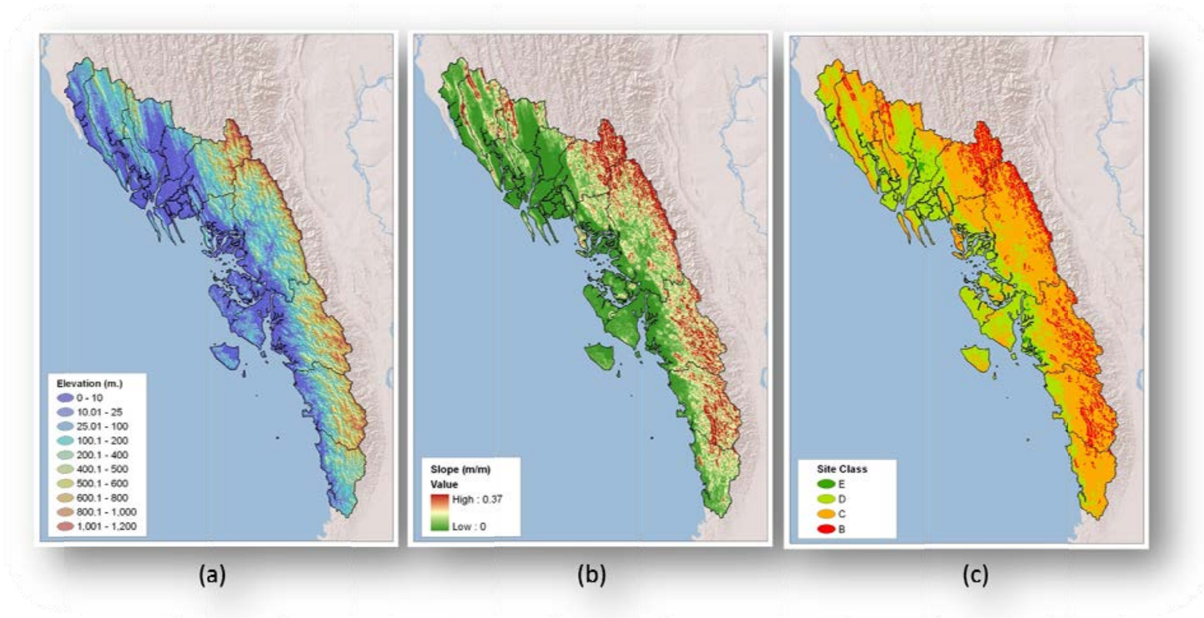


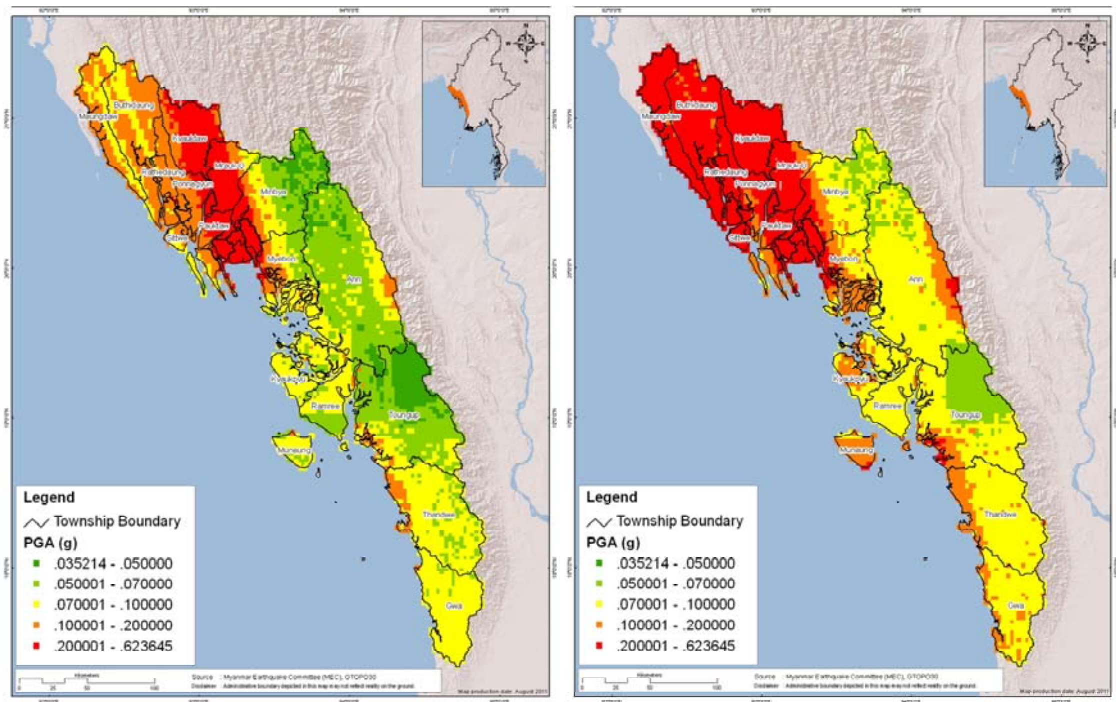
Figure 31: (a) The elevation map of Rakhine State, (b) Calculated topographic slope, (c) NEHRP-site-class map derived from the topographic slope

The site amplification factors used in the multi-hazard loss estimation methodology HAZUS-MH (FEMA, 2003) are adopted for this project. The site amplification factors are defined based on the NEHRP site class as well as the ground motion intensity, PGA, as shown in Table 8.

Table 8: NEHRP Site amplification factors (from FEMA, 2003)

Site Class B Acceleration		Site Amplification Factors				
PGA (g)		Site Class				
min	max	A	B	C	D	E
0.00	0.25	0.8	1.0	1.2	1.6	2.5
0.25	0.50	0.8	1.0	1.2	1.4	1.7
0.50	0.75	0.8	1.0	1.1	1.2	1.2
0.75	1.00	0.8	1.0	1.0	1.1	0.9
1.00	1.25	0.8	1.0	1.0	1.0	0.8
1.25		0.8	1.0	1.0	1.0	0.8

The amplification factors are then multiplied to the bedrock PGA values in Figure 30. The results are the PGA values expected at the ground surface, taking into account the underlying soil condition at the site (Figure 32). These are the PGA values that will be experienced by the people and the structures, hence an indication of the earthquake hazard.



(a) (b)

Figure 32: Estimated Peak Ground Acceleration (PGA) at surface level: (a) with 0.2% Annual Exceedance Probability (475-year return period). (b) with 0.04% Annual Exceedance Probability (2,475-year return period)

Hazard Maps and their Interpretation

The Peak Ground Acceleration, though meaningful for engineering applications, may not offer clear indication of the earthquake hazard levels to non-technical users. For the purpose of ensuring that the hazard maps are understood and utilized by policy makers and risk management practitioners, those PGA maps must be converted into a format that is more intuitive. The Modified Mercalli Intensity (MMI) scale offers a qualitative measure of earthquake intensity. The MMI scale uses Roman numerals (from I to XII) to describe the severity of ground shaking during an earthquake, which translates directly to damage on structures. Table 9 presents the MMI scale.

The observed MMI values usually correlate well against ground motion parameters such as the PGA. In lieu of a reliable database of MMI and PGA values collected from historical earthquakes in Rakhine state, a well-known empirical formula to convert PGA into MMI is used in this project. Trifunac and Brady (1975) suggested the following equation.

$$\mathrm{MMI} = \left(\frac{1}{0.3}\right) \times (\log(PGA \times 980) - 0.014)$$

The resulting hazard maps based on the qualitative MMI scale are presented in Figure 33 and Figure 34. The maps can be easily interpreted as follows. At any point on the map, there is a 0.2% (or 0.04%) chance that the MMI intensity shown at that point on the map will be exceeded during the next 1 year.

Table 9: Modified Mercalli Intensity (MMI) scale and descriptions (from U.S. Geological Survey)

MMI	Description
I	Not felt except by a very few under especially favorable conditions.
II	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

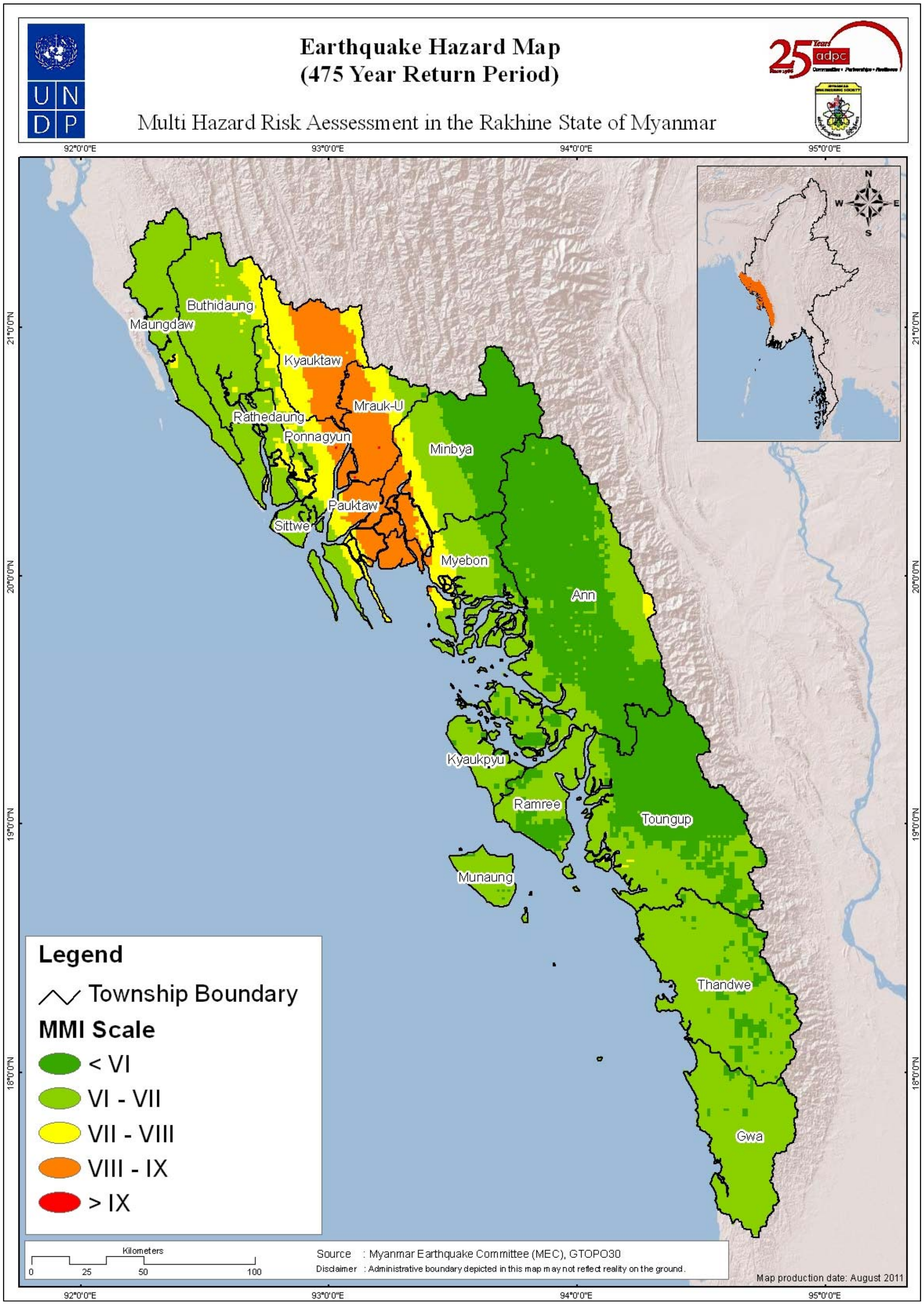


Figure 33: Earthquake hazard map based on MMI scale, 0.2% Annual Exceedance Probability (475-year return period)

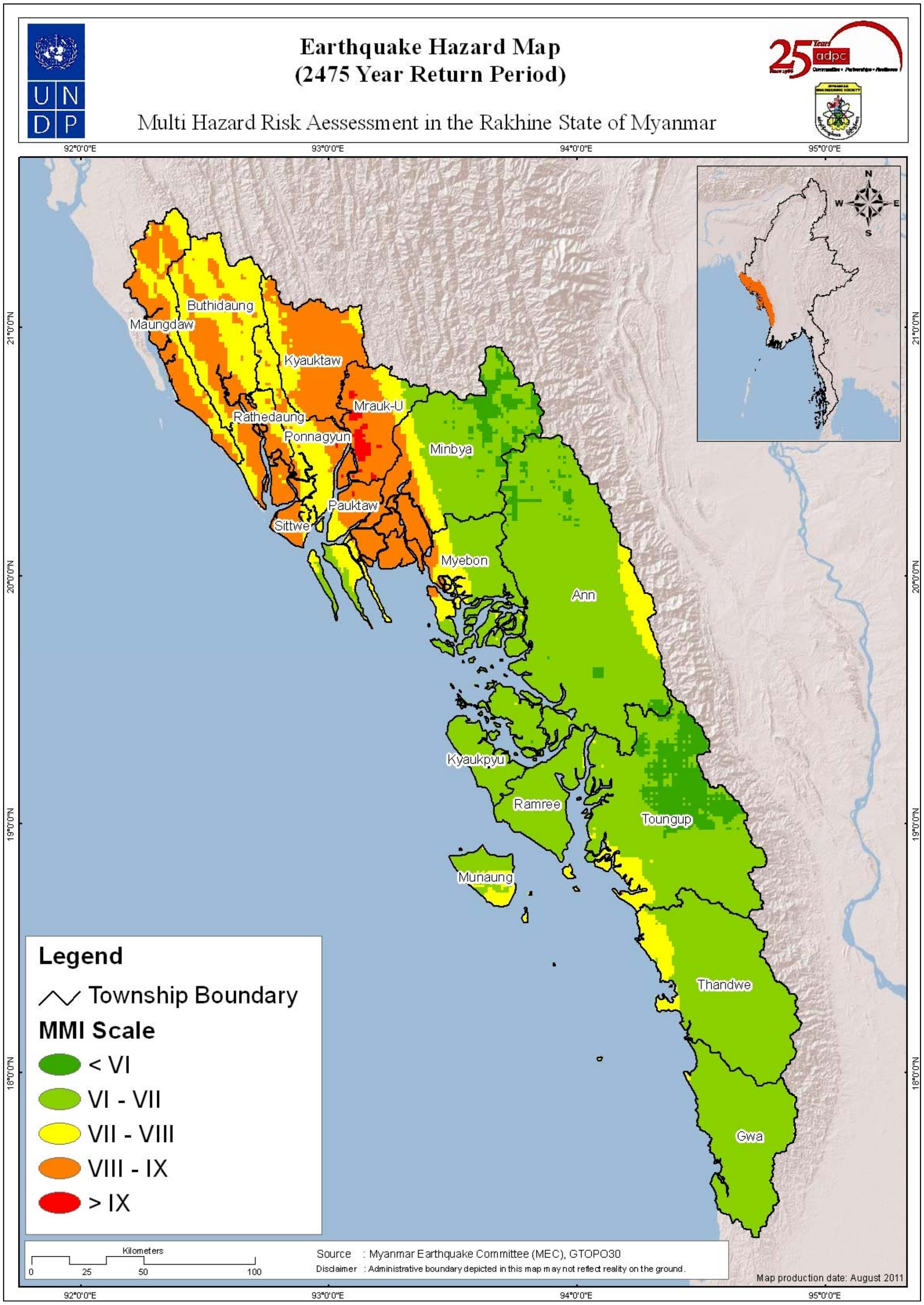


Figure 34: Earthquake hazard map based on MMI scale, 0.04% Annual Exceedance Probability (2,475-year return period)

Recommendation for improving the Hazard Maps

The derivation of earthquake hazard maps under this project involves several assumptions. Among them, one of the most glaring ones is that we assumed the topographical slope to be a good proxy to estimate the site class and ground motion amplification factors for Rakhine State. An accuracy of the topographically-derived site class can be greatly improved if there can be a number of site investigations to determine the actual soil type and conditions throughout Rakhine State. It is recommended that researchers in Myanmar conduct shear-wave velocity measurement tests in the field at many locations around Rakhine State and build a database of the site average shear-wave velocities that can be used to verify, calibrate, and possibly improve the original estimations.

Another harmful consequence of an earthquake is the shaking-induced liquefaction of the ground. Liquefaction is defined as a phenomenon where the soil that is saturated with water suddenly loses its strength to bear any weights due to the strong earthquake shaking, causing the soil to behave like liquid. The liquefaction phenomenon has caused significant damage to buildings and infrastructures during past earthquakes all over the world. Detailed studies of the liquefaction susceptibility of Rakhine State will further fortify an understanding of earthquake hazard in the state.

As the earthquake hazard calculation under this work is based on an on-going effort by the Myanmar Earthquake Committee. It will be useful if the final products be reviewed by Myanmar and international experts.

References

Allen, T.I. and Wald, D.J., 2007. Topographic Slope as a Proxy for Seismic Site-Conditions (Vs30) and Amplification around the Globe, Open-File Report 2007-1357, United States Geological Survey (USGS)

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Myo Thant, 2011. Seismic Hazard of Myanmar, part of the Myanmar Earthquake Risk Assessment Project, Asian Disaster Preparedness Center (ADPC)

Trifunac, M.D. and Brady, A.G., 1975. On the Correlation of Peak Acceleration of Strong Motion with Earthquake Magnitude, Epicentral Distance and Site Conditions. Pages 43–52 of: Proceedings of the U.S. National Conference on Earthquake Engineering.

Tsunami Hazard Assessment

This tsunami hazard map is derived from a deterministic analysis of the seismogenic tsunami hazard for Rakhine State of Myanmar. The spatial distribution of the tsunami inundation shown on the map is based on a static projection of maximum water surface elevation computed by employing a depth-averaged, two-dimensional numerical model of tsunami generation and propagation. The model used is the Cornell Multigrid Coupled Tsunami Model (COMCOT) which solves the non-linear shallow water equations on a dynamically coupled system of nested grids using finite difference numerical schemes.

The numerical simulations have been carried out for three 'maximum-credible' tsunamigenic seismic scenarios, two from Arakan fault off Myanmar and one from Northern Sumatra-Andaman subduction zone. The computed peak tsunami amplitudes from the three scenarios were used to derive an envelope of maximum values of tsunami water surface elevation along the coastline of Rakhine State for subsequent onshore inundation computations. The spatial distribution of the tsunami inundation depths is shown on the map in six color-coded depth ranges corresponding to low, moderate, high and very high levels of the hazard.

Data Availability and Sources

The primary data required for the present tsunami hazard assessment include topographic and bathymetric data pertinent to Rakhine State as well as fault plane parameters corresponding to worst-case seismic events for the respective subduction segments. Moreover, field measurements of water levels due to the December 2004 tsunami in western coast of Myanmar, and preferably along Rakhine coastline, are also required for model validation.

Table 10 summarizes the data requirements, possible sources and whether or not such data were available for the present study.

The accuracy of inundation modeling depends to a large extent on the resolution of topographic data used; however, owing to non-availability of high-resolution LIDAR or land-based survey maps, coarse resolution satellite based elevation data (ASTER) had to be used. Moreover, due to the same reason, the zero line/land line of Rakhine State had to be digitized from that given in the navigation charts.

Table 10: List of data requirements and availability for the tsunami hazard assessment

Type of Data	Source	Spatial Resolution	Availability
Bathymetric Data • **Entire Indian Ocean Basin** • **Seaboard off Western Myanmar** • **Local bathymetry at some nearshore locations**	GEBCO Navigation charts Myanmar Oceanographic	30 arc-seconds 1:150,000 or 1:300,000 Varying	Available Available (1:350,000) Not available
Elevation data of Coastal zone of Rakhine State • **LIDAR** • **Land based surveys** • **ASTER**	 Myanmar Survey Department JPL, Caltec	Horizontal < 1 m Vertical < 0.3 m 1:1000, 1:5000, 1:10,000 (at least 1 m contour interval) Horizontal = 30 m Vertical resolution not known	Not available Not available Available
Miscellaneous base data • **Administrative boundaries in vector format** • **Vector data depicting land use types, drainage network, road network, etc**	Myanmar Survey Department -ditto-	1:10,000 or better -ditto-	Available -ditto-
Seismic data • **Fault parameters of maximum credible events**	Scientific Publications	Varying	Available
Data on 2004 tsunami impact • **Tsunami heights** • **Extent of inundation**	Scientific Publications Scientific Publications	Varying Varying	Available (limited in extent) Not available

Hazard Assessment Methodology

Approach

Of the two approaches generally available for tsunami hazard assessments, i.e., the deterministic method and the probabilistic method, the deterministic (scenario-based) method is employed in the present study together with numerical simulations of tsunami to assess the level of threat posed to Rakhine State of Myanmar by 'maximum-credible' mega-thrust earthquakes that are plausible to occur in several subduction zones in the Indian Ocean Basin. The probabilistic method is not attempted owing to several reasons including the paucity of past tsunami observations for Myanmar and the insufficient understanding of recurrence intervals of seismic events in some of the subduction segments applicable to the present assessment.

Seismic scenarios

In a recent article, Okal and Synolakis (2008) identified five segments of subduction zones in the Indian Ocean that could generate destructive transoceanic tsunami. These seismic zones are located in the Arakan trench off Myanmar, off Southern Sumatra and Java and in the Makran coast of Pakistan and Iran, besides the Northern Sumatra-Andaman fault which triggered the December 2004 tsunami (Figure 35). However, the seismic zones off Southern Sumatra and Java are not considered in the present study since the orientation and location of these segments suggest that the bulk of the tsunami energy would be directed away from the western coast of Myanmar (source directivity, Ben-Menahem and Rosenman, 1972). Furthermore, the western coast of Myanmar is largely shielded by India and Sri Lanka against tsunami that could be generated in the Makran seismic zone; Makran tsunami waves that get diffracted off the southern tip of India and Sri Lanka would pose negligible threat. Accordingly, tsunamigenic potential of Arakan and Northern Sumatra-Andaman seismic zones only are considered in the following in assessing the tsunami hazard for the western coast of Myanmar.

Two scenarios have been identified by Okal and Synolakis (2008) to represent the worst-case seismic potential of the Arakan subduction zone: Scenario 1 is a fault model inspired by a repeat of the 1762 earthquake whilst Scenario 2 is categorized as a somewhat far-fetched but nevertheless feasible event to occur in a 470 km segment immediately north of the termination of the 2004 rupture. Moreover, the fault plane model of Grilli et al. (2007) is employed to represent the Mw = 9.3 (Stein and Okal, 2005) earthquake of 2004 as the maximum-credible event for the Northern Sumatra-Andaman seismic zone. A detailed description of the tsunamigenic seismic potential of these subduction zones is given in Okal and Synolakis (2008).

The fault parameters of the selected seismic events are given in Table 11, where H is the depth of the fault plane; L is the length of the fault; M_0 is the seismic moment; W is the width of the fault plane; Φ is the strike angle; δ is the dip angle; λ is the rake angle; Δu is the slip. These events mostly represent the 'maximum-credible' worst-case scenarios of seismic rupture for each segment of the subduction zones under consideration. Assuming that the sea surface follows the sea bed deformation instantaneously, Okada's (1985) dislocation model was employed to obtain the initial sea surface elevation for the above co-seismic tsunami sources.

Table 11: Fault parameters of seismic scenarios for tsunami assessment

Seismic Zone	Scenario	M_0 (dyn x cm)	Φ (deg)	δ (deg)	λ (deg)	*L* (km)	*W* (km)	*H* (km)	Δu (m)
Arakan off Myanmar	1	1.5×10^{29}	326	20	124	470	100	10	**6.5**
	2	2.8×10^{29}	20	15	90	470	175	10	**7**
Northern Sumatra-Andaman	**3**	$\mathbf{7.6 \times 10^{30}}$	**Fault parameters for this event are adopted from the five-segment source model of Grilli et al. (2007).**						

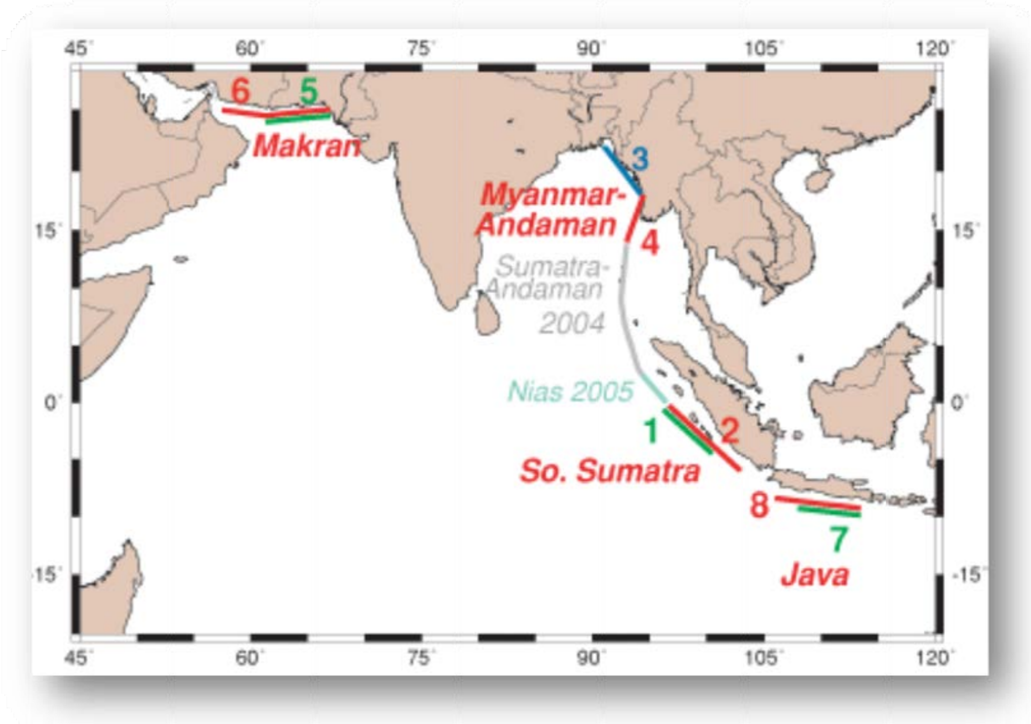


Figure 35: Active subduction zones in the Indian Ocean Basin: Myanmar-Andaman (Arakan); Northern Sumatra-Andaman; Southern Sumatra; Java; and Makran (after Okal and Synolakis, 2008)

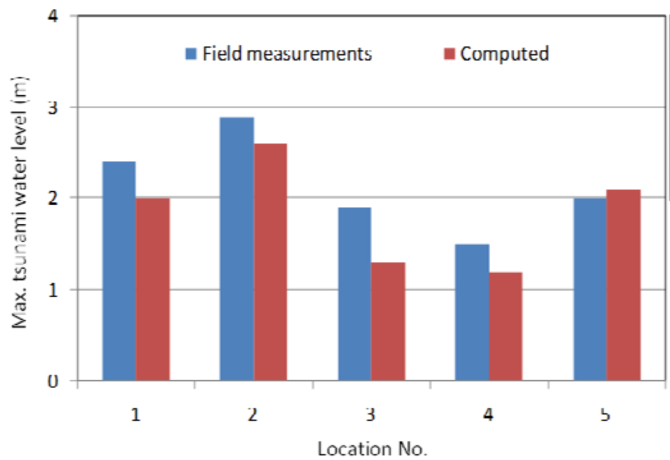
Numerical simulation of tsunami propagation

Numerical simulations of tsunami propagation were carried out by employing COMCOT (COrnell Multi-grid COupled Tsunami model) for all scenarios given in Table 11. A dynamically coupled system of two nested grids was employed to simulate the tsunami propagation from each of the seismic zones towards the shoreline of Rakhine State of Myanmar. The non-linear form of the depth-averaged shallow-water equations were used in the numerical simulations. COMCOT model has been validated by experimental data (Liu et al., 1995) and has been successfully used to investigate several historical tsunami events, including the 2004 Indian Ocean tsunami (Liu et al., 1994; Wang and Liu, 2006; Wijetunge et al., 2009a). Further details of the model including governing equations and numerical formulation can be found in Liu et al. (1998) and Wijetunge (2008, 2009b).

Whilst the inner, second-level grid was the same for all simulations, two different versions of outer grids were used to accommodate the different locations of the subduction segments. The bathymetric data for the outer grids employed in the simulations was obtained by interpolating GEBCO (2010) data with a resolution of 30 arc-seconds to a grid of 1.395 arc-minutes (~2500 m) spacing. Similarly, the computational domain of the inner grid, which is embedded in the outer grid for the simulation of tsunami propagation over the continental shelf off the western coast of Myanmar was set-up at a finer resolution of 0.279 arc minutes (~500 m). The bathymetry for the inner grid was also at first interpolated from GEBCO data and was then updated with data from navigation charts (UK Admiralty Chart Nos. 817 and 818). These navigation charts typically covered depths down to about 2000 m at a scale of 1:350,000.

Model validation

The tsunami propagation model set-up and formulation employed in the present study was further validated by comparing the computed water surface levels due to 2004 tsunami (Scenario-3) with available field measurements. Field observations of maximum water levels in the aftermath of the 2004 tsunami at several locations in the southern part of the west coast of Myanmar have been reported in Satake et al. (2005), Figure 36.



Location No.	Locality
1	Kyet Lut Beach
2	Sann Lan Village
3	Kaing Thaung Island
4	Aung Hlaing Vllage
5	Kapyet Thaung Villa

Figure 36: Comparison of field measurements of Satake et al. (2005) with respective computed maximum tsunami water levels at several locations along western coast of Myanmar

Figure 36 indicates that the computed tsunami water surface elevations are mostly about 10-20% lower than the respective field measurements, except at location no. 5, where the computed level is about 5% higher than the field record. However, the fact that the computed values of tsunami water levels are somewhat lower than the respective field observations is not entirely surprising because computed tsunami levels correspond to locations about 1 km offshore of the coastline whilst the field measurements have been made just inland of the shoreline. Accordingly, the agreement between the measured and the computed tsunami water levels can be considered satisfactory.

Maximum tsunami amplitudes off western coast of Myanmar

Figure 37 shows the computed maximum tsunami amplitudes across the computational domain for: a) Scenario-1, b) Scenario-2, and c) Scenario-3. Tsunami scenarios-1 and -2 can be considered near-field with little early warning time whilst scenario-3 intermediate- to far-field for Rakhine State of Myanmar.

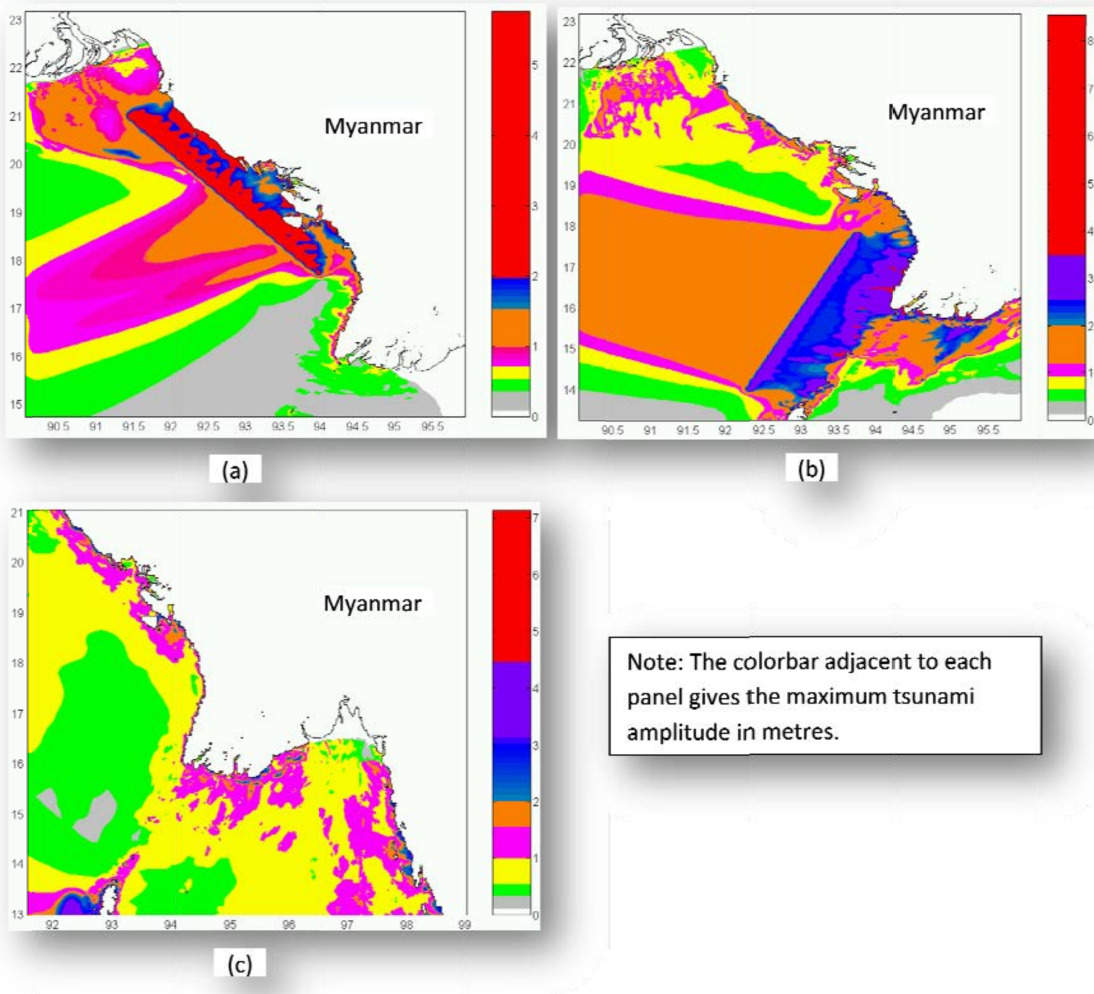


Figure 37: Maximum tsunami amplitudes off the western coast of Myanmar corresponding to: (a) Scenario-1, (b) Scenario-2, and (c) Scenario-3

Extraction of computed tsunami amplitudes near the shoreline

The computed tsunami amplitudes corresponding to each of the three scenarios simulated were extracted near the shoreline off Rakhine State (Figure 38). The variation of tsunami amplitudes shown in Figure 38 suggest that a single scenario cannot be considered as the worst-case for the entire length of the coastline of Rakhine State. For instance, Scenario-2 is the worst-case for coastline between 17~18º N whilst Scenario-1 is the worst-case for certain stretches of the southern part of the shoreline of Rakhine State. Consequently, in keeping with the objective of hazard mapping, an envelope of maximum tsunami amplitudes was then derived for use in subsequent inundation simulations by taking the highest value of computed tsunami amplitudes at each grid point near the shoreline from the three scenarios (Figure 39).

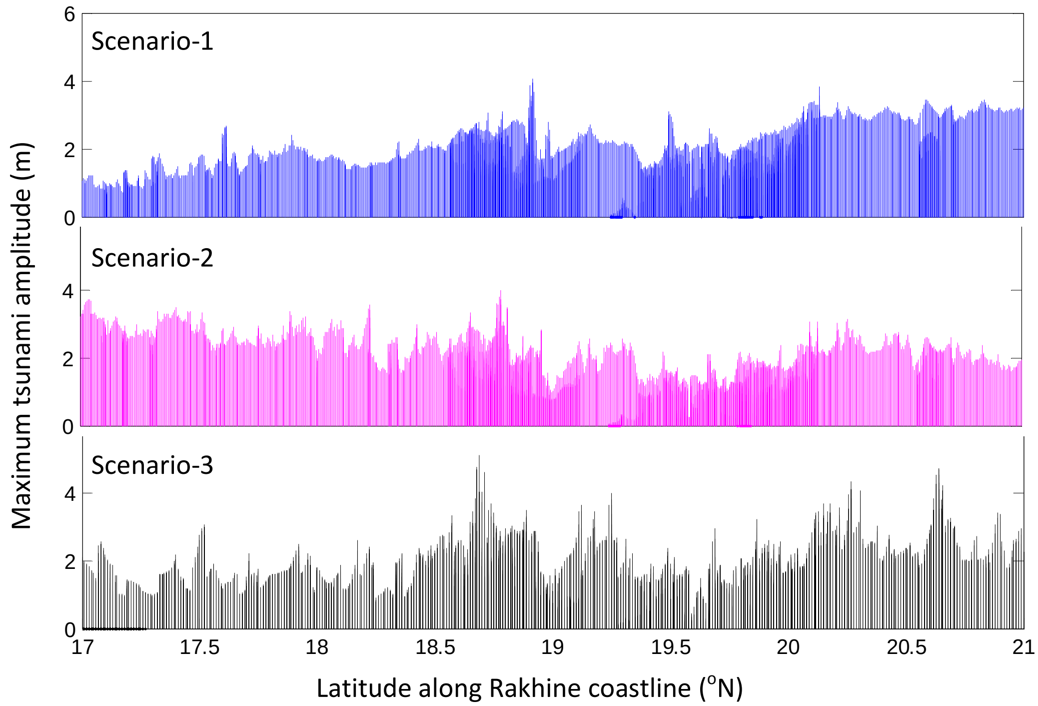


Figure 38: Computed maximum tsunami amplitudes near the shoreline of Rakhine State of Myanmar corresponding to seismic scenarios 1, 2 and 3

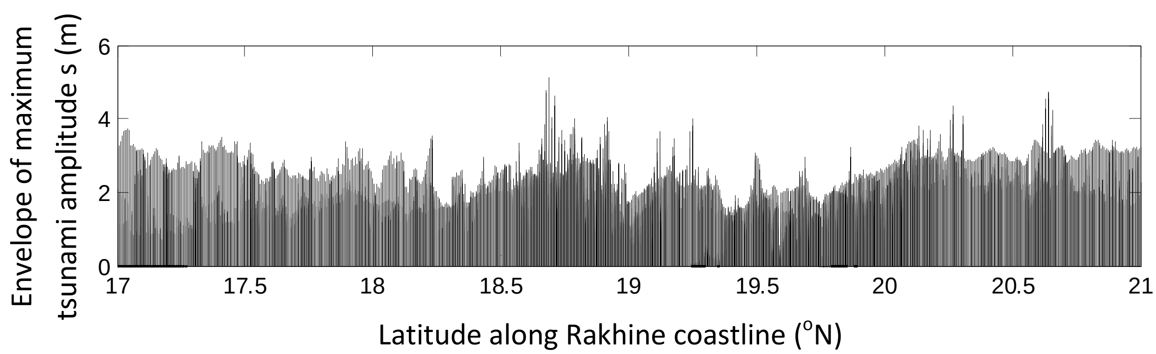


Figure 39: Envelope of maximum tsunami amplitudes near the shoreline of Rakhine State of Myanmar based on seismic scenarios 1, 2 and 3

Incorporation of tidal effects

The interaction of tsunami with the tide is not explicitly simulated in the tsunami propagation model. Therefore, the computed tsunami induced water surface levels near the shoreline were adjusted to "Mean High Water" sea-level condition at spring tide prior to inundation computations, thus representing a conservative sea level for the intended use of the tsunami hazard mapping. An average value of the maximum tidal range (2.4 m) corresponding to spring tide was obtained based on data from several tidal stations along the seaboard off Rakhine State (Table 12). Accordingly, the computed maximum tsunami water levels near the shoreline were superimposed with a further rise in water level of 1.2 m to take into account the worst-case tidal effect.

Table 12: Tidal range along seaboard off Rakhine State based on Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) conditions. (Source: Admiralty Chart Nos. 817 and 818)

Tidal Station			Max. tidal range based on MHWS and MLWS (m)
Location	**Latitude (N)**	**Longitude (E)**	
Chaungtha Kyun	$16^o\ 57^,$	$94^o\ 26^,$	2.0
Gwa Bay	$17^o\ 35^,$	$94^o\ 34^,$	2.1
Andrew Bay	$18^o\ 21^,$	$94^o\ 21^,$	2.2
Sagu Kyun	$18^o\ 48^,$	$93^o\ 59^,$	2.3
Searle Point	$18^o\ 54^,$	$93^o\ 37^,$	2.5
Kyaukpyu	$19^o\ 26^,$	$93^o\ 33^,$	2.8
Sittwe	$20^o\ 08^,$	$92^o\ 54^,$	2.3
S. Martin's Island	$20^o\ 37^,$	$92^o\ 19^,$	2.7
Average max. tidal range along seaboard off Rakhine State			**2.4**

Inundation simulations

GIS based modeling tools and supplementary Matlab software code developed for this purpose were used to obtain the likely inundation distribution onshore based on the computed tsunami heights near the coastline in a preceding step above. ASTER satellite based elevation data for the coastal areas of Rakhine State were used for inundation simulations owing to the non-availability of higher-resolution topographic data. The horizontal spatial resolution of the inundation simulations was 100 m, although this is constrained by the vertical resolution of ASTER topographic data available for DEM construction. The inundation distribution computed in this way is essentially static; however, in the absence of land use information for the area of study, a constant rate of decay of tsunami flood levels was allowed in the direction of flow.

Limitations

As the nature of the tsunami depends on the initial seabed deformation due to the earthquake, which is poorly understood, the largest source of uncertainty is the input earthquake. Another significant limitation is that the resolution of the modeling is no greater or more accurate than the bathymetric and topographic data used. The resolution of the model also constrains its ability to resolve some small-scale features of the onshore terrain including narrow waterways. Moreover, the tide has been linearly superimposed on the computed tsunami water levels on a conservative basis although the tide and tsunami interaction could be non-linear. It must also be noted that the present assessment of tsunami hazard to Rakhine State of Myanmar does not include any potential submarine landslides nor volcanic eruptions.

Hazard Maps and their Interpretation

The tsunami hazard maps depicting the spatial distribution of onshore inundation at high tide for Rakhine State of Myanmar are shown in Figure 40, Figure 41, and Figure 42. The depth of probable inundation on these maps is classified as given in Table 13. *(Note: The classification to be adopted finally ought to be discussed with the end users, and this may be revised accordingly.)*

Table 13: Classification of tsunami inundation depth

Depth of Inundation (m)	Color code
< 0.5 m	Green
0.5 – 1 m	Yellow
1 – 2 m	Orange
2 – 3 m	Magenta
3 – 5 m	Red
> 5 m	Purple

It must be emphasized that the inundation distribution depicted in the map corresponds to a worst-case arising out of plausible, maximum-credible tsunami scenarios derived in keeping with the present understanding of the seismicity of the subduction zones concerned. It must also be added that the next tsunamigenic earthquake in any of these subduction zones need not necessarily be as large as those depicted by the fault parameters given in Table 11.

Tsunamis are rare events, and owing to the paucity of known occurrences in the historical record, this map includes no information about the probability of any tsunami affecting any area within a specific period of time. Whilst this tsunami hazard map has been compiled with the currently available scientific information and base data, users are invited to notify the developers of any map discrepancies.

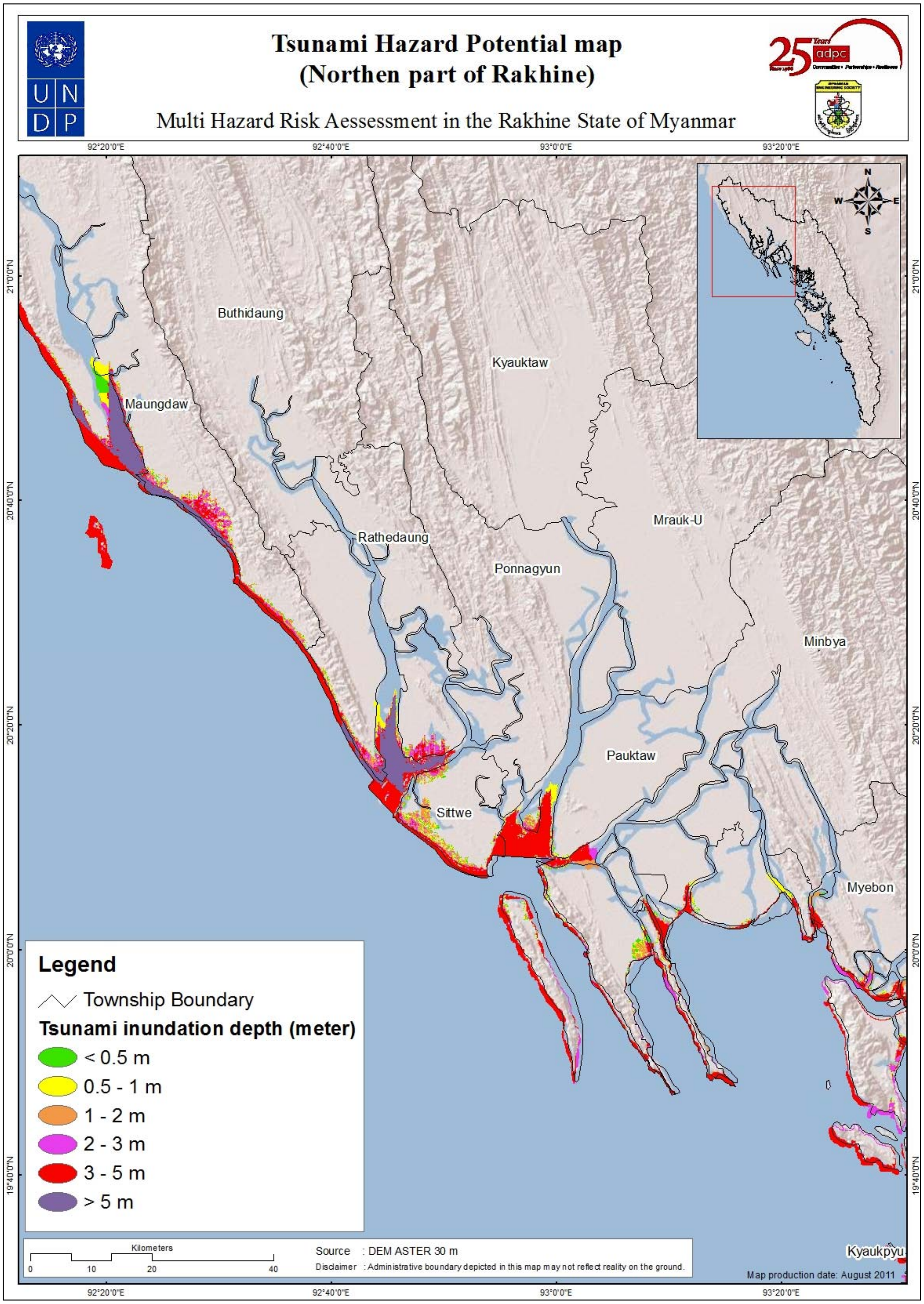


Figure 40: Tsunami hazard map for Rakhine State of Myanmar (northern part)

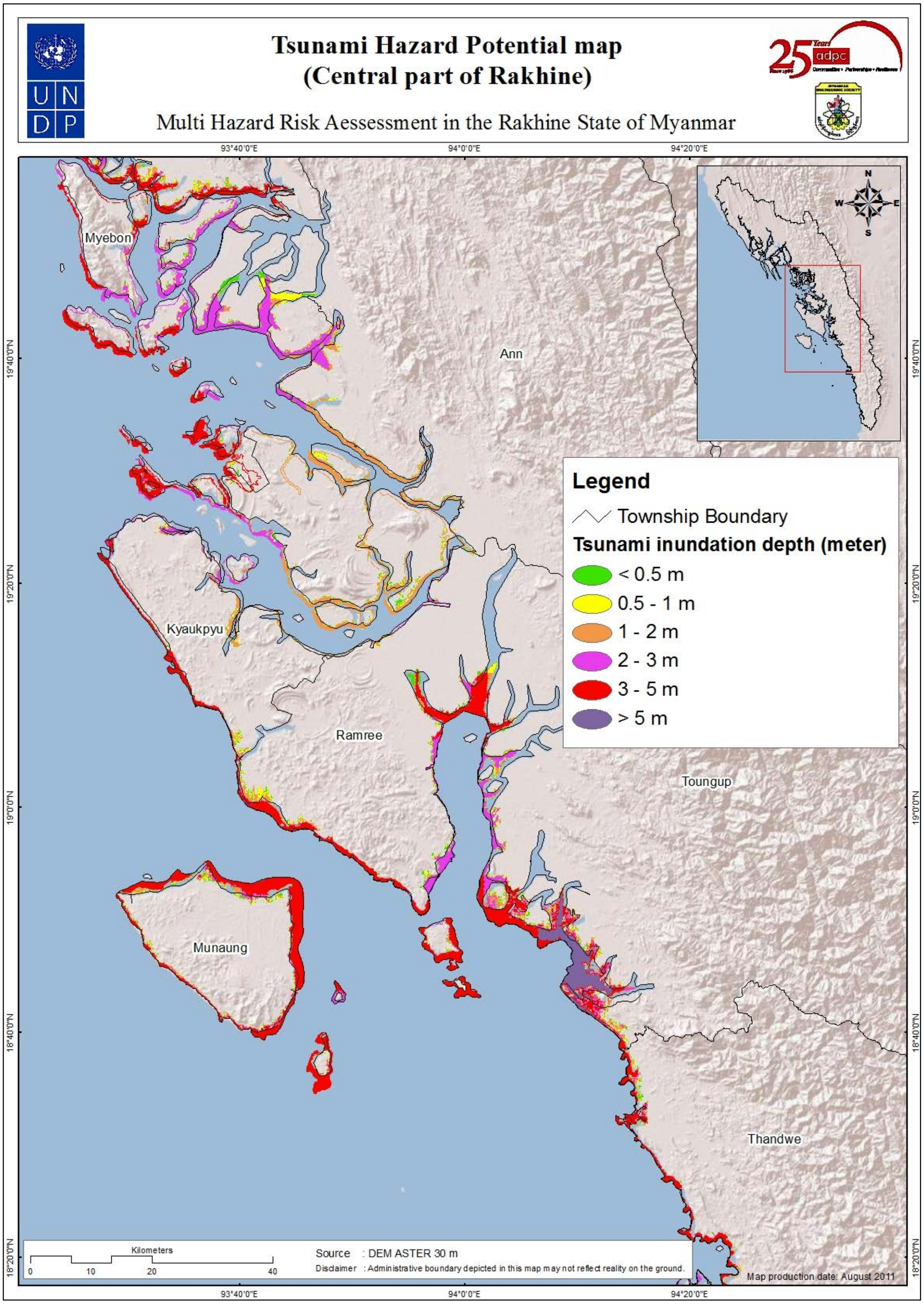


Figure 41: Tsunami hazard map for Rakhine State of Myanmar (central part)

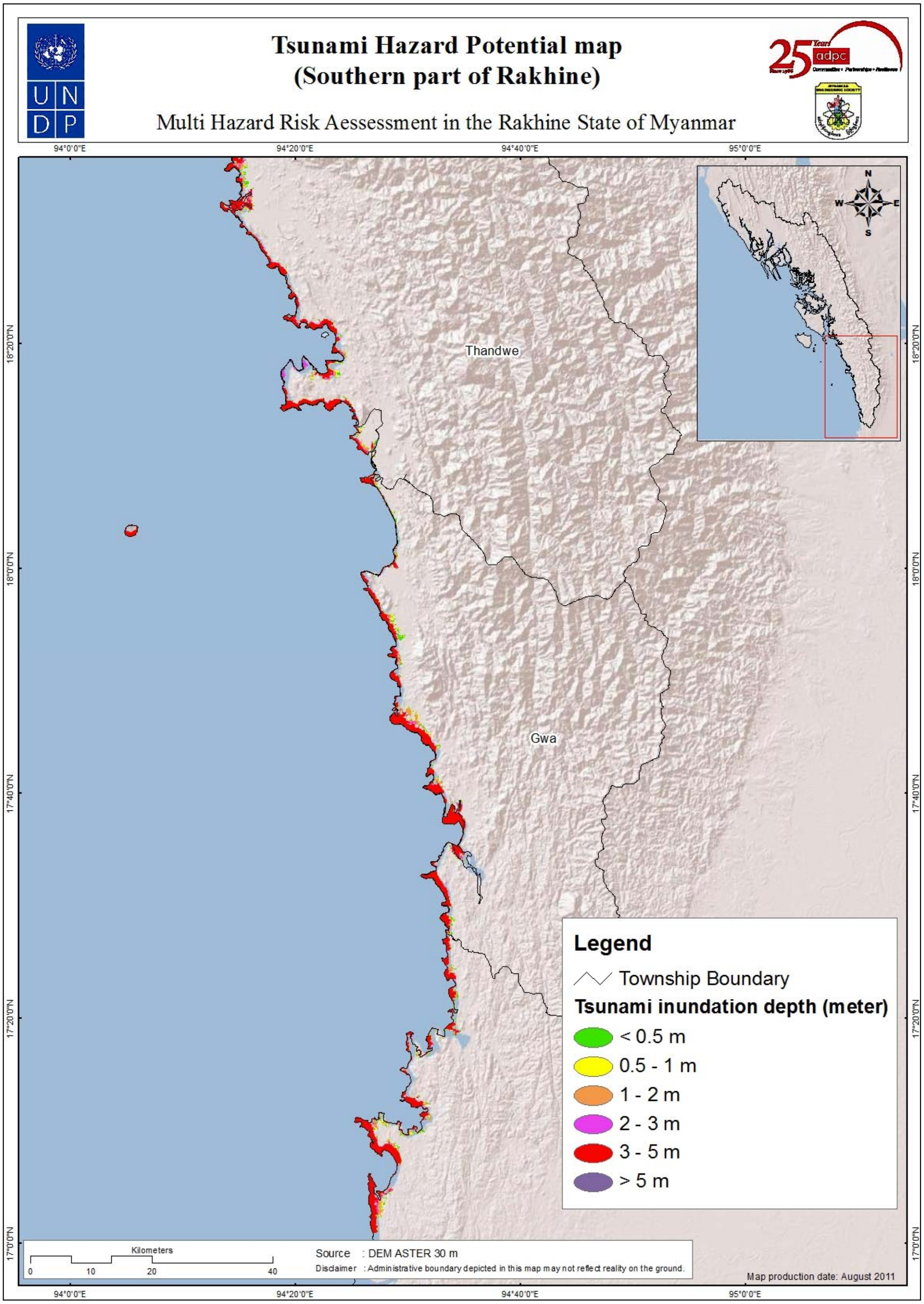


Figure 42: Tsunami hazard map for Rakhine State of Myanmar (southern part)

Recommendation for improving the Hazard Maps

The accuracy of inundation simulations could be improved by utilizing higher resolution topographic data such as those acquired through the LIDAR system. Tsunami hazard maps based on the deterministic method such as in the present assessment may be further enhanced by incorporating short- to medium-term scenarios together with their recurrence intervals as the understanding of the seismicity of the subduction zones concerned improves in the future. It is also desirable to carry out field verifications to detect any discrepancies, particularly since the vertical resolution of elevation data (ASTER) utilized in the present inundation simulations is coarse. The present version of the map could be further enhanced by incorporating more information relating to the tsunami hazard and mitigation measures.

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CHAPTER B: RESULTS FROM FIELD SURVEY

Questionnaire for Field Survey

Questionnaire for Village Tract Level Survey

Name of the district:

Name of the township:

Name of the village tract:

PART A: SOCIO ECONOMIC INFORMATIONS

1. i. Ward No. iii. Village:…………………………………………..
2. i. Family No. ………………….. ii. Population:………………………….. iii. Cultivable Land……………
3. *Occupation:* i. Agriculture……..%, ii. Fisheries………..% iii. Livesstocks………% iv. Others……….%
4. *Livestock*: i. Cattle…………..ii. Goats……… iii. Sheep………….. iv. Poultry……….. v. Others………..

PART B: INFORMATION ON BUILDINGS/HOUSING

Number of Buildings	*Concrete*	Wood	Masonry	*Brick-nogging*	*Others*

PART C: INFORMATION ON HAZARDS

Type of Hazard	*Duration*	Water Depth	Surge (YES/NO)		
Flood					
Cyclone					
Landslide					
Earthquake					

PART D: INFORMATION ON PAST DISASTER EVENTS

	Hazard:	Hazard:	Hazard:	Hazard:
	Year:	Year:	Year:	Year:
No. of deaths				
No. of injured				
No. of houses damaged				
No. of houses destroyed				
No. of livestock lost				
Type of lost livestock				
Area of cropland lost				
No. fishing boats lost				
No. fishing nets lost				
Height depth of water during the hazard				
Others				

Questionnaire for Local Municipality/ Relevant Agencies for Capacity Assessment

Name of the district: **Name of the township:**

PART A: INFORMATION ON POLICY DOCUMENT AND INITIATIVE FOR DISASTER MANAGEMENT

1. What is the Current Guidelines for Disaster Management of the Township?
2. Is this guideline/ Policy from the State Government or by the Municipality?
3. What are the major hazards in your township/municipality area?
4. Do you have any mechanism to help people/ community to deal with the Hazards?
5. Does the municipality have any specific fund for Disaster Management?

PART B: INFORMATION ON THE HUMAN RESOURCE AND EQUIPMENTS FOR RESCUE DURING DISASTER

1. Is there any unit in the Municipality to Deal with Disaster? Y/N (if yes, answer following)
2. How many staffs are involved in the Unit? (Please specify if these staffs are technical or non technical)
3. What are the equipments that the municipality currently has for rescue operation after any disaster?
4. Are these equipments are sufficient for such rescue operation?

Questionnaire for Sector Damage Assessment

Name of the district:
Name of the township:

INFORMATION ON PAST DISASTER EVENTS

Sectors	Hazard	Hazard	Hazard	Hazard
	Year:	Year:	Year:	Year:
Agriculture				
Area of land with crop damage				
Amount of Crop Damage				
Type and amount of crop damage				
Type of lost livestock				
Area of cropland lost				
Tourism				
Number of Tourist before the Hazard				
Number of Tourist after the Hazard				
Specific damage to the tourist facilities				
Fisheries				
No. fishing boats lost, and economic Loss				
Amount of Fish Loss				
Business				
Economic Loss in the Business Sector				
Type of Business got Interrupted				
Communication				
Km of road got Damaged				
Number of Bridge / Culvert Damaged				
Road blockage through landslide				
Road blockage through flood water				
Education				
Number of School Damaged				
Number of Collage Damaged				

Hazard Events in Rakhine State (1968-2010)

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
Ponnagyun	Cyclone	2010	Pa Day Thar	0	0	0	10	0	0	20	0	0	0
			Kun Taung	0	0	3	0	0	0	100	0	0	7
			Out Ywa (Urban)	0	0	71	0	0	0	0	0	0	0
	Flood	2010	Kon Tan Kyein Chaung	0	0	0	40	0	0	500	0	0	7
	Cyclone	2009	Kyauk Seik	0	0	1	0	0	0	0	0	0	2
	Cyclone	2008	Pa Day Thar	0	0	0	5	0	0	20	0	0	0
	Landslide	2008	Kyauk Seik	0	0	0	0	0	0	0	0	0	0
	Others	2008	Tan Zwei	0	0	25	3	0	0	0	0	0	0
Mrauk-U	Cyclone	2010	Myet Yaik Kyun	0	0	0	0	0	0	0	0	0	0
			Pi Pin Yin	0	0	0	0	0	0	0	0	0	0
			Nan Kya	0	0	0	0	0	0	0	0	0	0
			Myaung Bway	0	0	0	0	0	0	0	0	0	0
			Let Than Chi	0	0	5	0	0	0	0	0	0	0
	Flood	2010	Bu Ta Lone	0	0	0	0	0	0	36	0	0	0
			Let Than Chi	1	0	0	0	0	0	0	0	0	0
	Flood	2010	Kan Sauk	0	0	0	0	0	0	50	0	0	3
	Tornado	2010	Htan Ma Rit	0	0	0	10	0	0	30	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
	Cyclone	2009	Paung Htoke	0	0	0	0	0	0	0	0	0	4
			Taung U	0	0	1	1	0	0	30	0	0	5
	Cyclone	2007	Myet Yaik Kyun	0	0	0	0	0	0	10	0	0	0
	Flood	2007	Kyi Yar Pyin	0	0	0	0	0	0	0	0	2	5
	Tornado	2007	Kyi Yar Pyin	0	0	3	0	0	0	0	0	0	0
	Flood	1997	Paung Htoke	0	0	0	0	0	0	0	0	0	4
	Tornado	1997	Pu Rein	0	0	11	0	0	0	20	0	0	0
	Flood	1993	Kyauk Kyat	0	0	0	0	0	420	60	0	0	0
Kyauktaw	Others	2011	Hpa Yar Paung	2	0	0	0	0	0	0	0	0	0
	Tornado	2011	Thit Ta Pon	0	0	4	0	0	0	0	0	0	0
			Pyaung Seik	0	0	0	0	0	0	0	0	0	0
			Na Gu May	0	0	0	4	0	0	0	0	0	0
	Cyclone	2010	Kyauk Ta Lone	0	0	0	School	0	0	0	0	0	5
	Flood	2010	Taung Htaung	0	0	0	0	0	0	0	0	0	4
			Hpa Yar Paung	0	0	0	0	0	0	0	0	0	3
			Kun Ohn Chaung	0	0	0	0	40	Cattle	50	0	0	4
			Kan Sauk	0	0	0	0	0	0	0	0	0	4
			Pyaung Seik	0	0	1-school	0	2	Cattle	20	0	0	4
			Gwa Son	0	0	200	0	5	Cattle	150	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Ohn Pa Tee	0	0	0	0	0	0	80	0	0	0
			Na Gu May	0	0	0	0	0	0	100	0	0	4
	Landslide	2010	Ah Pauk Wa	0	0	2	0	0	0	100	0	0	5
	Cyclone	2009	Thit Ta Pon	0	2	4	0	3	cattle	7	0	0	4
			Nga/Hta Paung	0	0	0	0	0	0	225	0	0	0
			Kar Di	0	0	0	1monas;	0	0	20	0	0	0
	Flood	2009	Ma Tin Hmaing Chaung	0	0	0	0	0	0	120	0	0	5
			Ohn Pa Tee	0	0	0	0	9	Cattle	60	0	0	3.6
	Cyclone	2008	Tha Yet Ta Pin	0	0	3	0	0	0	120	0	0	5
			Ywar Ma Pyin	0	0	10	1	0	0	0	0	0	0
			Sa Hpo Thar	0	0	6	4	0	0	0	0	0	6
	Flood	2008	Min Thar Taung	0	0	4	0	0	0	0	0	0	5
			Kyar Nin Kan	0	0	3	3	0	0	10	0	0	7
			Kun Ohn Chaung	0	0	5	0	15	Cattle	30	0	0	3
	Tornado	2008	Hpa Yar Paung	0	0	0	0	0	0	0	0	0	0
	Cyclone	2007	Thit Ta Pon	0	0	0	1	6	cattle	5	0	0	5
	Flood	2005	Nga/Hta Paung	0	0	0	0	0	0	250	0	0	4
			Kar Di	0	0	0	0	0	0	25	0	0	3
	Flood	1997	Paik Thei	0	0	100	0	10	Cattle	10	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
Minbya	Cyclone	2010	Kin Seik	0	0	0	0	0	0	0	0	0	0
			Ywar Pyin	0	0	10	5	0	0	0	0	0	0
			Chaik Taung	0	0	17	0	0	0	49	0	0	0
			Taung Poet Gyi	0	0	11	0	0	0	0	0	0	0
			Nga/Way	0	0	67	0	0	0	0	0	0	1
			Bar Bu Taung	0	0	10	3	0	0	0	3	0	0
			San Bar Lay	1	0	7	0	50	Chicken	0	0	0	0
			Na Yan	0	0	6	0	0	0	0	0	0	6
			Pwint Htee	0	0	14	0	0	0	134	2	0	4
			Sat Kyar	0	0	6	2	0	0	0	0	0	0
			Ah Wa	0	0	55	37	0	0	0	0	0	0
	Flood	2010	Yan Htaing	0	0	110	120	40	cattle	200	0	0	3
	Flood	2009	Yan Htaing	7	2	85		20	cattle		2+2	0	7
Myebon	Cyclone	2010	Urban	10		985	1362	1922	Cattle, Pig	145	194	52	10
			Daing Bon	8	361	284	40	1987	Cattle, Poultry	987	1	30	9
			Koke Ko	0	0	0	0	0	0	1348	0	0	4
			Laung Da Reik	4	150	390	205	21	Cattle	1275	20	18	9
			Hpa Lar Kya	0	0	334	55	15	Cattle	949	65	11	5

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
	Cyclone	2007	Hpa Lar Kya	0	0	80	0	0	0	0	0	0	0
	Flood	2004	Urban	174	0	0	0	0	0	0	0	0	0
			Daing Bon	0	361	157	0	0	0	0	0	0	7
			Koke Ko	0	0	0	0	0	0	1200	205	0	3
			Laung Da Reik	0	0	120	140	50	Cattle	1000	5	9	6
			Hpa Lar Kya	0	0	35	0	0	0	949	11	3	
Maungdaw	Flood	2010	Kyein Chaung	0	0	62	0	0	0	0	0	0	5
			Done Paik (Aung Seik Pyin)	0	0	75	0	0	0	0	0	0	7
			Done Paik (Aung Seik Pyin)	0	0	0	0	0	0	0	0	0	5
			Yae Twin Kyun	0	0	45	0	0		80	0	8	5
			Tha Yet Oke	0	0	14	14	640	Cattles and poultry	200	0	0	4
			Pa Din	0	0	0	0	0	0	300	0	0	3
			(Du) Nyaung Pin Gyi	0	0	35	0	0	0	30	0	3	
			Tha Yae Kone Tan	0	0	0	0	0	0	0	0	0	2

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Tha yay kone tan	0	0	0	0	0	0	5	0	0	2
			Myoae U	0	0	0	0	0	0	5	0	0	2.5
	Landslide	2010	Kyein Chaung	0	0	0	0	2	Cattle	0	0	0	0
			Dar sha oake su	0	0	0	0	0	0	0	0	0	4
	Cyclone	1992	Shwe Zar Kat Pa Kaung	0	0	80	50	0	0	0	0	0	4
	Cyclone	1991	Myoae U	0	0	55	53	0	0	0	0	0	2
	Flood	1991	Chan Pyin	0	0	0	0	50	Cattle	0	0	0	3
			Ywet Nyoe Taung	0	0	0	0	0	0	0	0	0	
			Min Ga Lar Gyi (Pyin Hpyu)	3	0	75	18	100	Cattle	0	0	0	5
			Pan Taw Pyin	0	0	0	0	0	0	0		0	4
			(Pa) Nyaung Pin Gyi	0	0	0	0	3000	Prawns	0	0	0	3
			Gaw du thar ra	0	0	0	0	0	0	0	5	0	5
	Cyclone	1990	(Du) Nyaung Pin Gyi	0	0	0	0	0	0	50	0	0	6
	Flood	1990	(Du) Nyaung Pin Gyi	0	0	0	0	0	0	0	0	0	5
Buthida	Cyclone	2010	Kun Taing (a) Zee	0	0	28	3	0	0	0	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
ung			Pin Taung										
	Flood	2010	Nga Kyin Tauk	0	0	60	28	237	Poultry &goats	300	0	0	9
			Mee Chaung Khaung Swea	0	0	0	0	0	0	0	0	0	4
			Thin Ga Net	0	0	50	8	0	0	0	0	0	15
			Mee Chaung Zay	0	0	0	458	117	Goats and poultry	400	0	0	11
			Dar Paing Sa Yar	0	0	25	18	2	Cattle	45	0	0	9
			Chin Tha Mar	1	0	400	54	5	Cattle	1	4	4	15
			Kun Taing (a) Zee Pin Taung	0	0	14	8	20	Cattle	150	8	8	4
			Let Wea Det Pyin Shey	10	17	55	37	18	Cattle	16	0	0	11
			Ka Kyet Bet Kan Pyin	0	0	0	0	0	0	0	1	1	5
			Ka Kyet Bet	1	0	20	5	7	Cattle	50	1	1	8
			Ywet Nyo Taung	0	0	30	0	15	Cattle	30	3	2	8
	Landslide	2010	Ka Kyet Bet Kan	11	0	5	16	0	0	0	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Pyin										
	Others	2010	Inn Chaung	0	0	0	1	0	0	0	0	0	8
			Ah Lel Chaung	0	0	0	0	0	0	20	0	0	8
			Kin Chaung	0	0	6	0	0	0	0	0	0	8
Kyaukpyu	Cyclone	2010	Pyin Hpyu Maw	0	0	170	74	550	Poultry	124	7	80	5
			Taung Yin	0	188	1587	1335	250	Pig,fowl		17		6
			Gone Chein	0	0	481	125	25	Pig.fowl, Cow	120	3	10	1
			Ohn Taw	0	5	300	330	15	Pig.fowl, Cow	150	30	60	1
			Chaung Wa	0	0	640	170	3	Cow	100	0		10
			Leik Kha Maw	0	0	469	127	2	0		0	40	12
			Kat Tha Pyay	0	1	290	40	60	Pig.fowl, Cow	140	2	11	7
			Kandi	0	0	125	43	0	0	196.28	0	0	6
	Cyclone	2007	Chaung Wa	0	0	0	0	0	0	0	0	0	10
			Leik Kha Maw	0	0	0	0	0	0	0	0	0	0
			Kat Tha Pyay	0	0	27	12	80	Pig,Cow, Fowl	135	0	2	5

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Kandi	0	0	0	0	0	0	0	0	0	0
	Flood	2004	Taung Yin	0	102	1005	379	222	Pig,Fowl	0	10	0	0
			Ohn Taw	0	0	30	80	30	Pig.fowl, Cow	20	30	40	0
			Chaung Wa	0	0	170	3	4	Cow	180		10	0
			Leik Kha Maw	0	0	30	3	0	0	0	0	9	0
			Kat Tha Pyay	5	0	100	24	100	Pig,Cow, Fowl	140	13	10	0
			Kandi	0	0	189	21			126	4	6	0
	Cyclone	1997	Ohn Taw	0	0	50	100	30	Pig.fowl, Cow	50	50		0
Munaung	Cyclone	2010	Sun Pan Chaung	0	0	18	0	0	0	7	0	0	4
			Thit Pon	0	0	25	0	0	0	20	0	0	4
			Be Inn	0	0	4	0	0	0	155	0	0	5
			Kha Ohn Maw	0	0	0	0	0	0	120	0	0	3
			Thein Kone	0	0	2	0	0	0	95	0	0	3
			Kin Te	0	0	0	0	0	0		0	0	0
			Nga/Pon Kone	0	0	5	0	0	0	5	0	0	0
			Ka Mar	0	0	5	3	0	0	300	0	0	5
			Pyin Kauk	0	0	15	0	0	0	200	0	0	1.5

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Mein Ma Kywe	0	0	0	0	0	0	200	0	0	4
			Pa Lin	0	0	0	0	0	0	214	0	0	5
			Urban	0	0	1	0	0	0		0	0	0
	Flood	2008	Be Inn	0	0	15	0	0	0	150	0	0	6
	valcono	2008	Kan Zun	0	0	3	0	0	0	8	0	0	0
	Cyclone	2003	Sun Pan Chaung	0	0	14	1	0	0	10	0	0	6
			Thit Pon	0	0	15	0	0	0	15	0	0	6
			Be Inn	0	0	20	0	0	0	150	0	6	0
			Maung Ma Kan	0	0	0	0	0	0		0	0	0
	valcono	1999	Kan Zun	2	0	0	0	12	Cow	3	0	0	0
	Cyclone	1992	Sun Pan Chaung	0	0	22	3	0	0	8	0	5	0
			Thit Pon	0	0	230	23	15	Goats, Cow	10	100	4	0
			Be Inn	0	0	20	0	0	0	150	0	6	0
			Maung Ma Kan	0	2	154	0	0	0	0	0	0	0
			Urban	0	0	0	0	0	0	0	0	0	0
Ann	Cyclone	2011	Ga Nan Pyin	0	0	64	5	3	cattle	2747	11	46	12
	Flood	2011	Ge Laung	0	0	0	3	0	0	5 arce	0	0	15
			Ka Zu Kaing	0	0	110	30	0	0	400	0	0	10
			Ga Nan Pyin	0	0	0	0	0	0	750	0	0	3

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
										arce			
			Sa Khan Maw	0	0	0	5	8	poultry	0	0	3	10
			Da Let	0	0	0	10	0	0	600	0	0	6
			Taik Maw	0	0	0	8	0	0	0	0	0	8
	Flood	2010	Ka Zu Kaing	0	0	16	6	0	0	300	0	0	8
			Hpet Chaung	0	0	10	0	0	0	800	2	2	7
			Sa Ne	0	0		0	0	0	1234	0	0	8
			Da Let	0	0	15	75	0	0	200	0	0	
			Kyaukmyaung	0	0	3	0	0	0	7300	0	0	6
			Zin Taw	0	0	0	0	0	0	800	0	0	8
			Zin Taw	0	0	22	7	13	cattle	1280	0	0	7
	Flood	2009	Ge Laung	1	0	1	2	0	0	8	0	0	20
			Sa Khan Maw	0	0	25	10	3	cattle	0	1	3	15
	Cyclone	2004	Ga Nan Pyin	4	0	10	5	16	cattle	0	3	26	11
			Nyaung chaung	0	0	0	0	0	0	0	0	0	0
	Cyclone	1992	Ge Laung	0	3	12	2	5	cattle	0	0	0	0
			Sa Khan Maw	0	0	15	2	0	0	0	0	0	0
	Flood	1971	Da Let	0	0	0	30	0	0	650	0	0	8
Thandwe	Flood	2011	Auk Nat Maw	0	0	0	0	0	0	0	0	0	0
			Gwayt Chaung	0	0	0	0	0	0	15	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Ah Lei	0	0	0	0	0	0	0	0	0	4
			Lin mu taung	0	0	5	0	0	0	0	0	0	15
			Tha Yaw Taw	0	0	0	0	0	0	2 acre	0	0	3
			U yin kwin	0	0	6	20	0	0	0	0	0	12
	Flood	2007	Ah Htu	0	0	0	0	0	0	0	0	0	5
	Flood	2006	Hpa Yar Maw	0	0	0	3	0	0	15	0	0	5
			Tha Yaw Taw	0	0	0	0	0	0	0	0	0	6
			Ah Htu	0	0	0	0	0	0	0	0	0	4
	Cyclone	2004	Mya pyin	0	0	12	14	0	0	0	10	20	0
	Flood	2004	Hpa Yar Maw	3	0	0	6	0	0	20	0	0	5
			Lin mu taung	0	0	0	4	0	0	0	0	0	20
			Tha Yaw Taw	0	0	2	2	2	cattle	6	0	0	7
			U yin kwin	0	0	0	0	0	0	0	0	0	8
			Pa de kaw	0	0	0	1	0	0	5	0	0	12
	Cyclone	1994	Mya pyin	0	0	30	12	0	0	0	50	35	0
Toungup	Flood	2011	Ta Ya Ba	0	0	0	1	52	poultry	200	0	0	7
			Yan khaw	0	0	7	0	0	0	0	0	0	6
			Kyaw Kaing	0	3	2	0	0	0	12	2	3	6
			Sar Pyin	0	0	0	0	0	0	100	0	0	4
			Khu	0	0	0	0	0	0	10	0	0	6

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Nga Lone Maw	0	0	0	0	0	0	20	0	0	5
	Flood	2010	Nat Maw	0	0	0	0	0	0	150	0	0	3
			Sar Pyin	0	0	0	0	0	0	100	0	0	6
			Kyauk seik taung	0	0	0	0	0	0	50	0	0	5
			La Mu Maw	0	0	0	0	0	0	20	0	0	0
	Flood	2007	Ta Ya Ba	0	0	350	0	100	poultry	3	0	0	3
	Flood	2006	Ta Ya Ba	0	0	400	1	150	poultry	5	0	0	5
			Yan khaw	0	0	0	0	0	0	0	0	0	5
			Kan Day	0	0	0	0	1	cattle	25	0	0	4
			Kyaw Kaing	0	0	0	0	20	Poultry	0	0	20	0
			Khu	0	0	15	0	0	0	5	0	0	0
			Nga Lone Maw	0	0	5	0	0	0	15	0	0	5
	Landslide	2006	Ta Ra Gu	0	0	0	0	0	0	2	0	0	0
	Cyclone	1992	Pa La War	0	0	212	0	0	0	0	0	0	0
			Nga Lone Maw	0	0	15	0	2	cattle	0	0	0	0
			Yan khaw	0	0	10	0	0	0	0	0	0	5
			Kan Day	0	0	100	0	0	0	0	0	0	0
			Hpaung Khar	65	0	40	30	20	cattle	1107	0	5	10
			Nat Maw	1	0	9	0	0	0	0	0	0	0
			Kyaw Kaing	0	0	80	5	0	0	0	0	0	0

Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Sar Pyin	0	0	20	20	0	0	0	0	0	0
			Za Ni	0	0	109	0	0	0	0	0	0	0
			Khu	0	0	25	0	0	0	0	0	0	0
	Flood	1992	Nga mauk chaung	0	0	20	0	0	0	100	0	0	0
	Cyclone	1986	Kyauk seik taung	0	0	50	2	6	cattle	50	0	0	10
	Flood	1986	La Mu Maw	0	0	0	10	0	0	0	0	0	5
Gwa	Flood	2011	Daunt Chaung	0	0	0	18	0	0	0	0	0	15
			Bawin	0	0	0	7	0	0	0	0	0	7
	Cyclone	2006	Shwe Twin Tu	0	0	1	0	0	0	0	0	0	0
			Ma Kyay Ngu	0	0	170	120	0	0	0	0	0	3
	Flood	2006	Ya Haing Ku Toet	0	0	0	0	0	0	0	0	0	8
	Flood	2004	Ya Haing Ku Toet	0	5	200	0	0	0	0	0	0	8
	Cyclone		Shwe Twin Tu	0	0	0	1	1	cattle	0	0	0	0
			Daunt Chaung	0	0	180	0	0	0	0	0	0	2
			Yae Kyaw	0	0	0	0	0	0	0	0	0	0
		1982	Ma Kyay Ngu	1	50	50	40	1	cattle	0	0	0	3
Pauktaw	Cyclone	2010	Thar Zay	0	0	328		320	0	213	0	0	2.5
			Gyin Dway	0	0	20	95	15	0	600	10	12	4
			Chaung Zauk	0	0	98	48	3	0	640	0	0	4
			Kan Seik	0	3	420	125	10	0	900	20	30	0

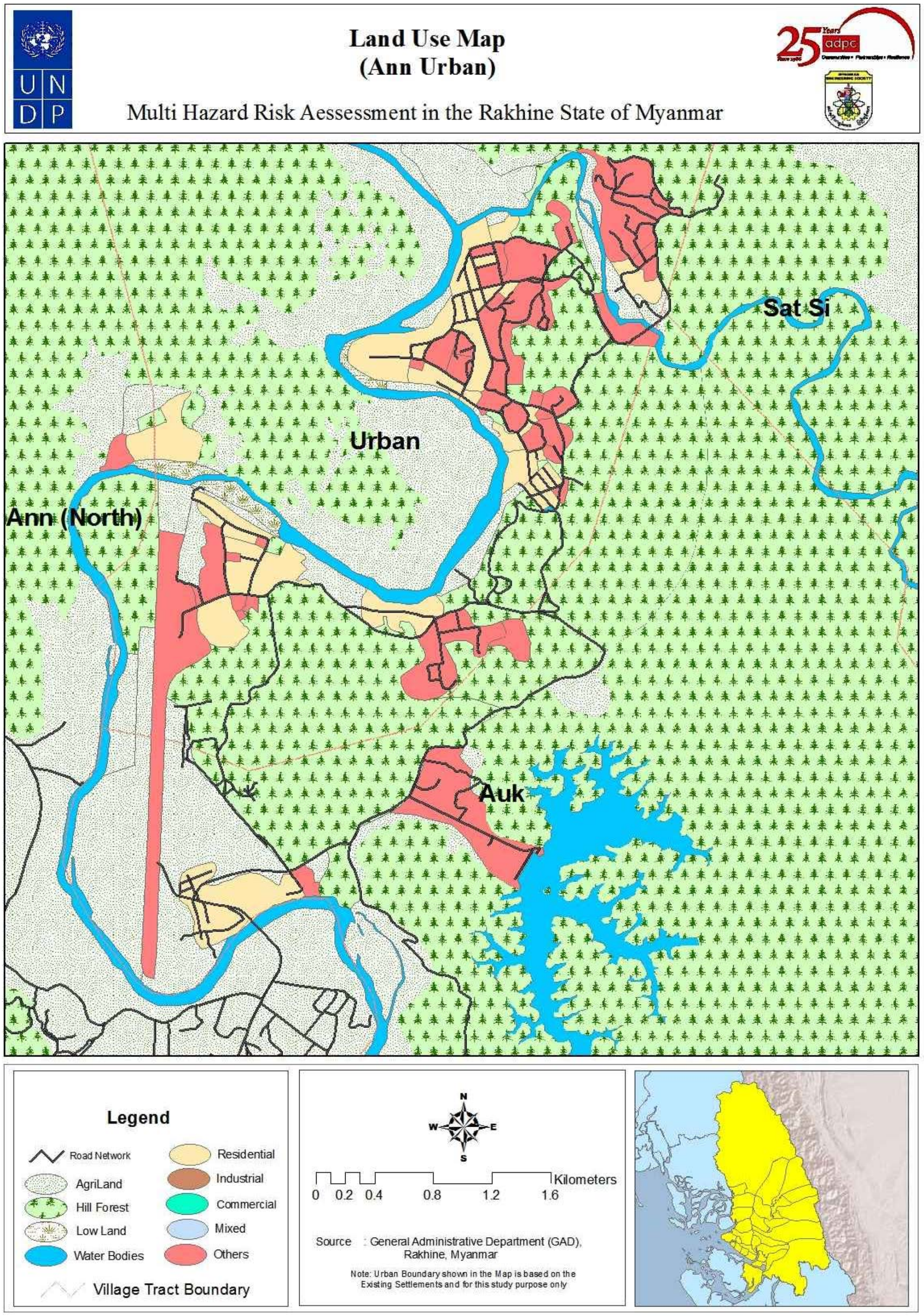
Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Taung Poke Kay	0	0	130	10	2	0	387	0	0	4
			Nan Tet Kyun	0	0	130	17	4	0	600	0	0	3
			Yin Ye Kan	0	0	0	0	0	0	0	0	0	0
			Kan Myint	0	0	140	27	10	0	0	0	0	0
			Byaing Thit	0	0	671	100	60	0	350	35	12	5
	Cyclone	2007	Thar Zay	0	0	0	0	0	0	0	0	0	0
			Gyin Dway	0	0	0	0	0	0	0	0	0	0
			Chaung Zauk	0	0	0	0	0	0	0	0	0	0
			Taung Poke Kay	0	0	0	0	0	0	0	0	0	0
			Nan Tet Kyun	0	0	0	0	0	0	0	0	0	0
			Yin Ye Kan	0	0	0	0	0	0	0	0	0	0
			Kan Myint	0	0	0	0	0	0	0	0	0	0
			Let Pan Pyar	0	0	60	0	0	0	0	0	0	0
	Flood	2006	Byaing Thit	0	0	10	0	0	0	300	0	12	6
	Cyclone	2004	Yin Ye Kan	0	0	0	0	0	0	0	0	0	0
			Kan Myint	0	0	0	0	0	0	0	0	0	0
			Let Pan Pyar	0	0	500	0	0	0	0	0	0	0
			Thar Zay	0	0	0	0	0	0	0	0	0	0
			Gyin Dway	0	0	0	0	0	0	0	0	0	0
			Chaung Zauk	0	0	0	0	0	0	0	0	0	0

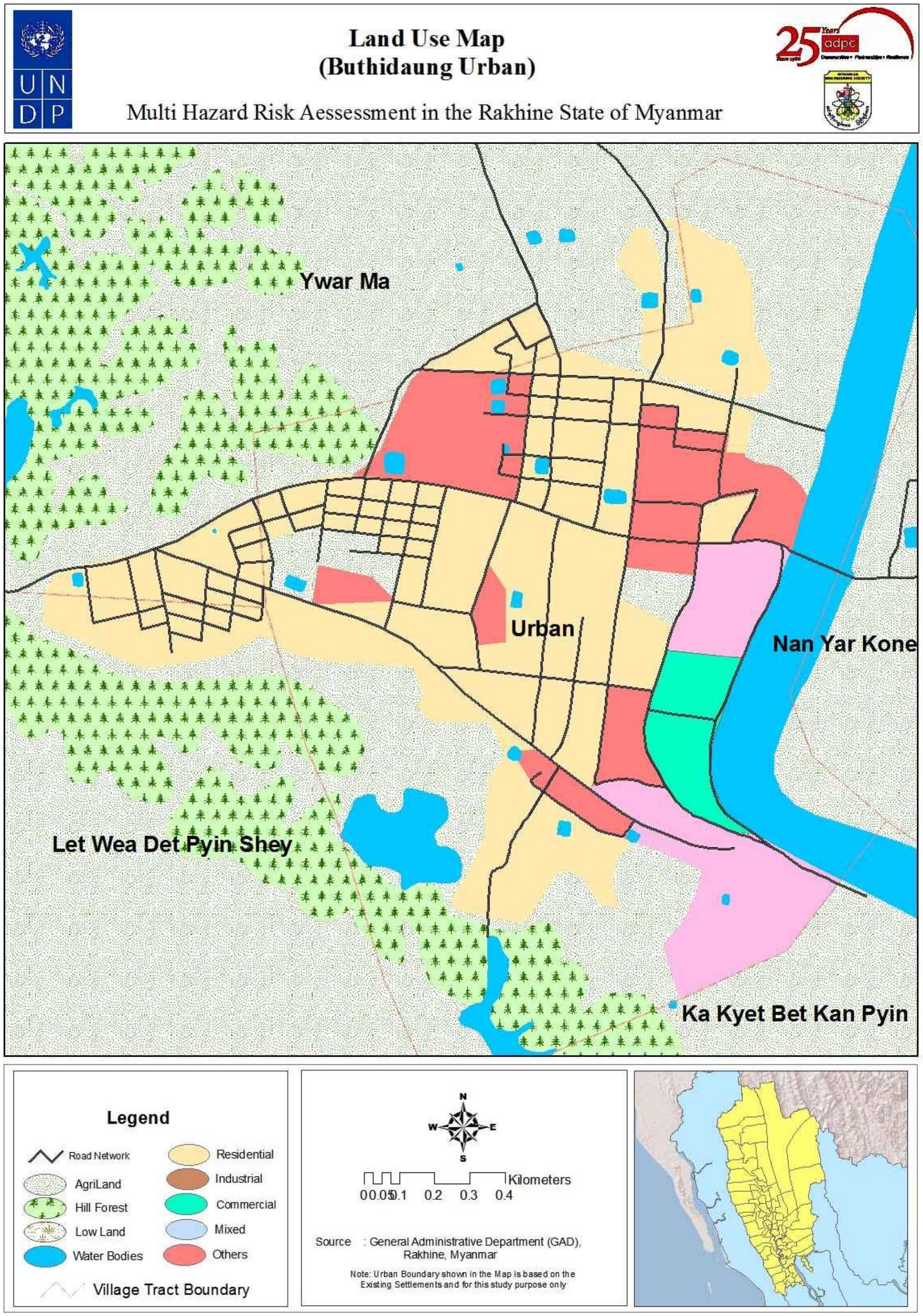
Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Taung Poke Kay	0	0	0	0	0	0	0	0	0	0
			Nan Tet Kyun	0	0	0	0	0	0	0	0	0	0
	Cyclone	1968	Thar Zay	0	0	0	0	0	0	0	0	0	0
			Gyin Dway	0	0	0	0	0	0	0	0	0	0
			Chaung Zauk	0	0	0	0	0	0	0	0	0	0
			Taung Poke Kay	0	0	0	0	0	0	0	0	0	0
			Nan Tet Kyun	0	0	0	0	0	0	0	0	0	0
			Yin Ye Kan	0	0	0	0	0	0	0	0	0	0
			Kan Myint	228	50	0	0	250	0	2600	30	40	8
Ratehdaun g	Cyclone	2010	U Gar	1	0	10	0	0	0	0	0	0	0
	Flood	2010	Kan Pyin	0	0	30	0	0	0	0	0	4	4
		2007	Pyein Taw	0	0	0	0	0	0	0	0	0	8
	Flood		Nyaung Pin Gyi	0	0	6	0	0	0	0	0	0	3
	Cyclone	2005	Ah Nauk Pyin	0	0	0	5	0	0	300	0	0	0
		2004	Pyein Taw	0	0	0	20	0	0	0	0	0	0
	Others		Kyauk Tan	0	0	0	2	0	0	0	0	0	0
		1968	Kyun Paw	0	0	0	0	0	0	100	0	0	0
	Cyclone		Kyun Gyi	3	10	100	5	20	Cattle, Poultry ,other	30	5	10	4

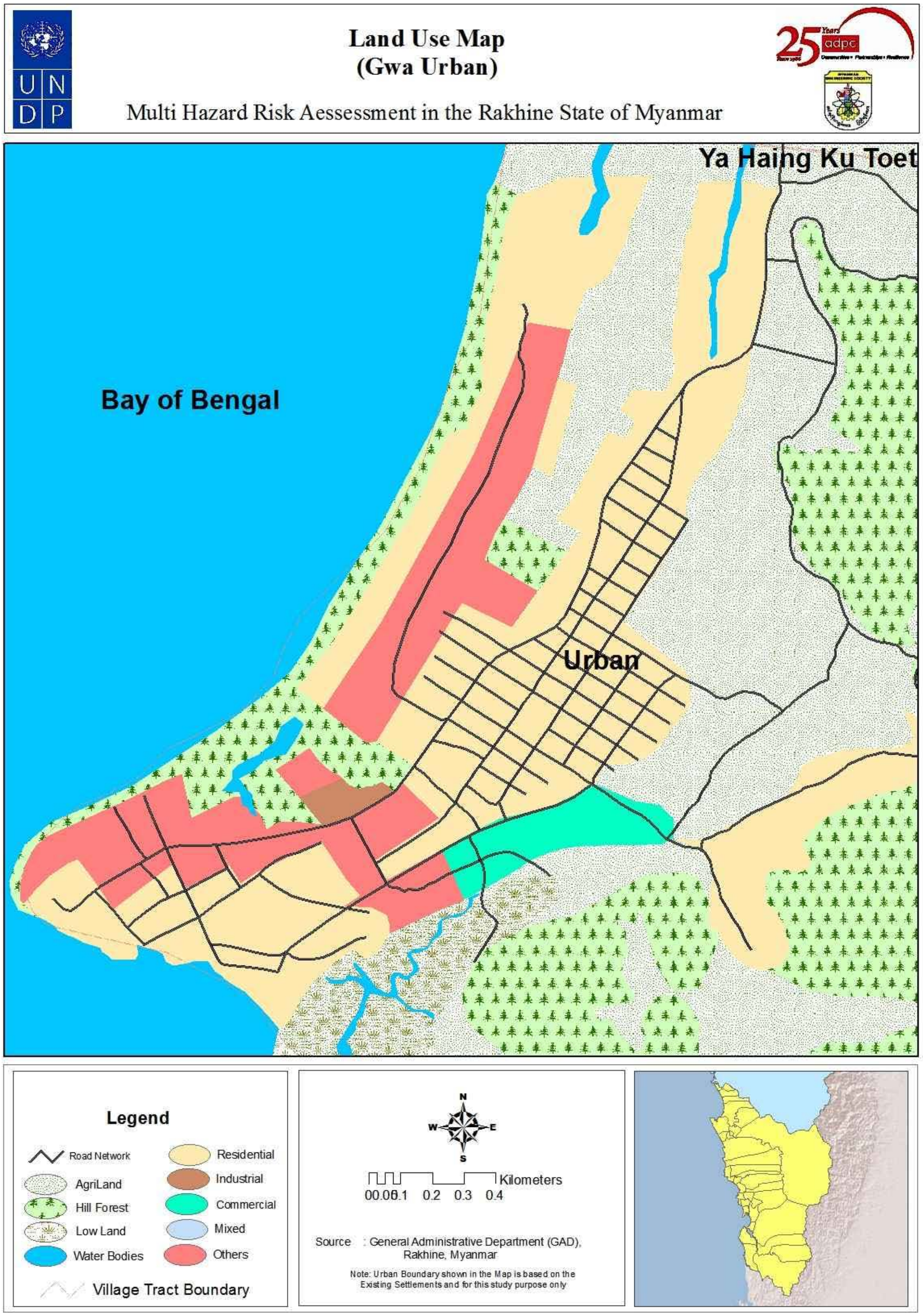
Township	Hazard	Year	Affected Village Tract	Population Affected		Structural Damage		Loss of Live stocks		Crop Damage (in Acres)	Loss in Fisheries		Height depth of water during disaster (in Feet)
				No. of Deaths	No. of Injured	No. of houses damaged	No. of houses destroyed	No. of Live stock lost	Types of Livestock loss		No. of fishing boats lost	No. of fishing net lost	
			Zee Kaing	2	0	400	100	12	Cattle,Poultry,other	0	0	2	4
	Flood	1968	Nyaung Pin Gyi	0	0	200	200	50	Catttle	0		0	8

Source: *GAD Records, interview with Village heads during exchange of views at respective townships during August & September 2011*

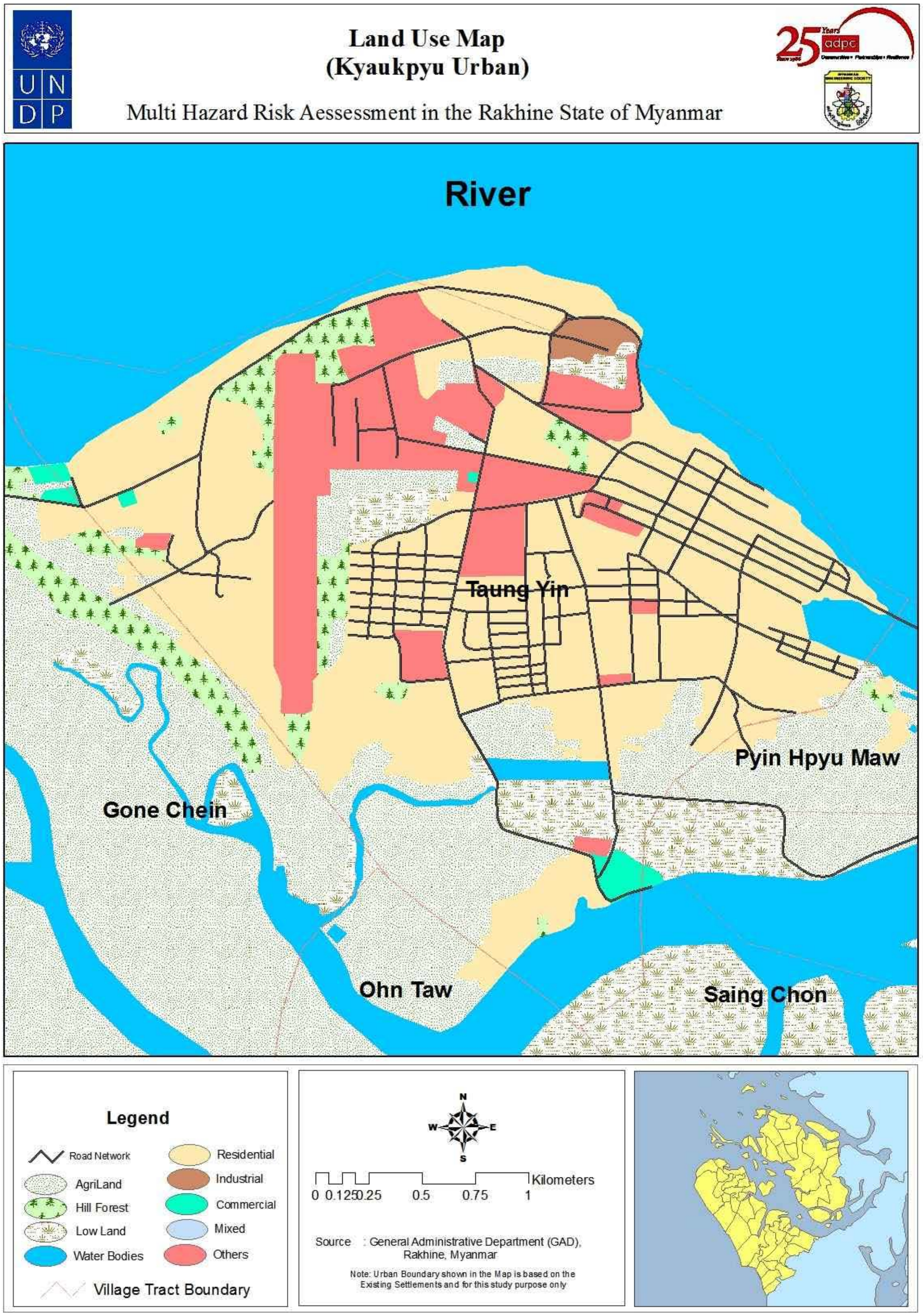
Land Use Maps of Urban Townships in Rakhine State

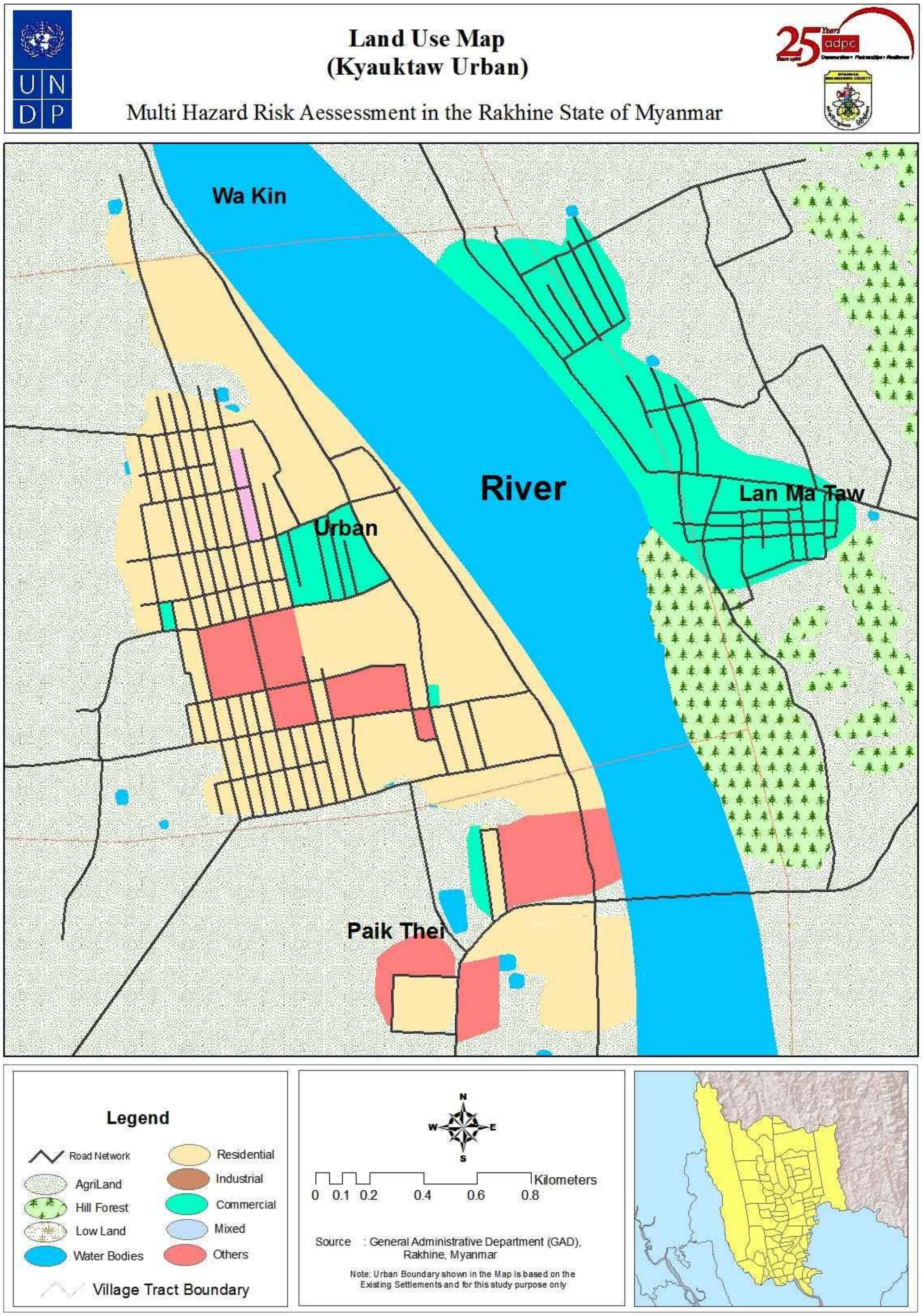


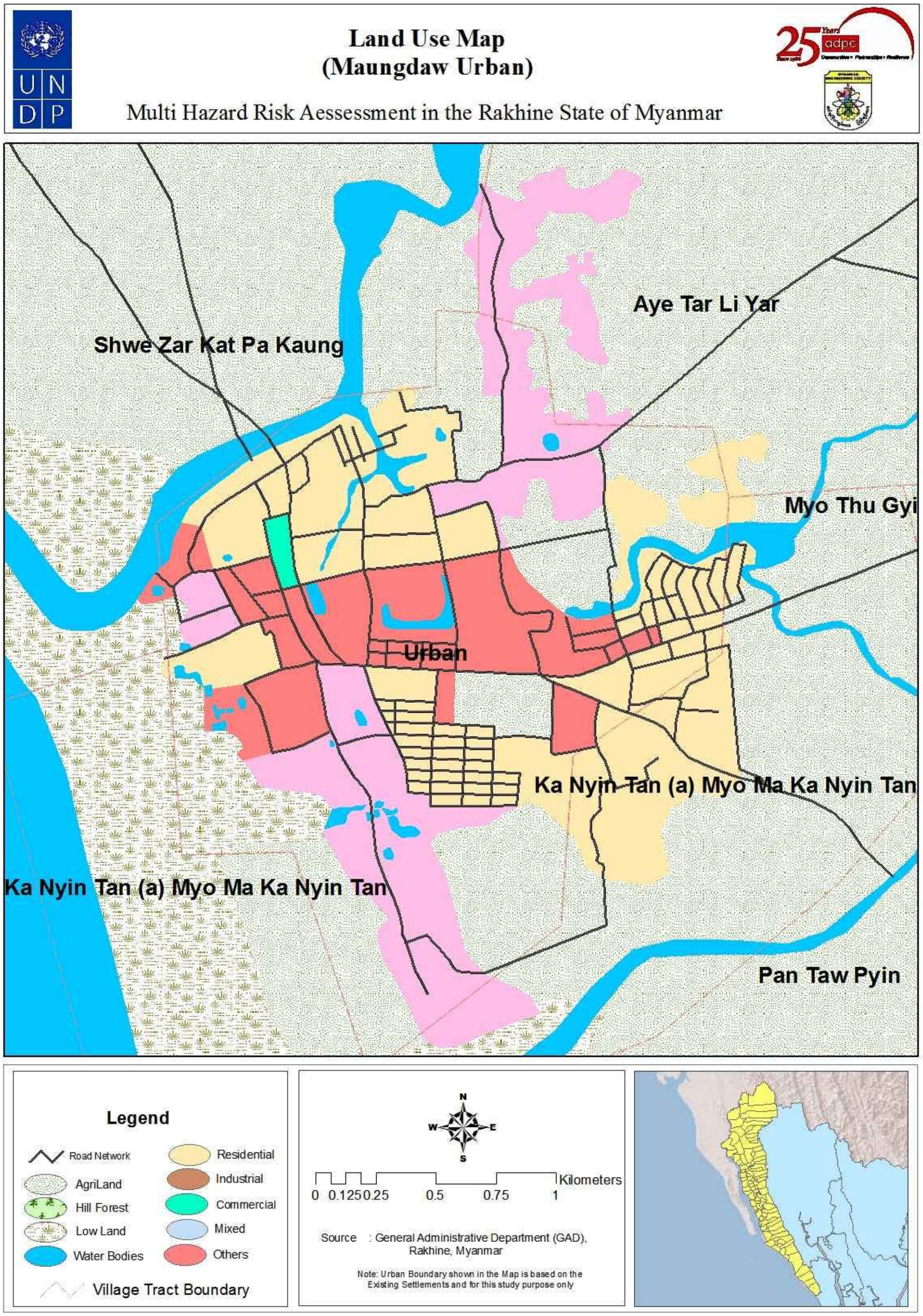

Land Use Map
(Buthidaung Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Ywar Ma
Urban
Nan Yar Kone
Let Wea Det Pyin Shey
Ka Kyet Bet Kan Pyin
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only



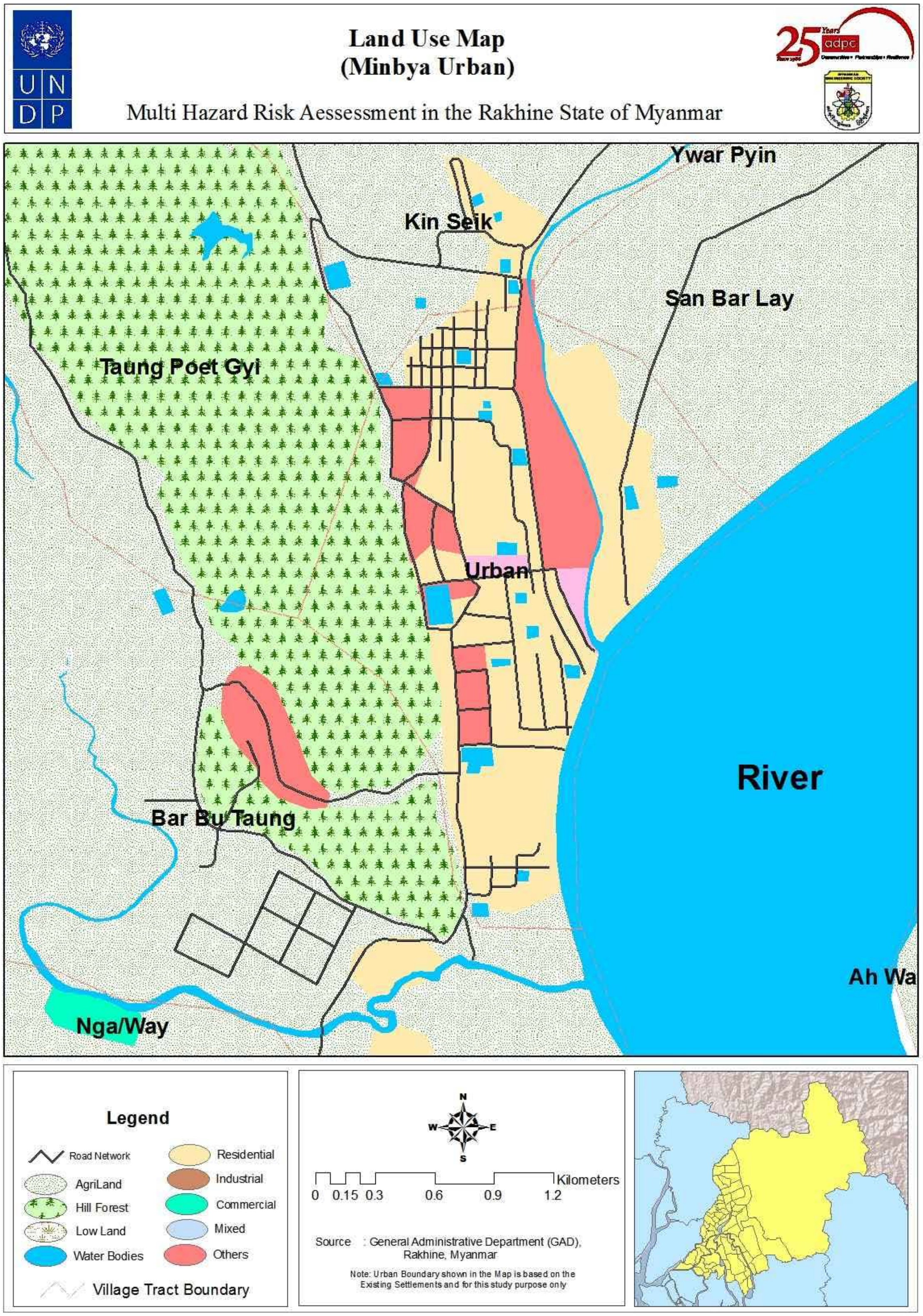
Land Use Map
(Gwa Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Ya Haing Ku Toet
Bay of Bengal
Urban
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
Kilometers
0 0.05 0.1 0.2 0.3 0.4
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

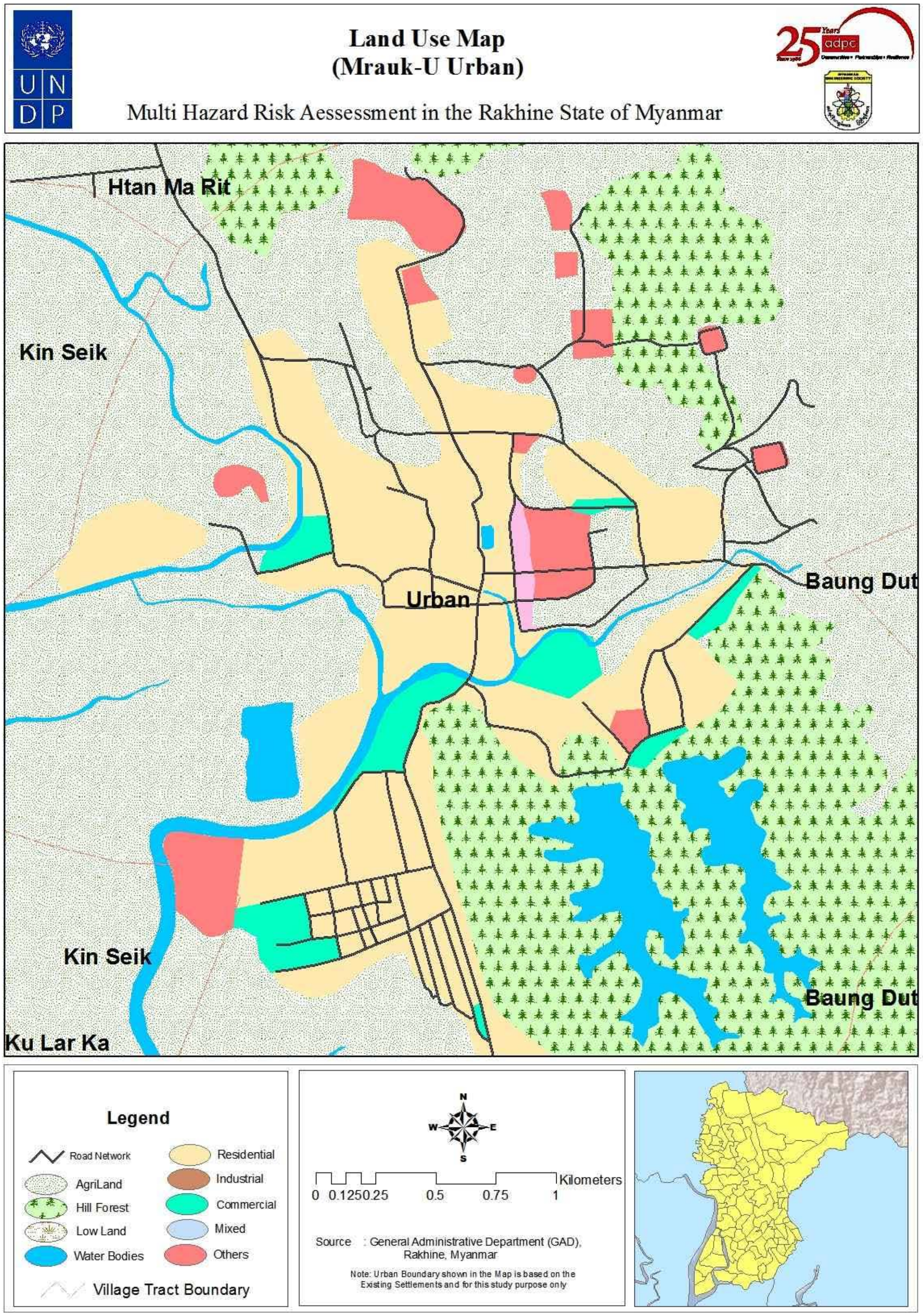

Land Use Map
(Kyaukpyu Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
River
Taung Yin
Pyin Hpyu Maw
Gone Chein
Ohn Taw
Saing Chon
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.1250.25 0.5 0.75 1
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

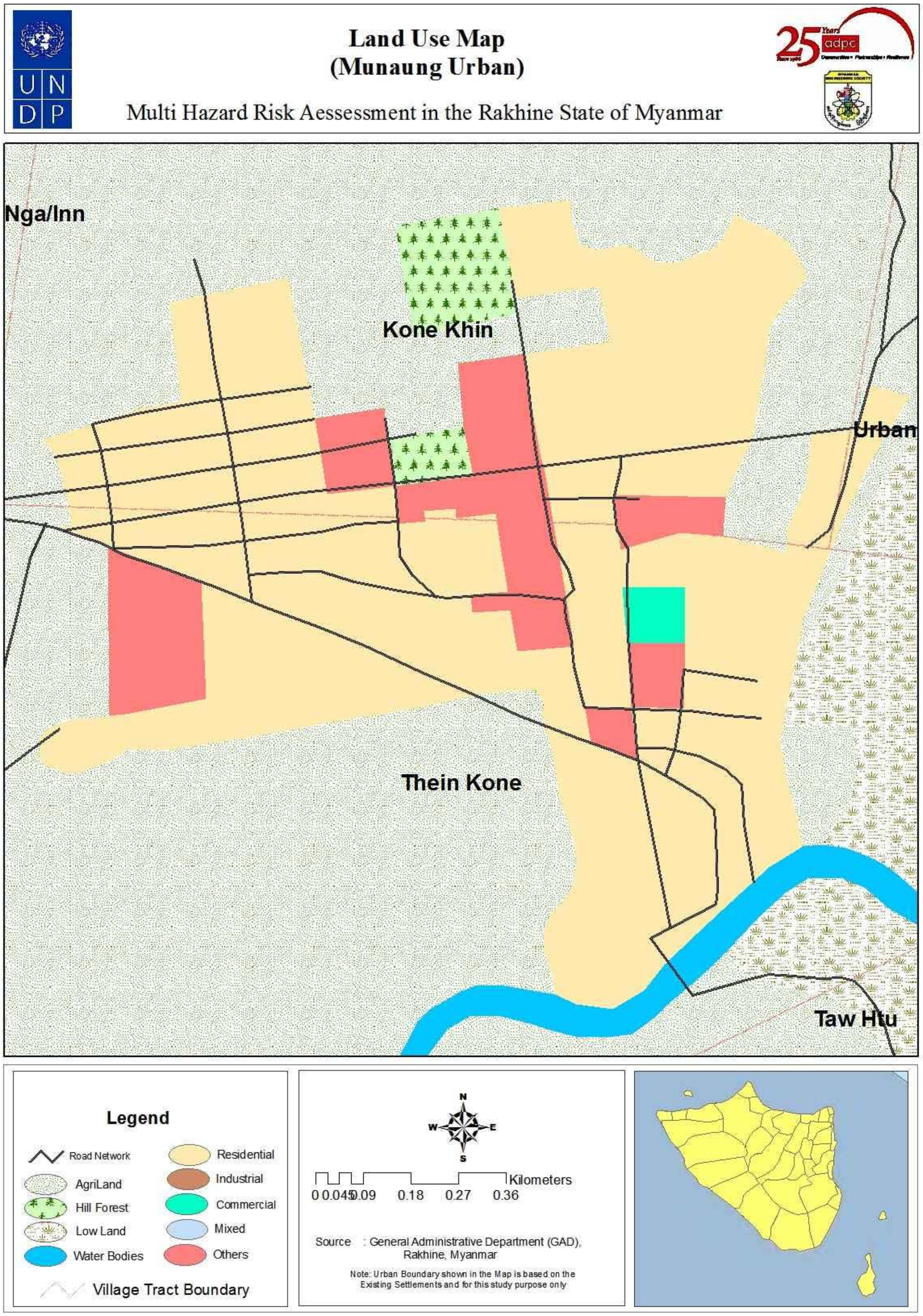

Land Use Map
(Kyauktaw Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Wa Kin
River
Urban
Lan Ma Taw
Paik Thei
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.1 0.2 0.4 0.6 0.8 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only



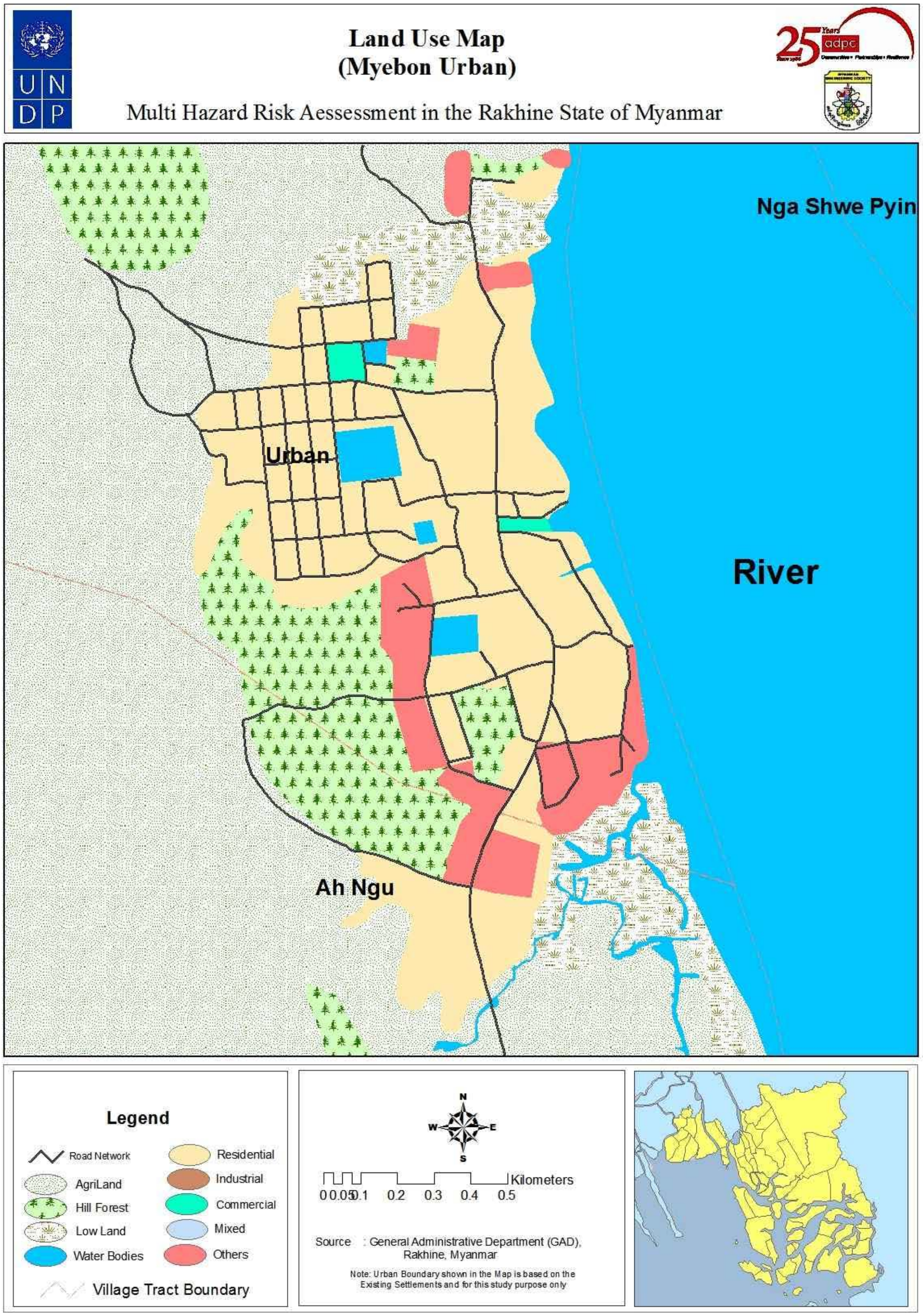
U N D P
Land Use Map
(Maungdaw Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
25 Years adpc
Aye Tar Li Yar
Shwe Zar Kat Pa Kaung
Myo Thu Gyi
Urban
Ka Nyin Tan (a) Myo Ma Ka Nyin Tan
Ka Nyin Tan (a) Myo Ma Ka Nyin Tan
Pan Taw Pyin
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.1250.25 0.5 0.75 1
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Land Use Map
(Minbya Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
UNDP
Ywar Pyin
Kin Seik
San Bar Lay
Taung Poet Gyi
Urban
River
Bar Bu Taung
Ah Wa
Nga/Way
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.15 0.3 0.6 0.9 1.2 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Land Use Map
(Mrauk-U Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Htan Ma Rit
Kin Seik
Urban
Baung Dut
Kin Seik
Baung Dut
Ku Lar Ka
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.1250.25 0.5 0.75 1
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

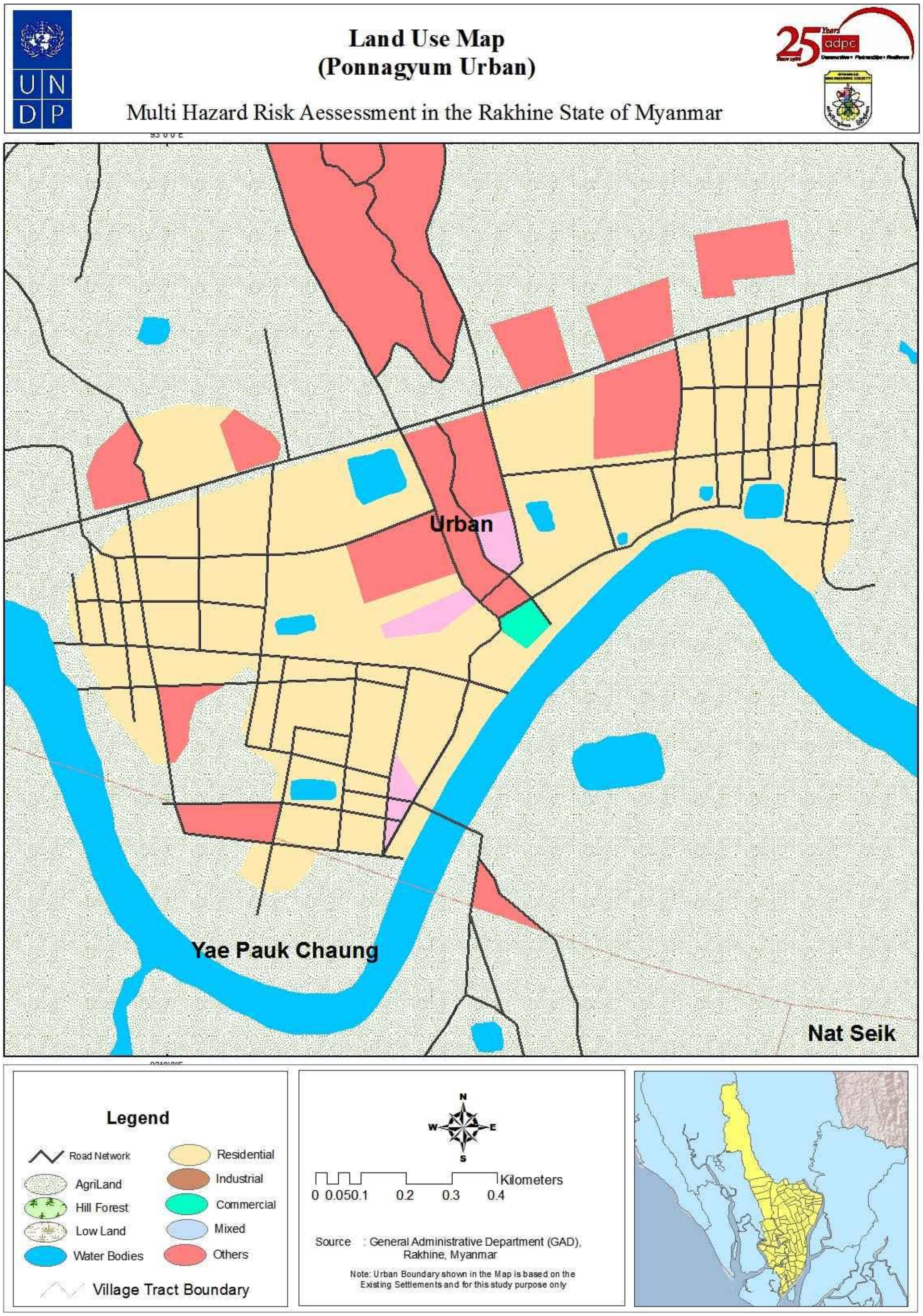


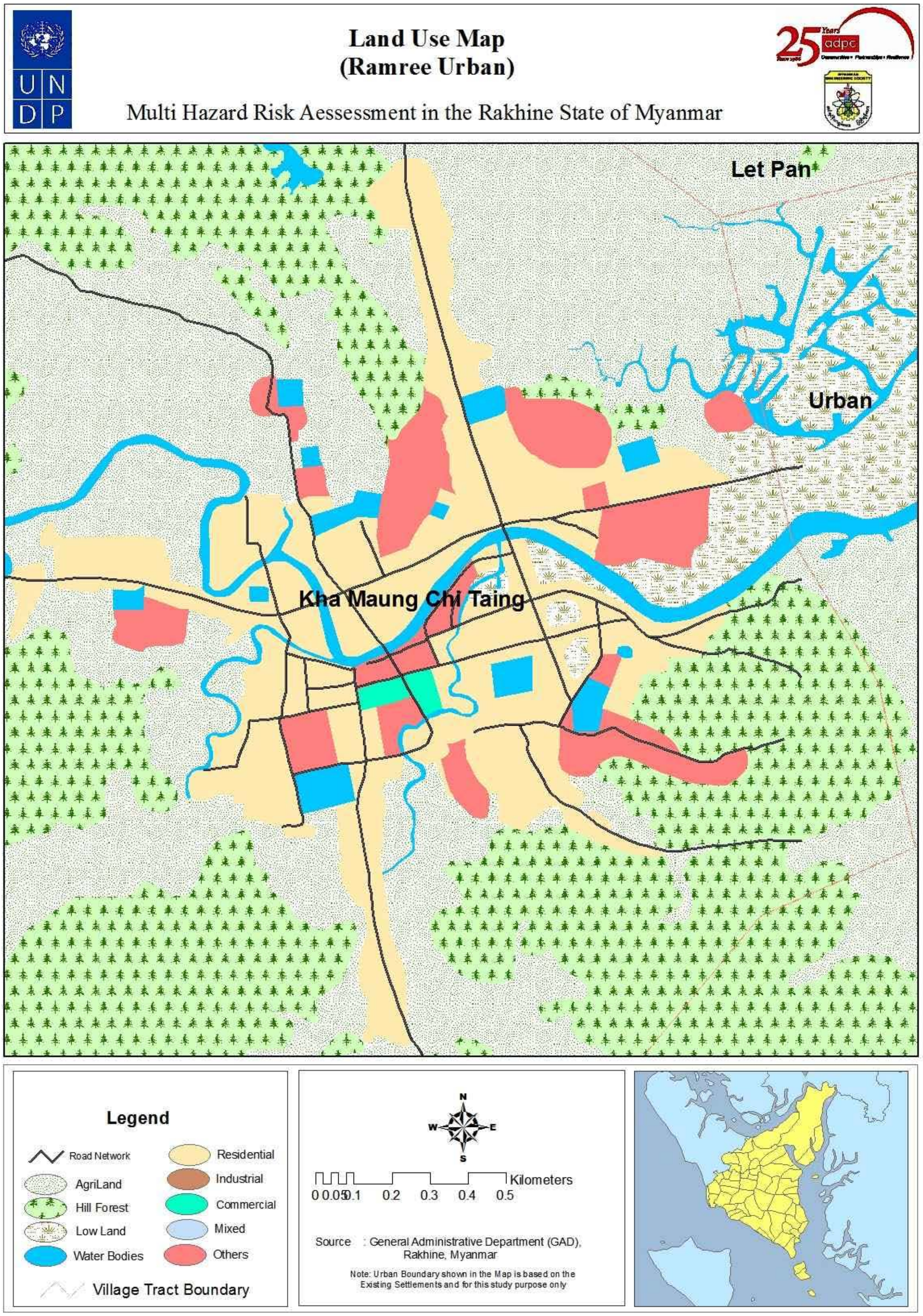
Land Use Map
(Munaung Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Nga/Inn
Kone Khin
Urban
Thein Kone
Taw Htu
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
S
E
W
0 0.045 0.09 0.18 0.27 0.36 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

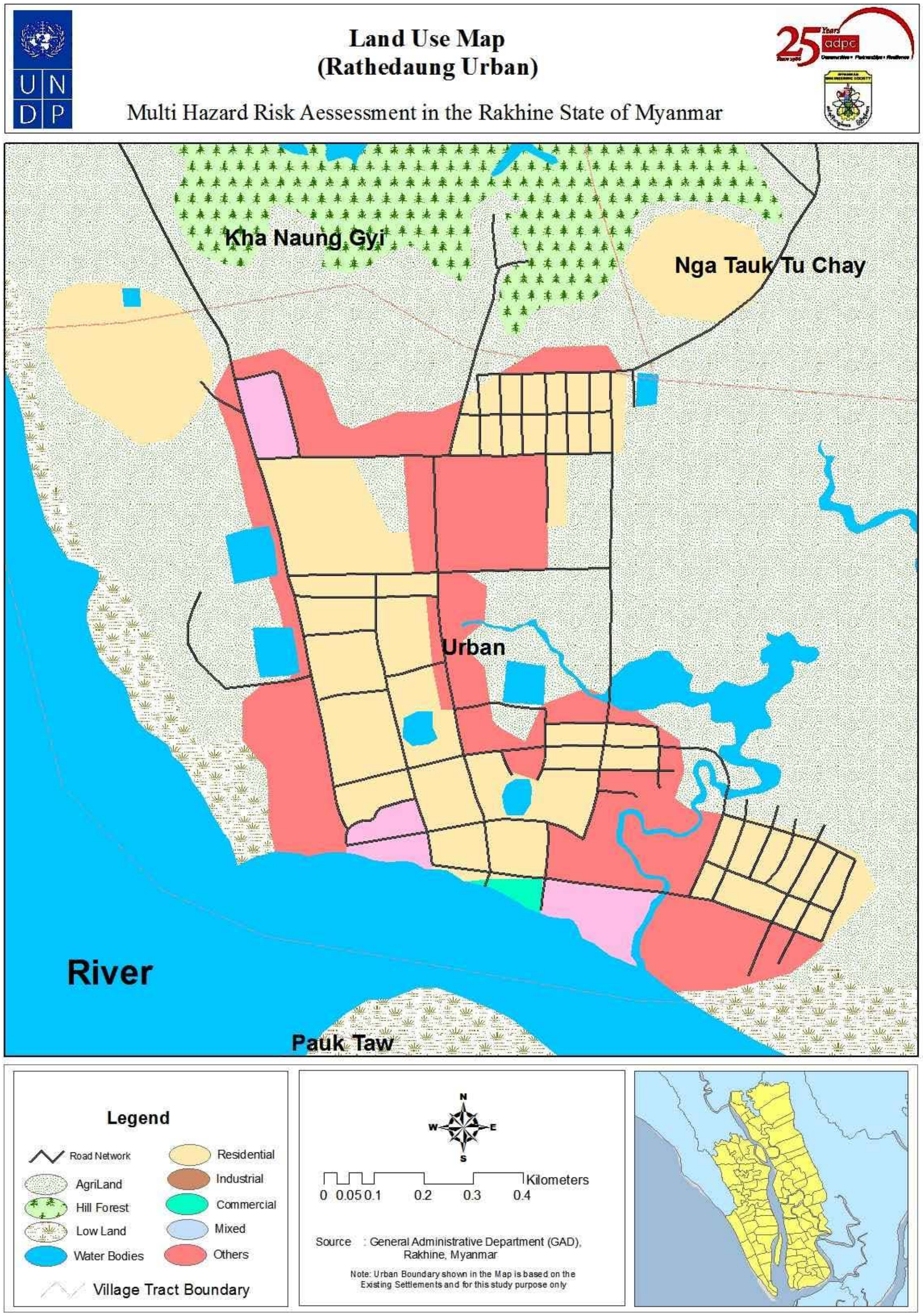


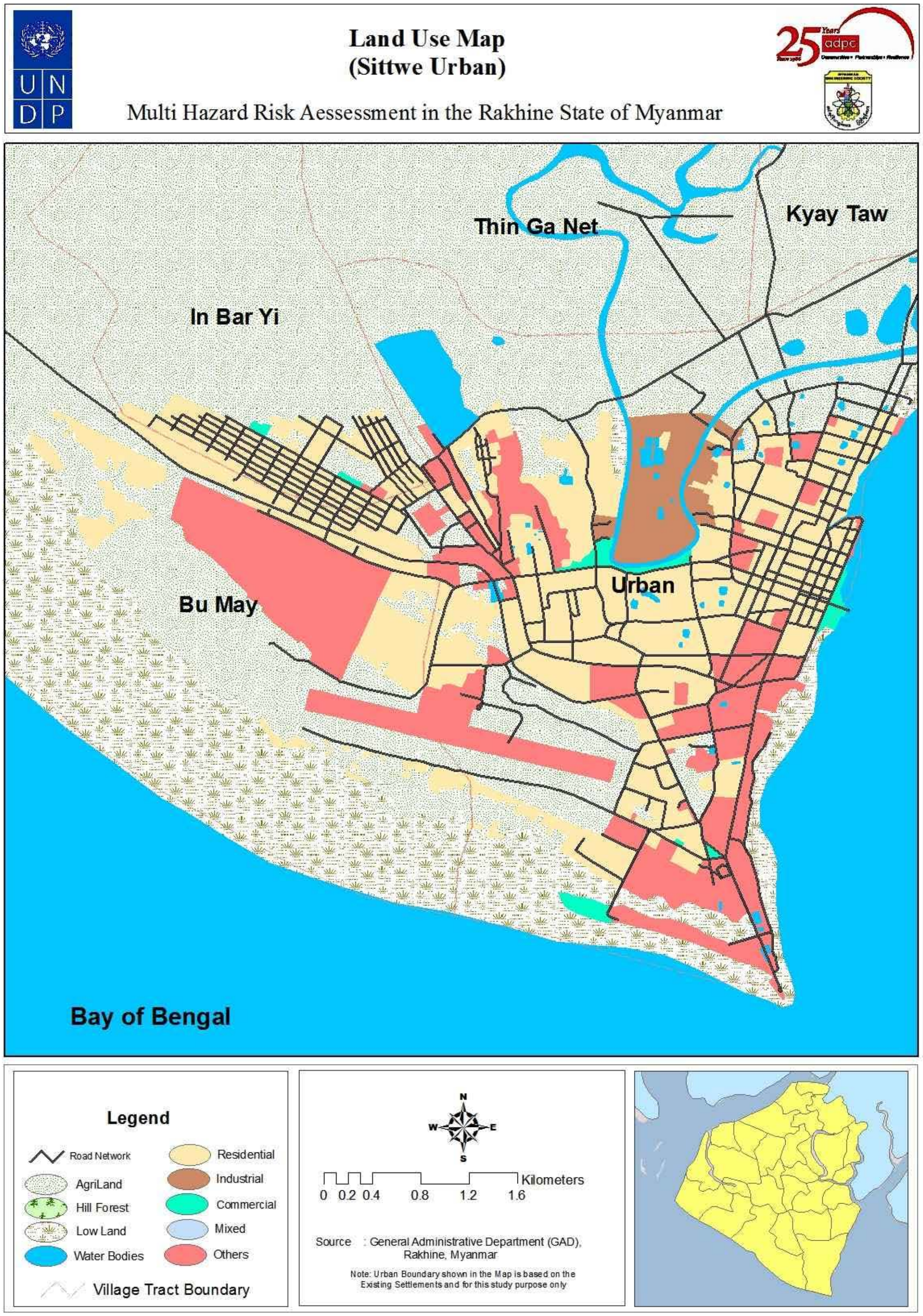
U N D P
Land Use Map
(Myebon Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
25 Years adpc
Nga Shwe Pyin
Urban
River
Ah Ngu
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4 0.5 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

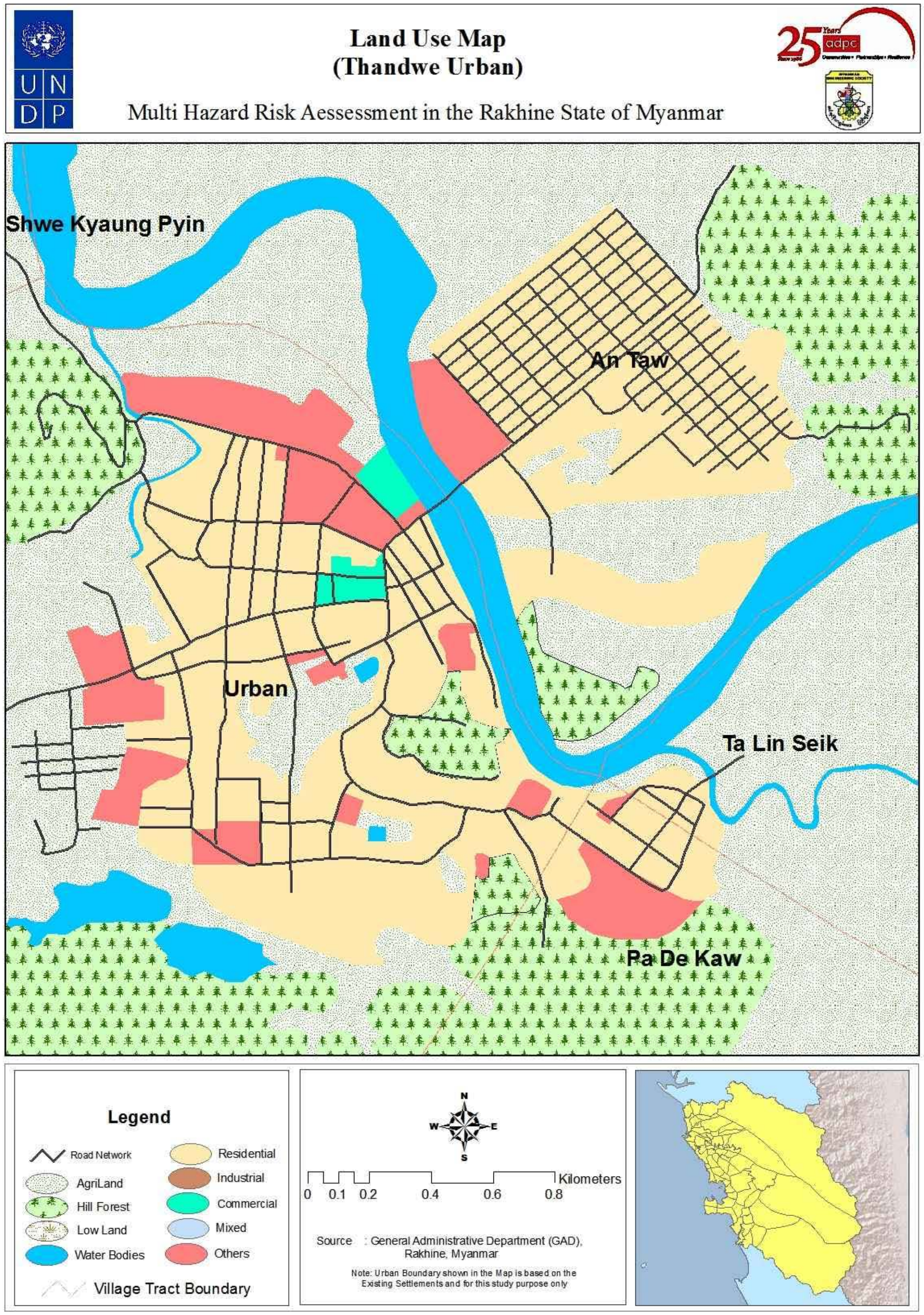
Land Use Map
(Pauktaw Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N D P
Ywar Chaung Gyi
Nat Taung Pyin
Urban
River
Nan Tet Kyun
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.1 0.2 0.4 0.6 0.8 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

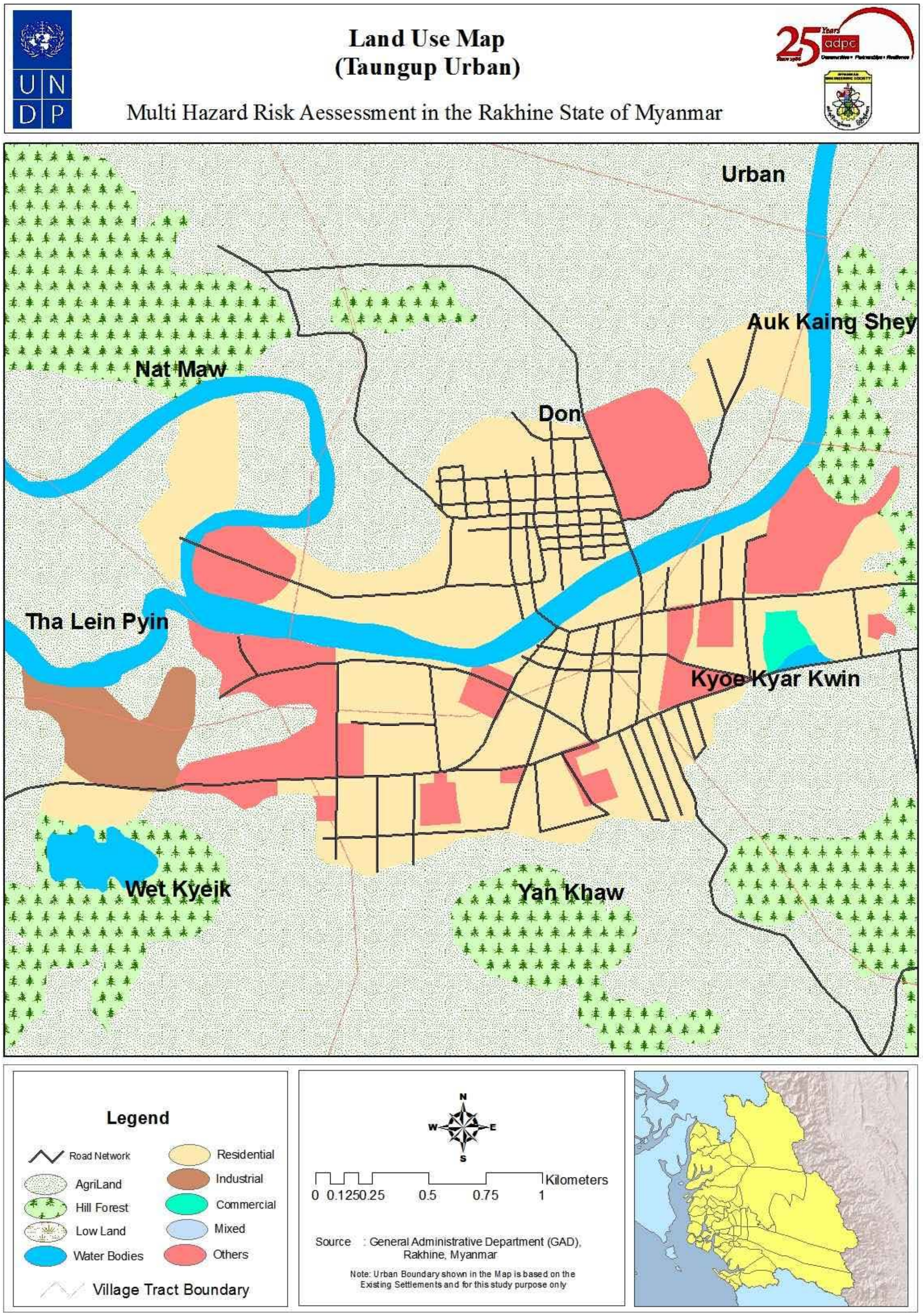

Land Use Map
(Ponnagyum Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Urban
Yae Pauk Chaung
Nat Seik
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.050.1 0.2 0.3 0.4
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Land Use Map
(Ramree Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
UNDP
Let Pan
Urban
Kha Maung Chi Taing
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4 0.5
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

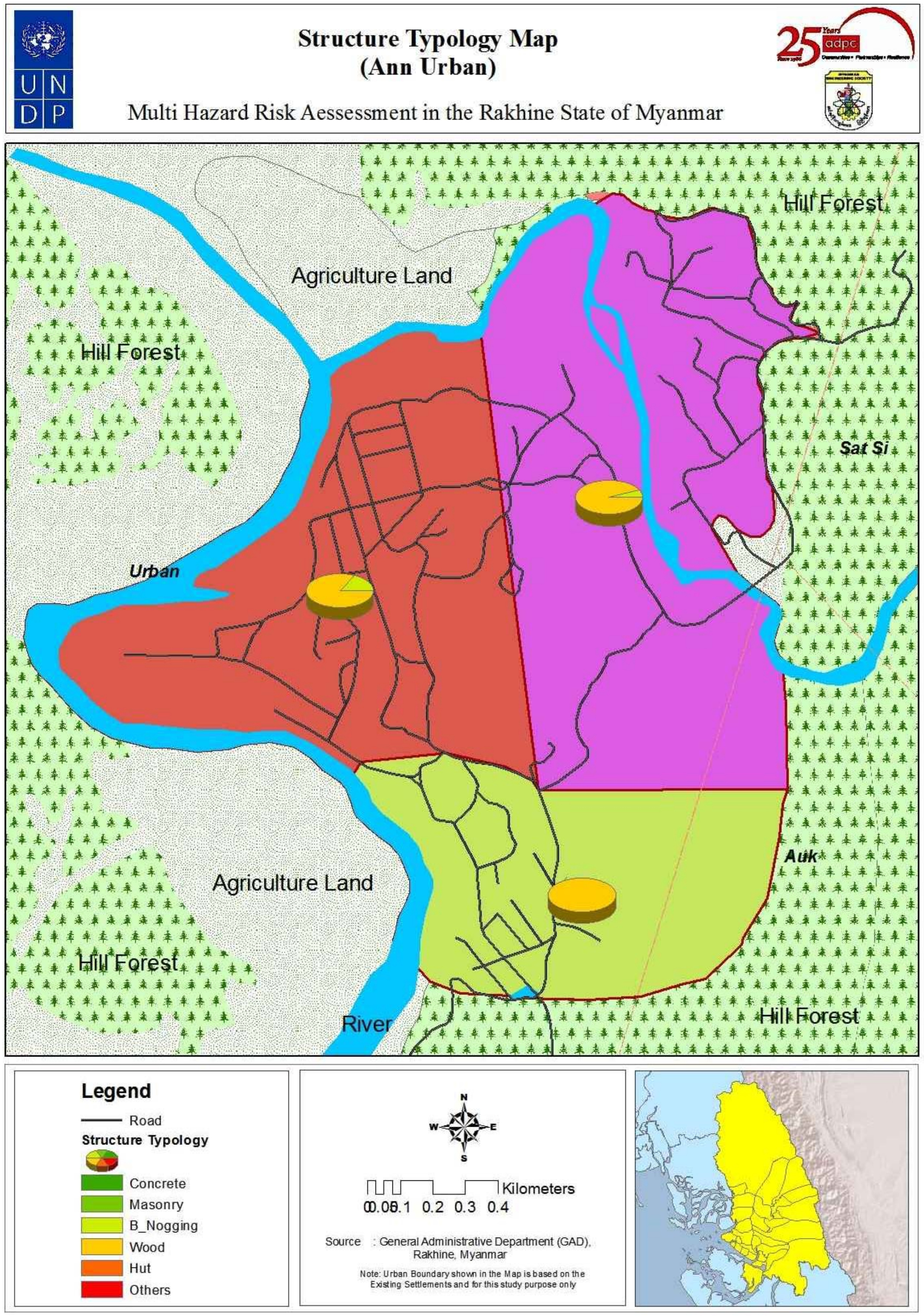

Land Use Map
(Rathedaung Urban)
U N D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Kha Naung Gyi
Nga Tauk Tu Chay
Urban
River
Pauk Taw
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

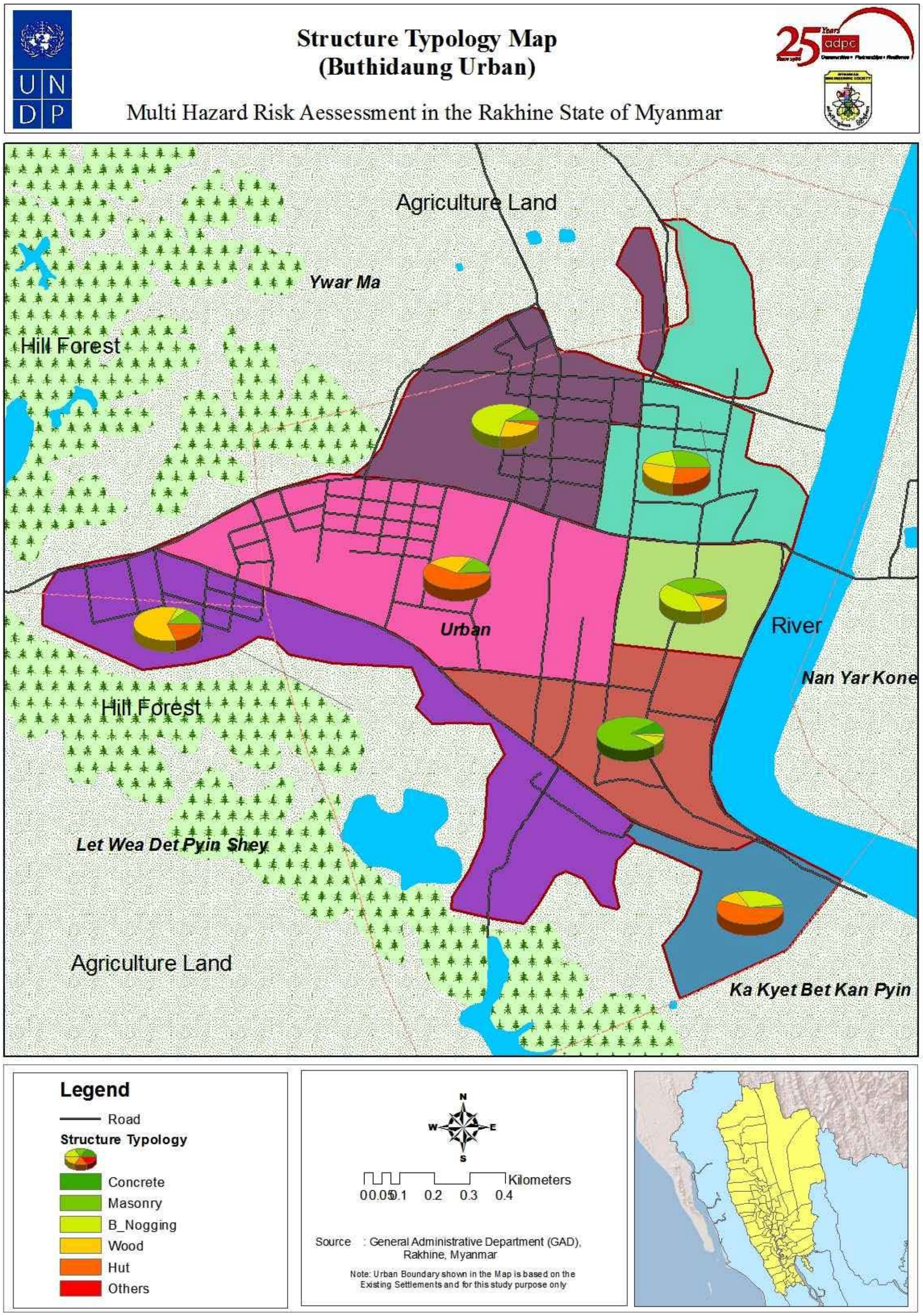

Land Use Map
(Sittwe Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Thin Ga Net
Kyay Taw
In Bar Yi
Urban
Bu May
Bay of Bengal
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.2 0.4 0.8 1.2 1.6 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Land Use Map
(Thandwe Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N D P
25 Years adpc
Shwe Kyaung Pyin
An Taw
Urban
Ta Lin Seik
Pa De Kaw
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Village Tract Boundary
Residential
Industrial
Commercial
Mixed
Others
N
W
E
S
0 0.1 0.2 0.4 0.6 0.8 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

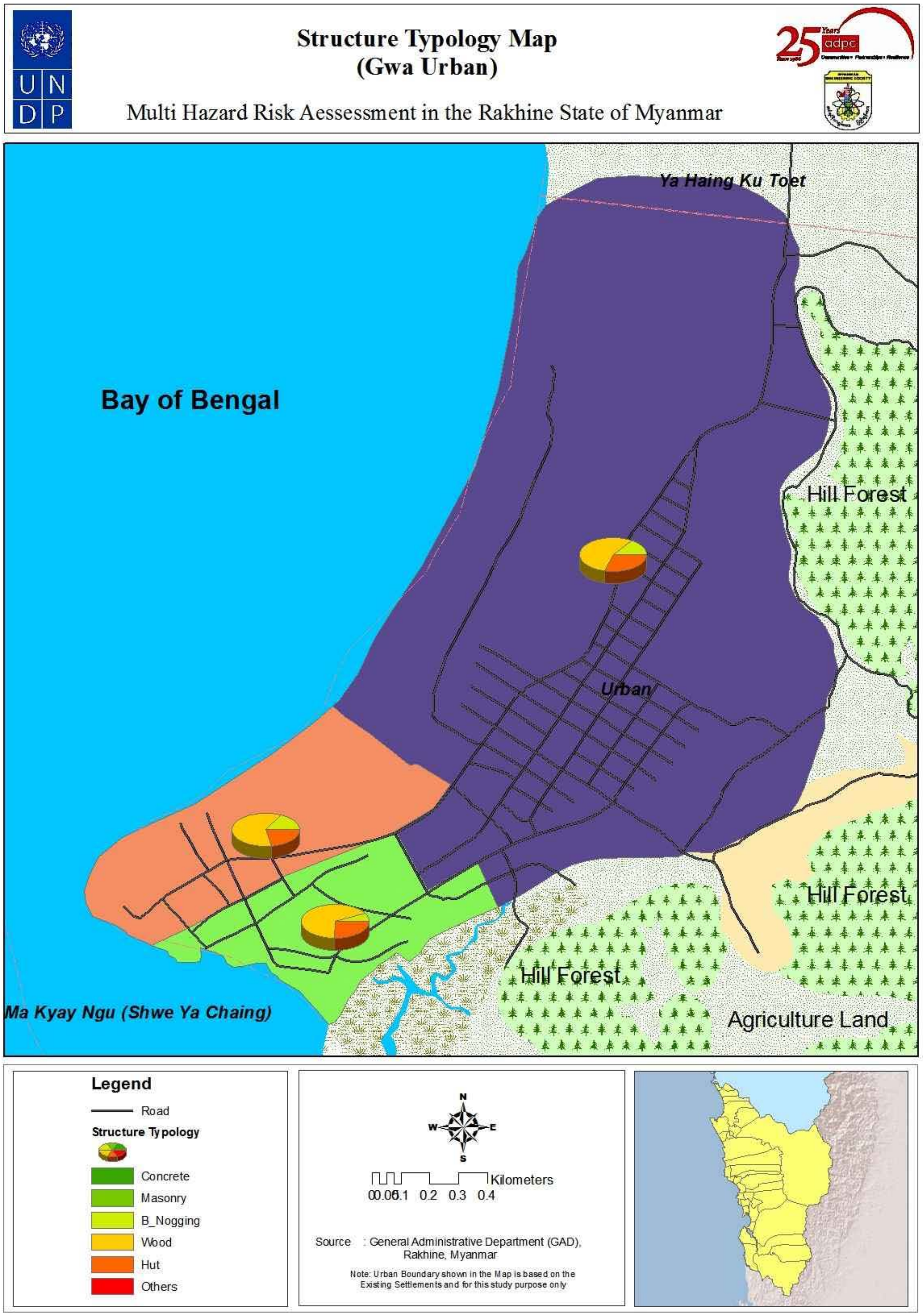

Land Use Map
(Taungup Urban)
U N D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Urban
Auk Kaing Shey
Nat Maw
Don
Tha Lein Pyin
Kyoe Kyar Kwin
Wet Kyeik
Yan Khaw
Legend
Road Network
AgriLand
Hill Forest
Low Land
Water Bodies
Residential
Industrial
Commercial
Mixed
Others
Village Tract Boundary
N
W
E
S
0 0.1250.25 0.5 0.75 1 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

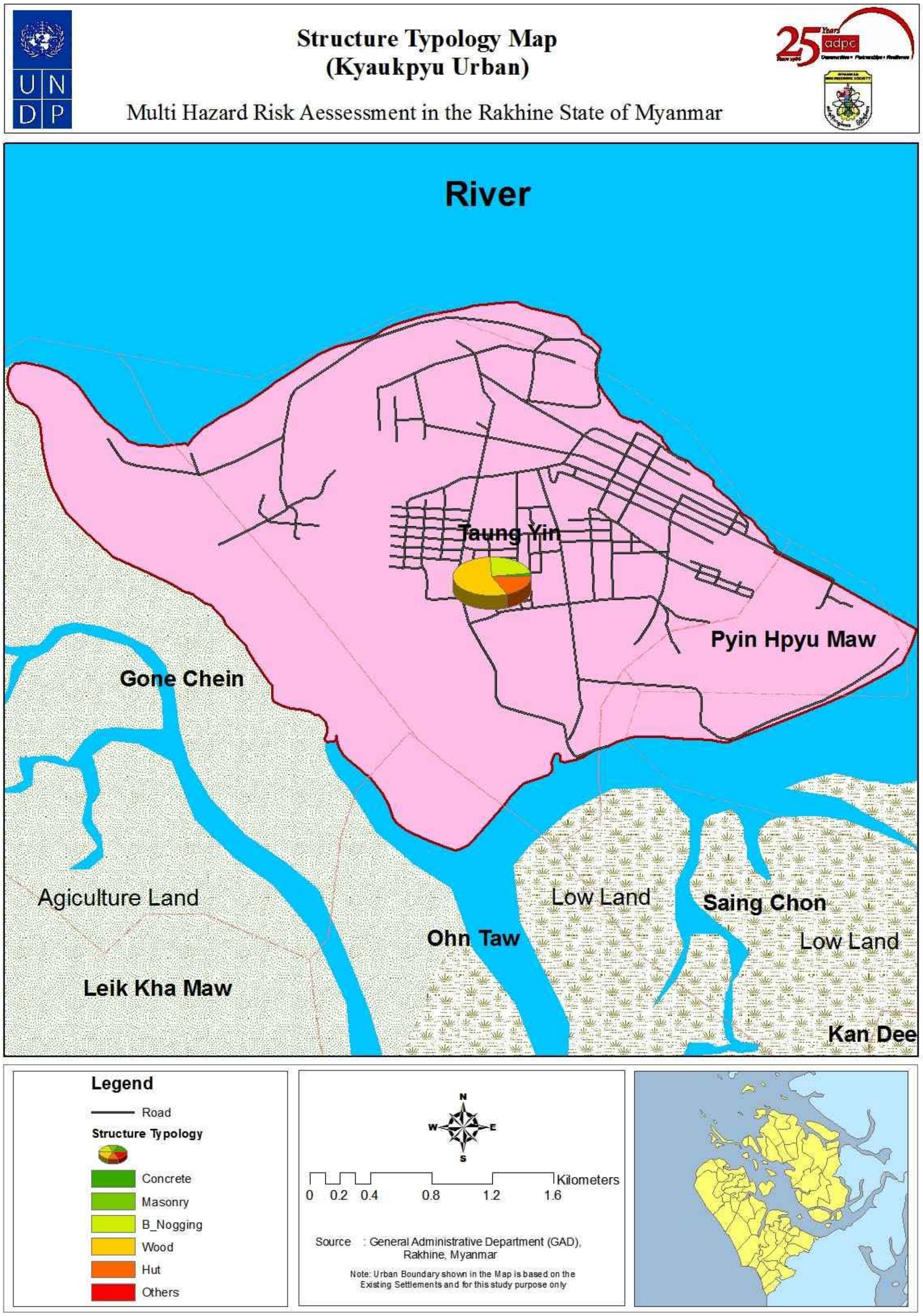
Building Structure Distribution of Urban Townships in Rakhine State

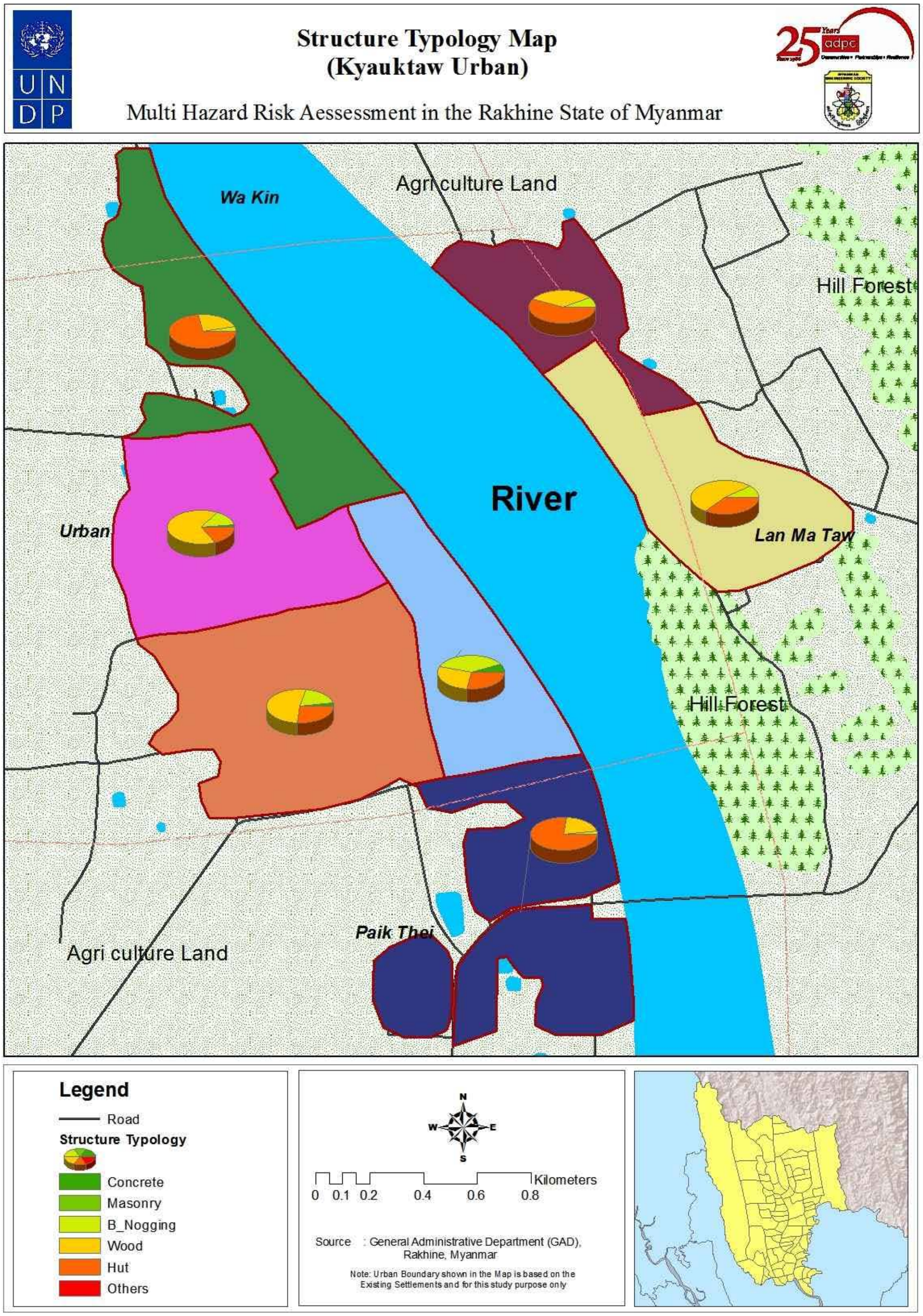


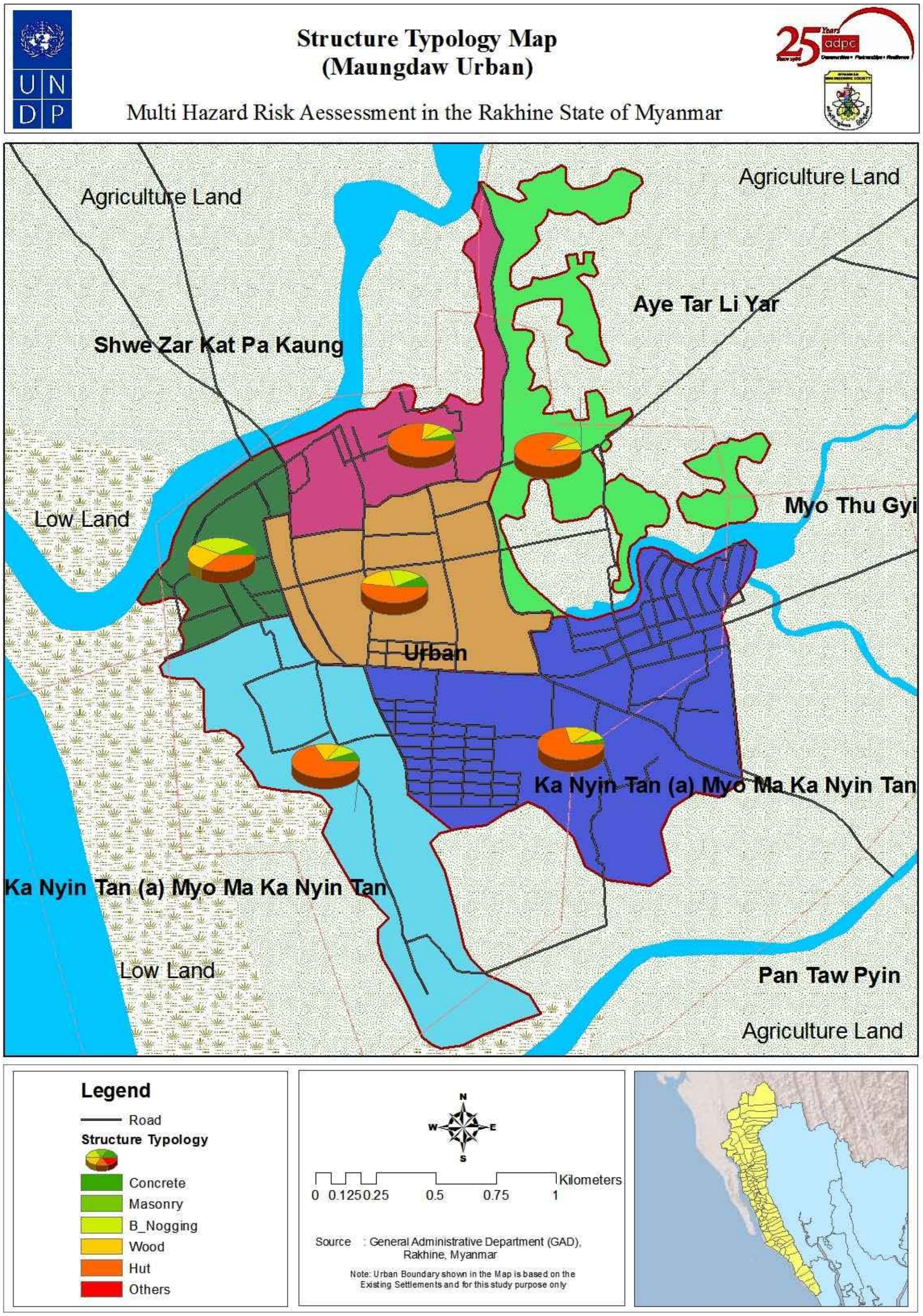


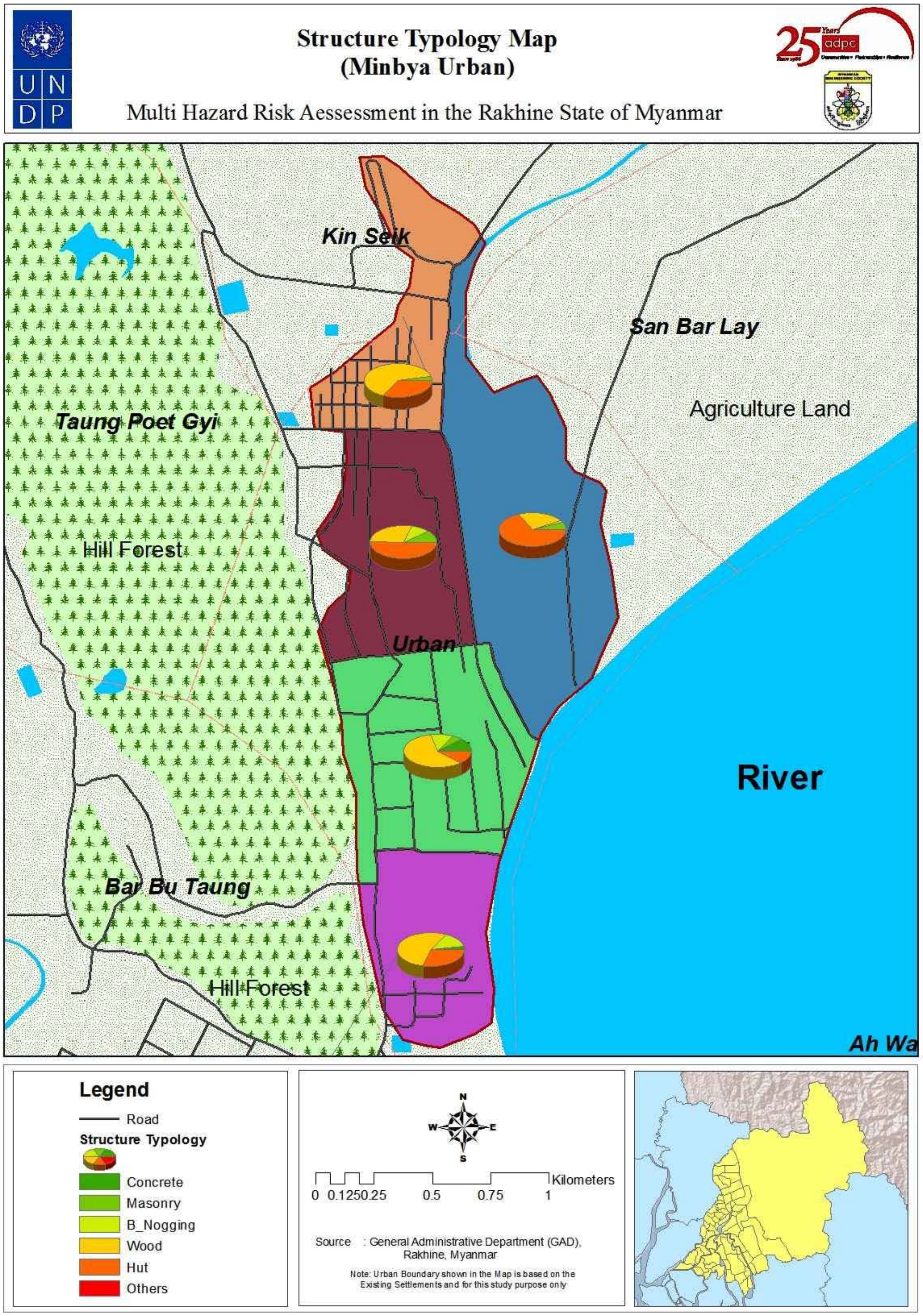
Structure Typology Map
(Buthidaung Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Agriculture Land
Ywar Ma
Hill Forest
Urban
River
Nan Yar Kone
Hill Forest
Let Wea Det Pyin Shey
Agriculture Land
Ka Kyet Bet Kan Pyin
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Structure Typology Map
(Gwa Urban)
U N
D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
25 Years adpc
Ya Haing Ku Toet
Bay of Bengal
Hill Forest
Urban
Hill Forest
Hill Forest
Agriculture Land
Ma Kyay Ngu (Shwe Ya Chaing)
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
Kilometers
0 0.05 0.1 0.2 0.3 0.4
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

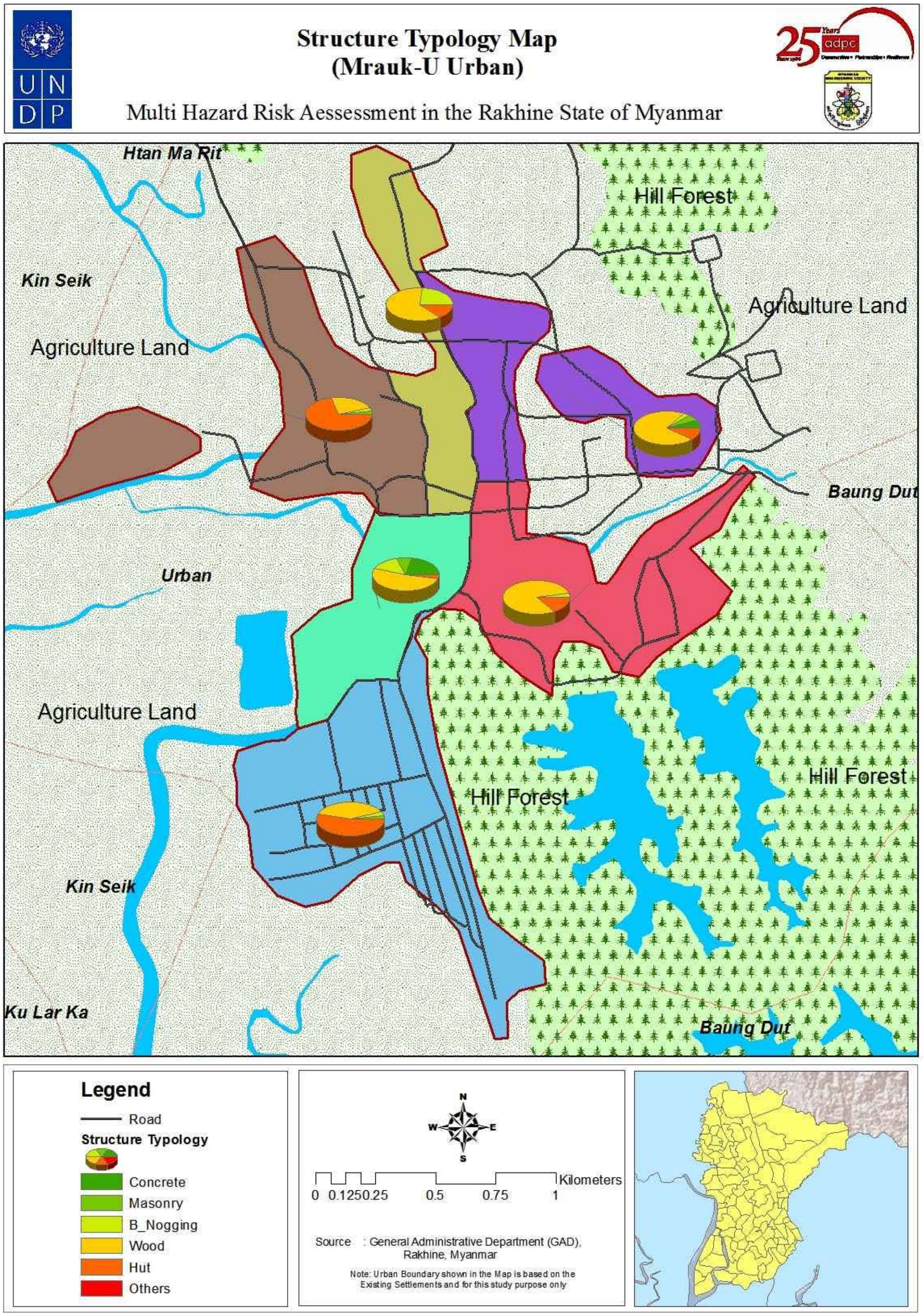

U N D P
Structure Typology Map
(Kyaukpyu Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
25 Years adpc
River
Taung Yin
Pyin Hpyu Maw
Gone Chein
Agiculture Land
Low Land
Saing Chon
Low Land
Ohn Taw
Leik Kha Maw
Kan Dee
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.2 0.4 0.8 1.2 1.6
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

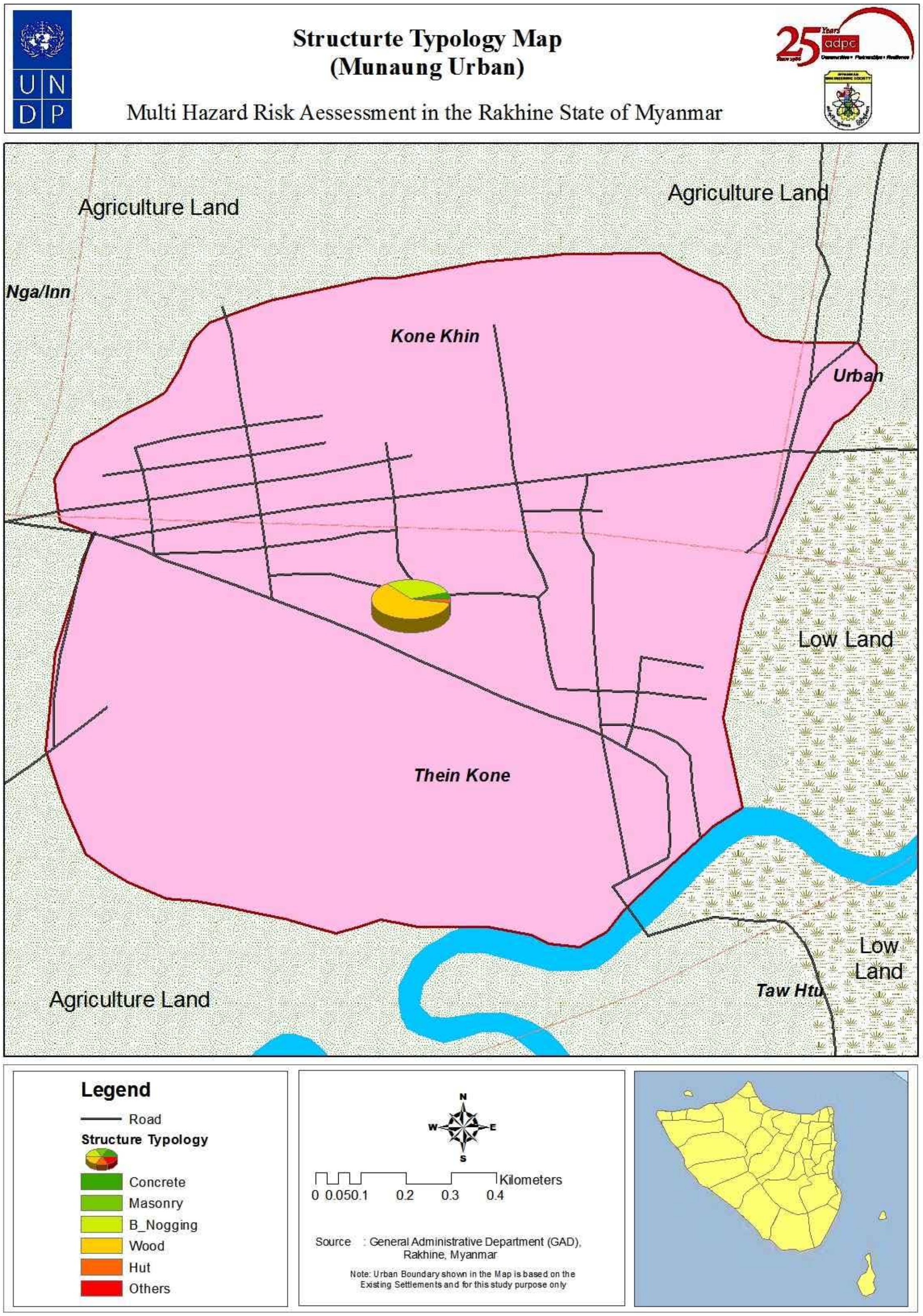

Structure Typology Map
(Kyauktaw Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
UNDP
25 Years adpc
Wa Kin
Agri culture Land
Hill Forest
River
Urban
Lan Ma Taw
Hill Forest
Paik Thei
Agri culture Land
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.1 0.2 0.4 0.6 0.8 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

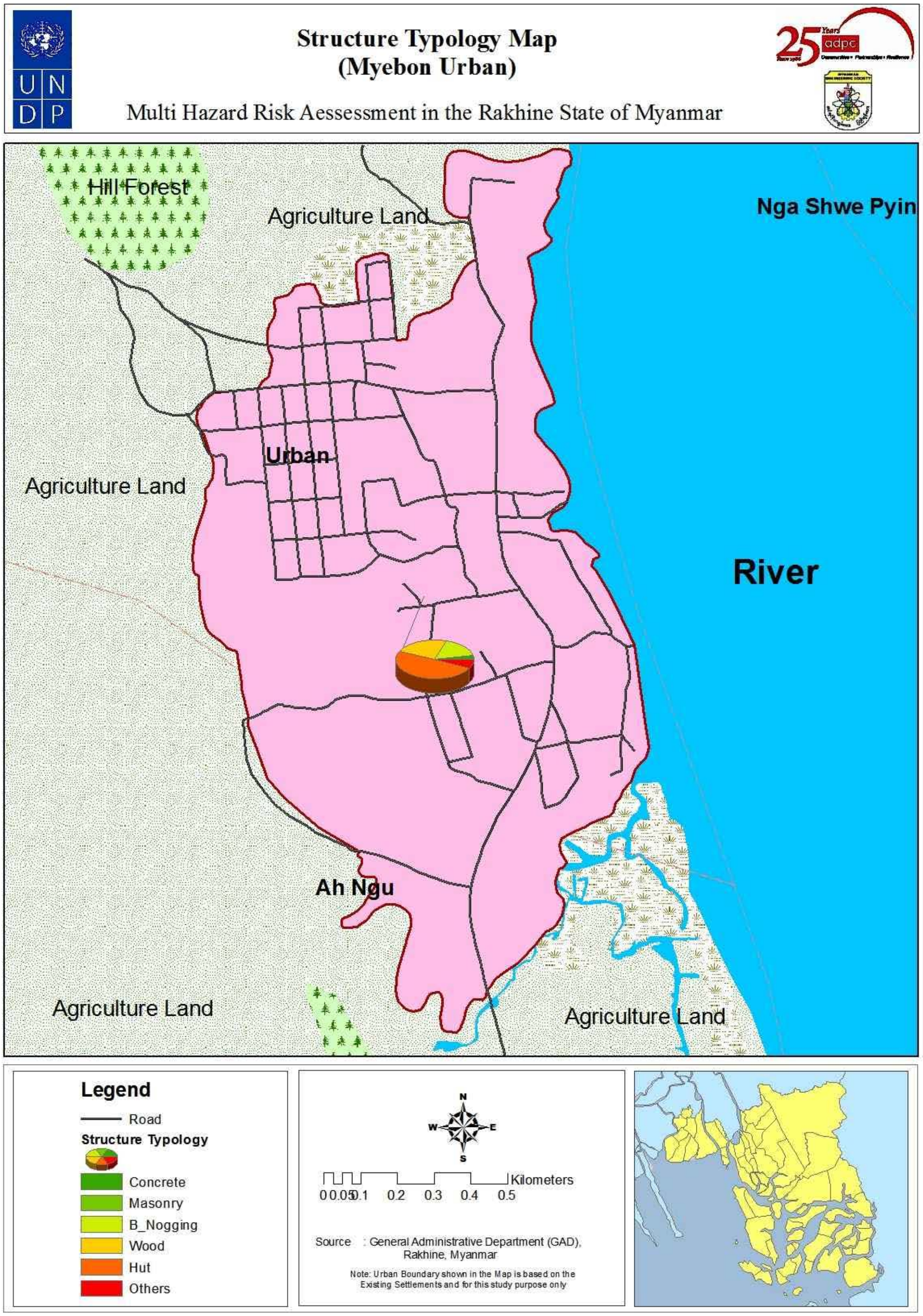

Structure Typology Map
(Maungdaw Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Agriculture Land
Agriculture Land
Aye Tar Li Yar
Shwe Zar Kat Pa Kaung
Low Land
Myo Thu Gyi
Urban
Ka Nyin Tan (a) Myo Ma Ka Nyin Tan
Ka Nyin Tan (a) Myo Ma Ka Nyin Tan
Low Land
Pan Taw Pyin
Agriculture Land
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.1250.25 0.5 0.75 1
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

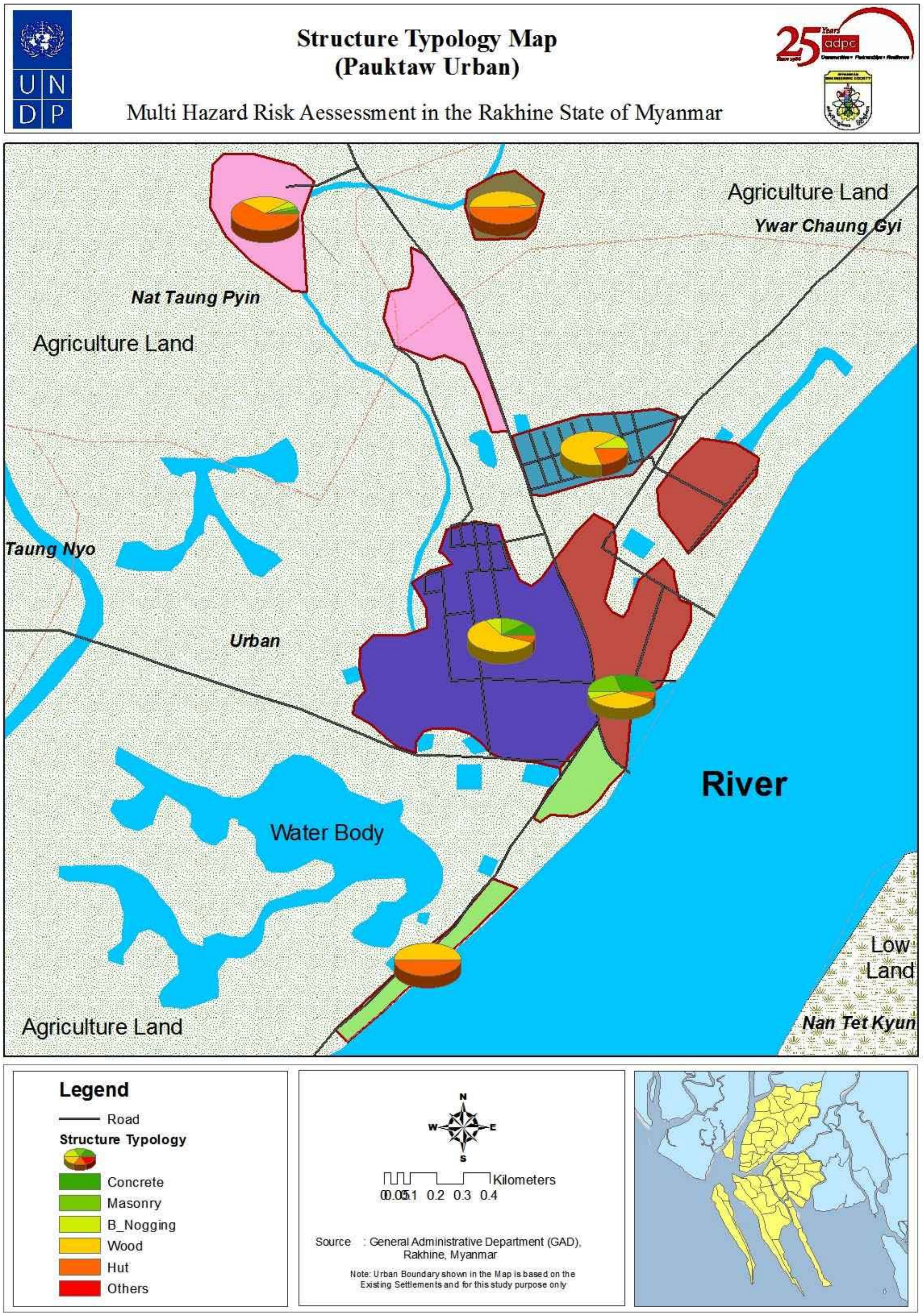


Structure Typology Map
(Minbya Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
UNDP
Kin Seik
San Bar Lay
Agriculture Land
Taung Poet Gyi
Hill Forest
Urban
River
Bar Bu Taung
Hill Forest
Ah Wa
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.1250.25 0.5 0.75 1 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

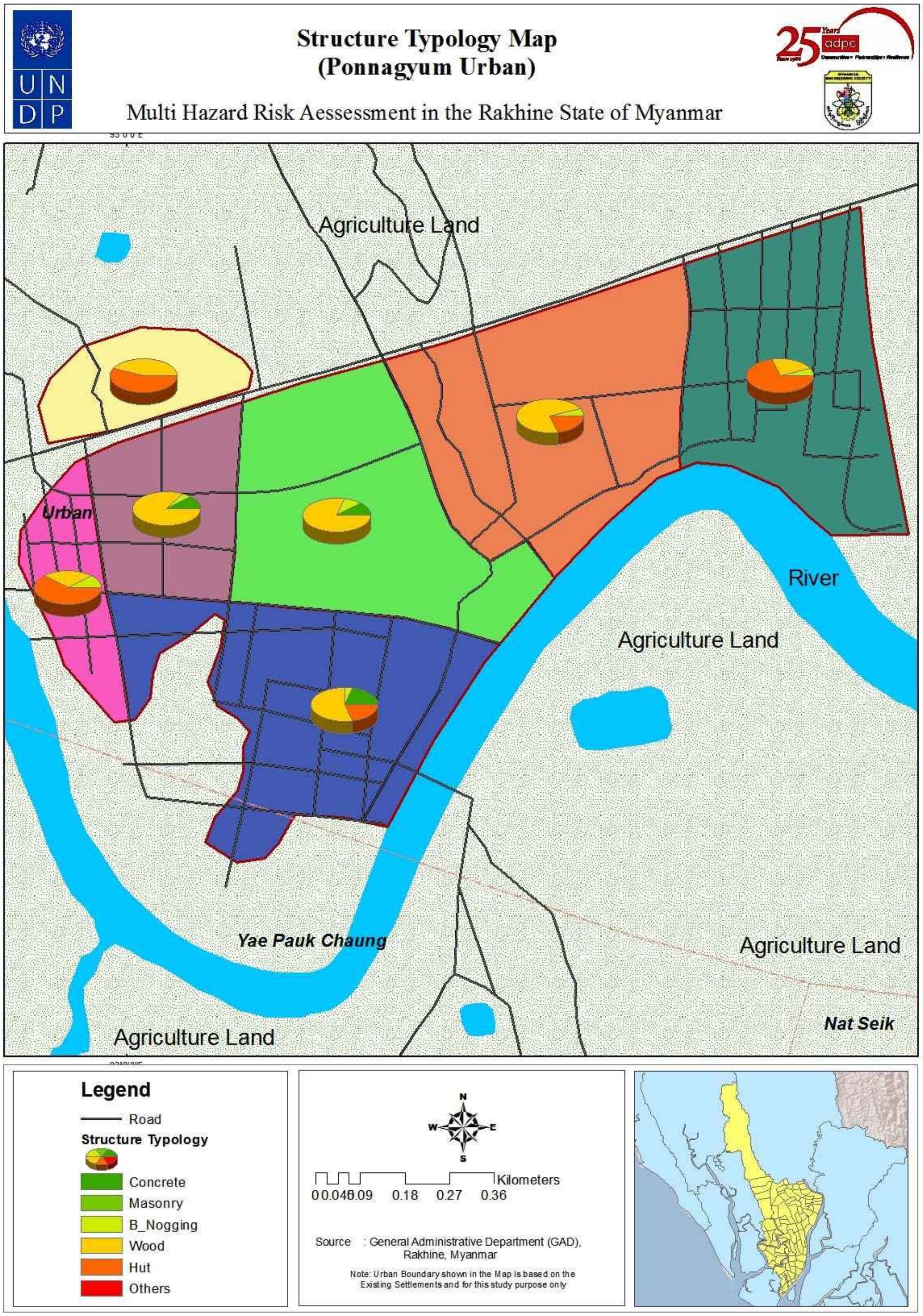

Structure Typology Map
(Mrauk-U Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
UNDP
Htan Ma Rit
Hill Forest
Kin Seik
Agriculture Land
Agriculture Land
Baung Dut
Urban
Agriculture Land
Hill Forest
Hill Forest
Kin Seik
Ku Lar Ka
Baung Dut
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.1250.25 0.5 0.75 1
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Structurte Typology Map
(Munaung Urban)
U N D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Agriculture Land
Agriculture Land
Nga/Inn
Kone Khin
Urban
Low Land
Thein Kone
Low Land
Agriculture Land
Taw Htu
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
Kilometers
0 0.050.1 0.2 0.3 0.4
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

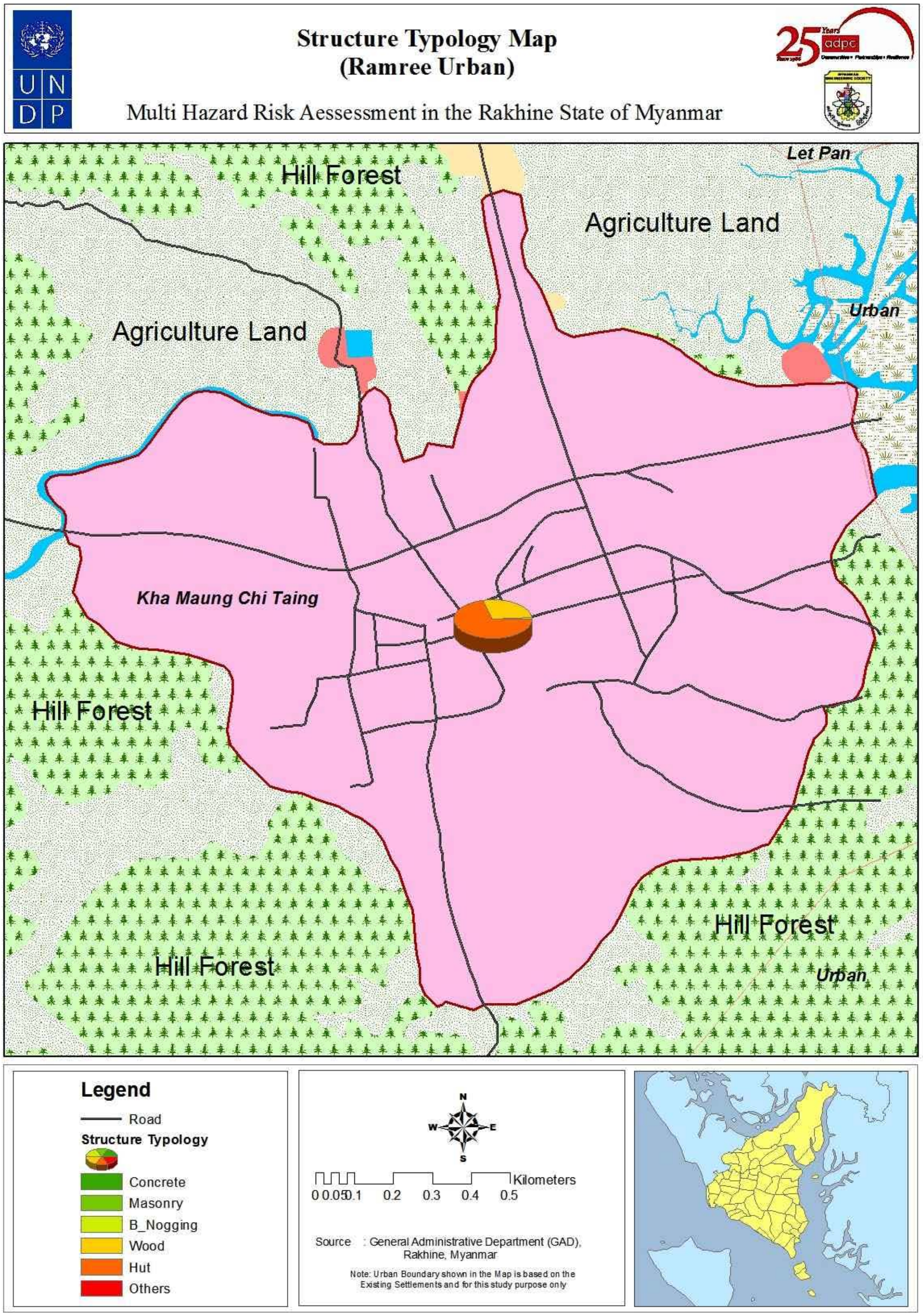

Structure Typology Map
(Myebon Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Hill Forest
Agriculture Land
Nga Shwe Pyin
Urban
Agriculture Land
River
Ah Ngu
Agriculture Land
Agriculture Land
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
Kilometers
0 0.05 0.1 0.2 0.3 0.4 0.5
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

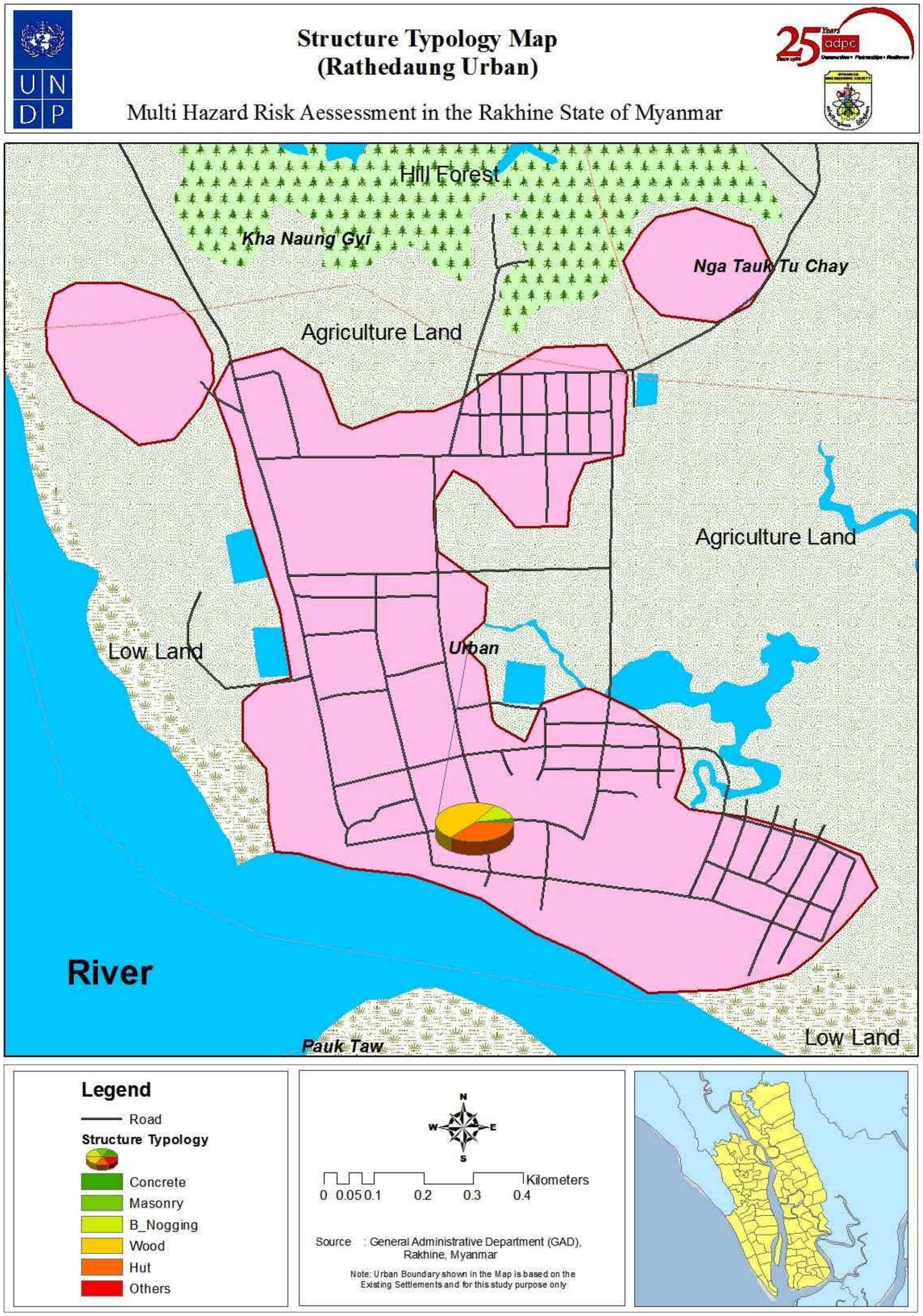


Structure Typology Map
(Paukture Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N
D P
Agriculture Land
Ywar Chaung Gyi
Nat Taung Pyin
Agriculture Land
Taung Nyo
Urban
River
Water Body
Low Land
Agriculture Land
Nan Tet Kyun
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only



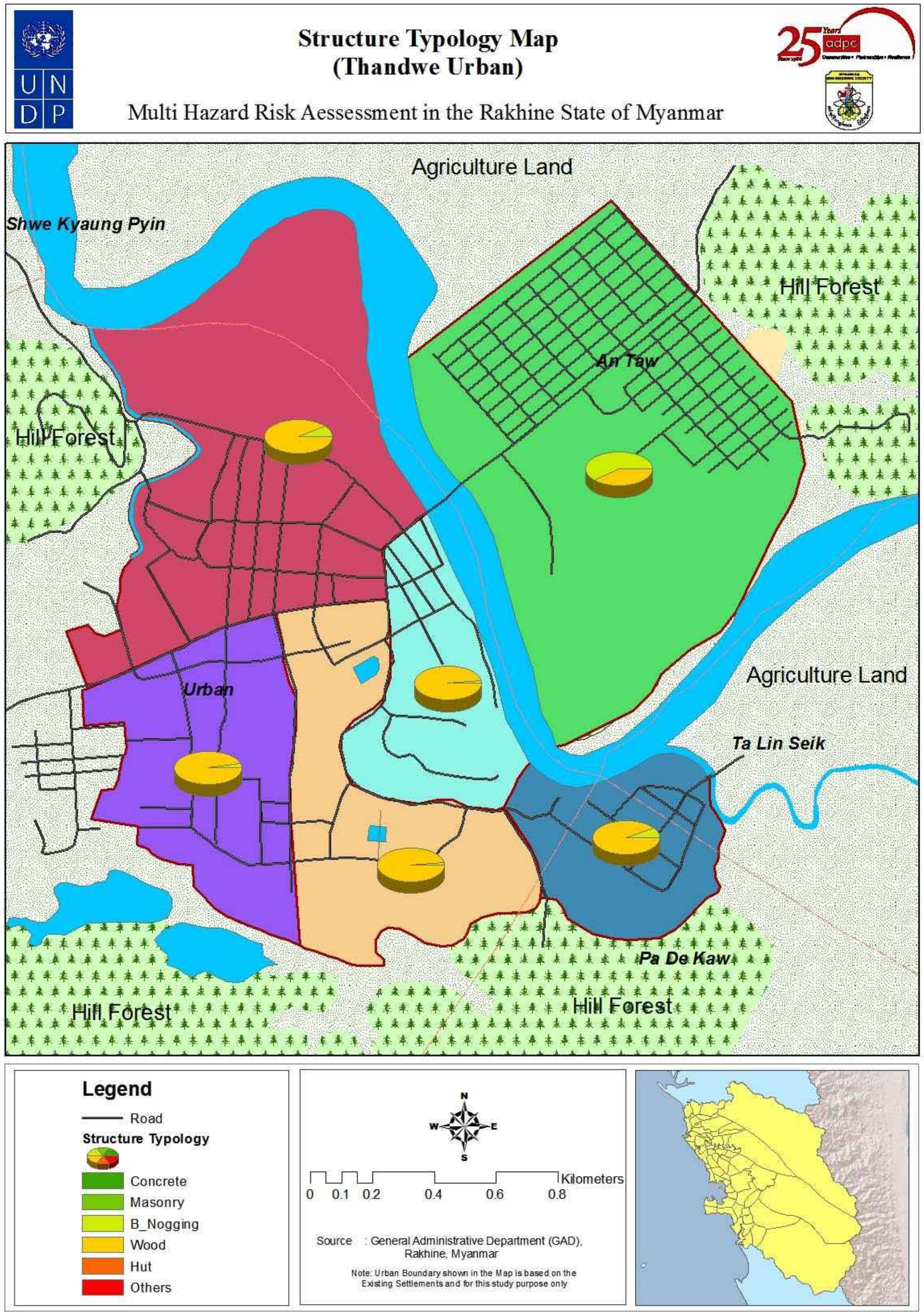
Structure Typology Map
(Ponnagyum Urban)
U N D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Agriculture Land
Urban
River
Agriculture Land
Yae Pauk Chaung
Agriculture Land
Nat Seik
Agriculture Land
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
Kilometers
0 0.045 0.09 0.18 0.27 0.36
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


Structure Typology Map
(Ramree Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
UNDP
Hill Forest
Agriculture Land
Let Pan
Urban
Agriculture Land
Kha Maung Chi Taing
Hill Forest
Hill Forest
Hill Forest
Urban
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.05 0.1 0.2 0.3 0.4 0.5 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

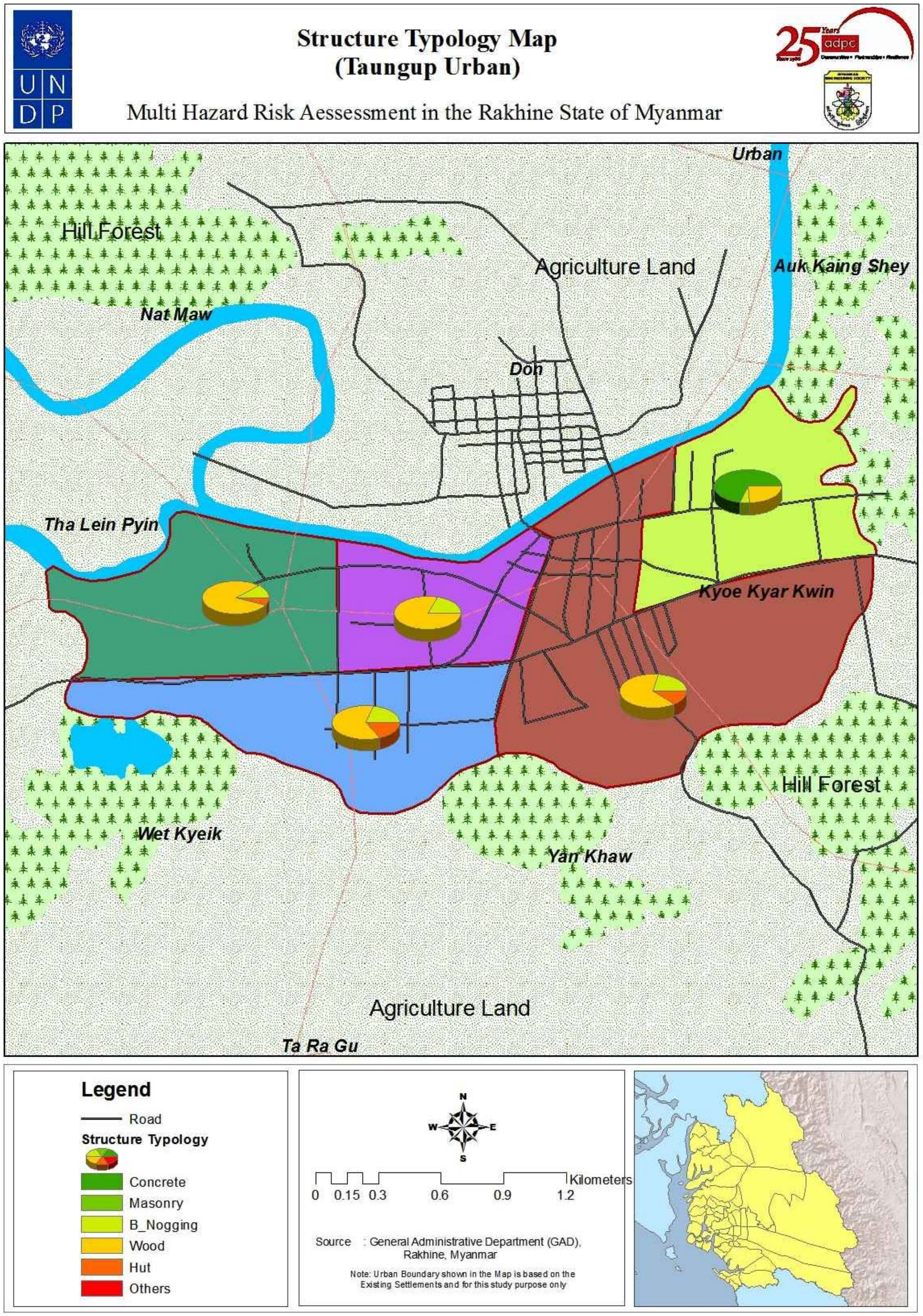


Structure Typology Map
(Rathedaung Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
U N D P
Hill Forest
Kha Naung Gyi
Nga Tauk Tu Chay
Agriculture Land
Agriculture Land
Low Land
Urban
River
Pauk Taw
Low Land
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
S
E
W
0 0.05 0.1 0.2 0.3 0.4
Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only


U N D P
Structure Typology Map
(Sittwe Urban)
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
25 Years adpc
Kyay Taw
Thin Ga Net
Agriculturte Land
Agriculturte Land
In Bar Yi
Urban
Agriculturte Land
Bu May
Low Land
Bay of Bengal
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.150.3 0.6 0.9 1.2 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only



Structure Typology Map
(Thandwe Urban)
U N D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Agriculture Land
Shwe Kyaung Pyin
Hill Forest
An Taw
Hill Forest
Urban
Agriculture Land
Ta Lin Seik
Pa De Kaw
Hill Forest
Hill Forest
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.1 0.2 0.4 0.6 0.8 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only



Structure Typology Map
(Taungup Urban)
U N D P
Multi Hazard Risk Aessessment in the Rakhine State of Myanmar
Urban
Hill Forest
Agriculture Land
Auk Kaing Shey
Nat Maw
Don
Tha Lein Pyin
Kyoe Kyar Kwin
Hill Forest
Wet Kyeik
Yan Khaw
Agriculture Land
Ta Ra Gu
Legend
Road
Structure Typology
Concrete
Masonry
B_Nogging
Wood
Hut
Others
N
W
E
S
0 0.15 0.3 0.6 0.9 1.2 Kilometers
Source : General Administrative Department (GAD), Rakhine, Myanmar
Note: Urban Boundary shown in the Map is based on the Existing Settlements and for this study purpose only

CHAPTER C: DETAILED VULNERABILITY CALCULATION

The primary objective of vulnerability assessments is to identify people or places that are most susceptible to harm and to identify vulnerability-reducing actions (Stephen and Downing, 2001; Downing et al., 2001; Clark et al., 2000; Polsky et al., 2003). The concept of vulnerability expresses the multidimensionality of disasters by focusing attention on the totality of relationships in a given social situation which constitute a condition that, in combination with environmental forces, produces a disaster (Bankoff et al., 2004). In the pressure-and-release frame-work (PAR), Blaikie et al. (1994) defined vulnerability as a system's ability to respond and recover from stresses, a system's sensitivity and adaptive capacity.

In this study the vulnerability is quantified as a function of sensitivity and resilience. Sensitivity refers to the degree to which an individual or group is likely to experience harm when exposed to a threat. The IPCC report of 2001 defines sensitivity as 'the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of flooding). Resilience has its focus on resources and adaptive capacity and acts as a counter, or antidote, to vulnerability (O'Brien et al., 2006).

Though many approaches can be used to estimate the vulnerability, this study adopted the approach that utilizes experts' judgment and the Analytical Hierarchy Process (AHP). The following conceptual equation for calculating vulnerability indices specific for each village tract in Rakhine State was adopted, where relative importance of sensitivity and resilience was calculated separately.

$$Vulnerability = (RIS \times Sensitivity) - (RIR \times Resilience)$$

Where,

RIS = Relative Importance of ***Sensitivity*** *for Vulnerability Analysis for Rakhine State*

RIR = Relative Importance of ***Resilience*** *for Vulnerability Analysis for Rakhine State*

Sensitivity reflects pre-existing conditions of the people, the built-environments, and the social settings that may make them susceptible to adverse effects due to external stimuli, which can be either natural or man-made events.

Resilience is defined as the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure.

This project separately analyzed sensitivity for Social & Human sector, Production sector, and Physical Infrastructure sector based on expert judgment using AHP and conceptual relation described below. Disaster resilience of Rakhine State was assessed based on disaster risk management mechanism, preparedness and accessibility. Subsequent sections describe the assumptions and the calculation of Sensitivity and Resilience in details.

Sensitivity

Sensitivity reflects pre-existing conditions of the people, the built-environments, and the social settings that may make them susceptible to adverse effects due to external stimuli, which can be either natural or man-made events. Several indicators of the sensitivity in Rakhine State have been considered in this study.

Population Sensitivity Index: This project assumed that population sensitivity is independent of the hazard types. This assumption may be changed in the future when a good collection of detailed data of disaster events and their impacts on people of Rakhine become available. The population sensitivity indices irrespective of the hazards were calculated according to the following conceptual equation and using the relative importance (or weights) of different population groups.

$$PSI = \left(\sum_{i=1}^{Np} FP_i \times SRP_i \right) \times ToP$$

Where,

PSI	=	*Population Sensitivity Index*
FP_i	=	*Fraction of Each Population Group (obtained from GAD)*
SRP_i	=	*Relative Importance for Each Population Group*
ToP	=	*Total Number of Population within the Village Tract (obtained from GAD)*
Np	=	*Number of Population Group: 4 in this study*

The relative importance (SRP) for each of the population groups was computed using a pair-wise comparison under the Analytical Hierarchy Process (AHP) scheme. Resulting SRP's are presented in Table 14 below.

Table 14: Relative Importance (SRP) by Population Group

Population Group	Relative Importance (SRP)
Male > 18	0.05
Female > 18	0.18
Male < 18	0.22
Female < 18	0.55

The population sensitivity index (PSI) was calculated for every administrative unit considered for vulnerability mapping, which is a village tract. Finally the calculated values for the population sensitivity indices were divided into five quantile groups, which then were indexed as *Very High*, *High*, *Medium*, *Low*, and *Very Low* vulnerability scale accordingly.

Infrastructure Sensitivity Index: Infrastructure sensitivity indices for all hazards were calculated based on the breakdown of structural typologies in each village tract, according to the following conceptual equation and using the relative importance factors (or weights) of different structure typology groups.

$$SSI = \left(\sum_{i=1}^{Ns} FS_i \times SRS_i\right) \times ToS$$

Where,

SSI = *Infrastructure Sensitivity Index*
FS_i = *Fraction of Each Structure Typology Group*
SRS_i = *Relative Importance for Each Structure Typology Group*
ToS = *Total Number of Structures within the Village Tract*
Ns = *Number of Structure Typology Group*

The relative importance (SRS) for each of the structure typology groups was computed using a pair-wise comparison under the Analytical Hierarchy Process (AHP) scheme. The SRS is dependent of the hazard type since one structure typology that is highly sensitive to one hazard may not be as sensitive to the other hazards. The computed SRS's are presented in Table 15 to Table 21 below.

Table 15: Relative Importance (SRS) by Structure Typology Group, for Flood Hazard

Flood	
Structure Typology	Relative Importance (SRS)
Concrete	0.03
Masonry	0.08
Brick-Nogging	0.06
Wood	0.16
Hut	0.27
Others	0.40

Table 16: Relative Importance (SRS) by Structure Typology Group, for Cyclone Hazard

Cyclone	
Structure Typology	Relative Importance (SRS)
Concrete	0.02
Masonry	0.07
Brick-Nogging	0.04
Wood	0.14
Hut	0.30
Others	0.43

Table 17: Relative Importance (SRS) by Structure Typology Group, for Earthquake Hazard

Earthquake	
Structure Typology	Relative Importance (SRS)
Concrete	0.08
Masonry	0.20
Brick-Nogging	0.46
Wood	0.04
Hut	0.07
Others	0.15

Table 18: Relative Importance (SRS) by Structure Typology Group, for Storm Surge Hazard

Storm Surge	
Structure Typology	Relative Importance (SRS)
Concrete	0.03
Masonry	0.05
Brick-Nogging	0.07
Wood	0.12
Hut	0.58
Others	0.15

Table 19: Relative Importance (SRS) by Structure Typology Group, for Tsunami Hazard

Tsunami	
Structure Typology	Relative Importance (SRS)
Concrete	0.03
Masonry	0.09
Brick-Nogging	0.05
Wood	0.08
Hut	0.57
Others	0.18

Table 20: Relative Importance (SRS) by Structure Typology Group, for Forest/Rural Fire Hazard

Forest/Rural Fire	
Structure Typology	Relative Importance (SRS)
Concrete	0.05
Masonry	0.07
Brick-Nogging	0.08
Wood	0.35
Hut	0.35
Others	0.10

Table 21: Relative Importance (SRS) by Structure Typology Group, for Landslide Hazard

Landslide	
Structure Typology	Relative Importance (SRS)
Concrete	0.05
Masonry	0.10
Brick-Nogging	0.15
Wood	0.25
Hut	0.30
Others	0.15

The infrastructure sensitivity index (SSI) was calculated for each hazard and for every administrative unit considered for vulnerability mapping, which is a village tract. Finally the calculated values for the infrastructure sensitivity indices were divided into five quantile groups, which then were indexed as *Very High*, *High*, *Medium*, *Low*, and *Very Low* vulnerability scale accordingly for all hazards.

Livelihood Sensitivity Index: Livelihood sensitivity indices for all hazards were calculated according to the following conceptual equation and using the relative importance factors (or weights) of different livelihood groups.

$$LSI = \left(\sum_{i=1}^{No} FL_i \times SRL_i \right) \times ToP_{18}$$

Where,

LSI	=	*Livelihood Sensitivity Index*
FL_i	=	*Fraction of Each Livelihood Group*
SRL_i	=	*Relative Importance for Each Livelihood Group*
ToP_{18}	=	*Total Number of Population (Above 18) within the Village Tract*
No	=	*Number of Livelihood Group*

The relative importance (SRL) for each of the structure typology groups was computed using a pair-wise comparison under the Analytical Hierarchy Process (AHP) scheme. The SRL is dependent of the hazard type since one livelihood group that is highly sensitive to one hazard may not be as sensitive to the other hazards. The computed SRL's are presented in Table 22 to Table 28 below.

Table 22: Relative Importance (SRL) by Livelihood Group, for Flood Hazard

Flood	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.25
Fisheries	0.50
Livestock	0.14
Others(Service+Business)	0.11

Table 23: Relative Importance (SRL) by Livelihood Group, for Cyclone Hazard

Cyclone	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.55
Fisheries	0.08
Livestock	0.22
Others(Service+Business)	0.15

Table 24: Relative Importance (SRL) by Livelihood Group, for Earthquake Hazard

Earthquake	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.08
Fisheries	0.14
Livestock	0.24
Others(Service+Business)	0.55

Table 25: Relative Importance (SRL) by Livelihood Group, for Storm Surge Hazard

Storm Surge	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.27
Fisheries	0.53
Livestock	0.14
Others(Service+Business)	0.06

Table 26: Relative Importance (SRL) by Livelihood Group, for Tsunami Hazard

Tsunami	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.27
Fisheries	0.53
Livestock	0.14
Others(Service+Business)	0.06

Table 27: Relative Importance (SRL) by Livelihood Group, for Forest/Rural Fire Hazard

Forest/Rural Fire	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.55
Fisheries	0.05
Livestock	0.15
Others(Service+Business)	0.25

Table 28: Relative Importance (SRL) by Livelihood Group, for Landslide Hazard

Landslide	
Livelihood Group	Relative Importance (SRL)
Agriculture	0.45
Fisheries	0.25
Livestock	0.14
Others(Service+Business)	0.16

Resilience

Resilience is defined as the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

This study adopted the following conceptual equation for calculating resilience for Rakhine State, Myanmar. The relative importance of the DRM mechanism, preparedness and accessibility for resilience was calculated from expert's opinion using Analytical Hierarchy Process (AHP).

$$Resilience = (RIM \times Mechanism) + (RIP \times Preparedness) + (RIA \times Accessibility)$$

Where,
RIM = Relative Importance of Disaster Risk Management ***Mechanism*** *for Resilience Assessment*
RIP = Relative Importance of Disaster ***Preparedness*** *for Resilience Assessment*
RIA = Relative Importance of Disaster ***Accessibility*** *for Resilience Assessment*

Mechanism Index: Disaster Risk Management mechanism indices are calculated based on the administrative settings, availability of plans, policies, and inter-linkages between different national and international partners. The scoring of the mechanism was based on data obtained from the field survey as well as policy documents at a state and township levels. Every township is then given a relative weight based on the mechanism status and classified as *Very Good*, *Good*, *Fair*, *Bad* and *Very Bad*.

Preparedness Index: Disaster Preparedness indices are calculated based on the availability of staffs, funds, and equipments for emergency and disaster management. The scoring of the preparedness was based on data obtained from the field survey as well as policy documents at a state and township levels. Every township is then given a relative weight based on the preparedness status and classified as *Very Good*, *Good*, *Fair*, *Bad* and *Very Bad*.

Accessibility Index: Accessibility Indices are calculated based on the average distance of the settlement areas within a village tract from the nearest major road network. It was classified as shown in Table 29. Note that even though water transportation is another important mode of transportation for Rakhine State, it was not considered for the accessibility index under this study because under an event of disaster (especially cyclones, storm surge, flood, and tsunami), water transportation may not be fully serviceable. Much detailed data on the functionality of those water transportation under a disaster situation, as well as detailed locations of the ports, capacity, and transportation routes may be required. The research team considers it as a potential future work to improve the calculation of the Accessibility Indices.

Table 29: Accessibility Index based on Distance from nearest Road Network

Average Distance from nearest Road Network (km)	Accessibility Index
< 1.0	Very Good
1.0 1.5	Good
1.5 - 2.0	Fair
2.0 - 2.5	Poor
>2.5km	Very Poor

An Analytical Hierarchy Process (AHP) was utilized to compute the Relative Importance factors for each of the resilience factors, taking inputs from questionnaire survey as well as interview of experts. Table 30 presents the relative importance factors adopted in this study.

Table 30: Relative Importance of Resilience Factors

Resilience Factors	Relative Importance
Mechanism *(RIM)*	0.10
Preparedness *(RIP)*	0.45
Accessibility *(RIA)*	0.45

As a result, the Resilience equation becomes:

$$Resilience = (0.10 \times Mechanism\ Index) + (0.45 \times Preparedness\ Index) + (0.45 \times Accessibility\ Index)$$

Vulnerability Calculation

Referring to the equation for computing the vulnerability, shown below,

$$Vulnerability = (RIS \times Sensitivity) - (RIR \times Resilience),$$

An Analytical Hierarchy Process (AHP) again was adopted to calculate the relative importance of for the Sensitivity and the Resilience based on expert judgment survey. A questionnaire was designed for collecting expert judgment on relative importance of different factors and groups for assessing the multi hazard vulnerability for Rakhine State. The questionnaire form was distributed among a group of stakeholders and experts who have had extensive experience in the field of disaster management in Myanmar. A sample of the questionnaire form is provided in Chapter D.

The relative importance factors for Sensitivity and Resilience are shown in Table 31 below.

Table 31: Relative Importance Factors for Sensitivity and Resilience

Vulnerability Factors	Relative Importance
Sensitivity (RIS)	0.83
Resilience (RIR)	0.17

And finally, the equation for computing the vulnerability becomes:

$$Vulnerability\ Index = (0.83 \times Sensitivity\ Index) - (0.17 \times Resilience\ Index)$$

The vulnerability indices for the 3 sectors considered corresponding to the priority hazard types can be computed and mapped accordingly. Table 32 summarizes the vulnerability maps that are provided in this study.

Table 32: Summary of the Vulnerability Maps provided in this report

Sectors \ Hazard Types	Earthquake	Cyclone	Storm Surge	Flood	Landslide	Forest/Rural Fire	Tsunami
Human and Social Sector							
based on population group	☑ *common for all hazard types*						
based on livelihood	☑	☑	☑	☑	☑	☑	☑
Physical Infrastructure Sector	☑	☑	☑	☑	☑	☑	☑
Production Sector	☑ *common for all hazard types, except earthquake & landslide*						

Note on Criteria Priority/Ranking Analysis in AHP Approach

The criteria priorities were analyzed with AHP approach developed by Saaty (1990). The methodological steps of the AHP followed in the present research can be explained in following steps:

Step 1: The problem is decomposed into a hierarchy of goal, criteria, sub-criteria and alternatives. This was the most creative and important part of this process.

Step 2: Data were collected from experts or decision-makers (See Questionnaire) corresponding to the hierarchic structure. Compilation of experts opinions were done by the following steps

- Factor that got maximum votes in pair-wise comparison considered as important than the other

- Weight (1-9 Scale) that got maximum frequency for the important factor consider as strength importance
- The same process followed for all pairs

In case of inconsistent result, some value for the comparison that got most heterogeneous evaluation was rearranged taking comparison that provided most homogenous decision as a standard to generate a consistent pair wise comparison matrix.

Step 3: The pair wise comparisons of various criteria generated at step 2 were organized into a square matrix. The diagonal elements of the matrix are 1.

Step 4: The principal Eigen value and the corresponding normalized right Eigen vector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized Eigen vector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives.

Step 5: The consistency of the matrix of order n was evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level then answers to comparisons may be re-examined. The consistency index, CI, was calculated as

$$CI = (\lambda_{max} - n)/(n - 1)$$

Where λ_{max} is the maximum Eigen value of the judgment matrix. This CI was then compared with that of a random matrix, RI. The ratio derived, CI/RI, is termed the consistency ratio, CR. Saaty (1990) suggests the value of CR should be less than 0.1.

Example Calculation of the Relative Importance by AHP

Pair-Wise Comparison Matrix_03

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Sensitivity of Different Age and Sex Groups for Population Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Male>18	√	Female>18	1	2	3	4	5	6	7	8	9
☐	Male>18	√	Male<18	1	2	3	4	5	6	7	8	9
☐	Male>18	√	Female<18	1	2	3	4	5	6	7	8	9
☐	Female>18	√	Male<18	1	2	3	4	5	6	7	8	9
☐	Female>18	√	Female<18	1	2	3	4	5	6	7	8	9
☐	Male<18	√	Female<18	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pairwise Comparison Matrix

	Male<18	Female<18	Male>18	Female>18
Male<18	1	0.25	4	2
Female<18	4	1	7	3
Male>18	0.25	0.14285714	1	0.2
Female>18	0.5	0.33333333	5	1

Step 1:

We sum each column of the reciprocal matrix to get

	Male<18	Female<18	Male>18	Female>18
Male<18	1	0.25	4	2
Female<18	4	1	7	3
Male>18	0.25	0.14285714	1	0.2
Female>18	0.5	0.33333333	5	1
Sum	5.75	1.72619048	17	6.2

Then we divide each element of the matrix with the sum of its column, we have normalized relative weight. The sum of each column is 1.

	Male<18	Female<18	Male>18	Female>18
Male<18	0.173913043	0.14482758	0.235294118	0.322580645
Female<18	0.695652174	0.57931034	0.411764706	0.483870968
Male>18	0.043478261	0.08275862	0.058823529	0.032258065
Female>18	0.086956522	0.19310345	0.294117647	0.161290323
Sum	1	1	1	1

The normalized principal Eigen vector can be obtained by averaging across the rows

	Male<18	Female<18	Male>18	Female>18	Priority Vector
Male<18	0.173913043	0.14482758	0.235294118	0.322580645	0.22
Female<18	0.695652174	0.57931034	0.411764706	0.483870968	0.54
Male>18	0.043478261	0.08275862	0.058823529	0.032258065	0.05
Female>18	0.086956522	0.19310345	0.294117647	0.161290323	0.18

The normalized principal Eigen vector is also called priority vector.

Relative Importance of Different Gender and Age Groups for Sensitivity Assessment

Population Group	Relative Importance
Male >18	0.05
Female > 18	0.18
Male <18	0.22
Female <18	0.55

To check the consistency we need what is called Principal Eigen value. Principal Eigen value is obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix.

	Male<18	Female<18	Male>18	Female>18	Priority Vector	
Male<18	0.173913043	0.14482758	0.235294118	0.322580645	0.22	0.173913043X0.22
Female<18	0.695652174	0.57931034	0.411764706	0.483870968	0.54	0.57931034X0.54
Male>18	0.043478261	0.08275862	0.058823529	0.032258065	0.05	0.058823529X0.05
Female>18	0.086956522	0.19310345	0.294117647	0.161290323	0.18	0.161290323X0.18
Principal Eigen value=						4.2604299

Prof. Saaty proved that for consistent reciprocal matrix, the largest Eigen value is equal to the size of comparison matrix , or $\lambda_{max} = n$. Then he gave a measure of consistency, called Consistency Index as deviation or degree of consistency using the following formula

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Thus, in our previous example, we have $\boldsymbol{\lambda_{max}}$**=4.2604299** and the size of comparison matrix is **n=4**, thus the consistency index is

CI = (4.2604299-4)/3 = 0.08681

Knowing the Consistency Index, the next question is how we use this index. Again, Prof. Saaty proposed that we use this index by comparing it with the appropriate one. The appropriate Consistency index is called Random Consistency Index (*RI*).

He randomly generated reciprocal matrix using scale $\frac{1}{9}, \frac{1}{8}, \ldots, 1, \ldots, 8, 9$ (similar to the idea of Bootstrap) and get the random consistency index to see if it is about 10% or less. The average random consistency index of sample size 500 matrices is shown in the table below

Table : Random Consistency Index (*RI*)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Then, he proposed what is called Consistency Ratio, which is a comparison between Consistency Index and Random Consistency Index, or in formula

$$CR = \frac{CI}{RI}$$

If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

For our previous example, we have **CI=0.08681** and *RI* for **n=4** is 0.9, then we have *CR*= (0.08681/0.9)= 0.096. Thus, this evaluation about is consistent.

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Chapter D: Questionnaire Form for Expert Survey on Vulnerability Assessment

Expert Opinion Survey

On

Multi Hazard Vulnerability Analysis

For

The Project

Multi Hazard Risk Assessment for Rakhine State, Myanmar

Form No.: …………. Date: / /2010

Respondent's Background

Name:

……………………………………………………………………………………….…………

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Organization:

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Job Title/Role:

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Field of Expertise:

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Address

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Phone:

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E-Mail:

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The Fundamental Scale for Pair-Wise Comparison

When we measure something with respect to a property, we usually use some known scale for that purpose. Pair-wise comparisons are quantified by using a scale. Such a scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represent the importance, or weight, of the previous linguistic choices. The values of the pair-wise comparisons in the AHP are determined according to the scale introduced by Saaty (1990) where 9 as the upper limit of his scale, 1 as the lower limit and a unit difference between successive scale values.

Intensity of Importance	Definition
1	**Equal Importance**
2	Weak Importance
3	**Moderate Importance**
4	Moderate Plus
5	**Strong Importance**
6	Strong Plus
7	**Very Strong Importance**
8	Very Very Strong
9	**Extreme Importance**

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Example

Suppose we have to choose one fruit from **Apple** and **Banana** for **Gaining Energy** from the same mass.
I would like to ask you, which fruit you like better than the other and how much you prefer it *in comparison* with the other for achieving your **Goal**.
Let us make a relative scale to measure how much you prefer **Apple** compared to **Banana**.
If you like **Banana** better than **Apple**, mark a tick on left side of Banana and tick a score between number 1 and 9 representing your likeliness.

For instance you **strongly** favor banana to apple for gaining energy from the mass then you give mark like this

Criteria				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
	Apple	√	**Banana**	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Expert Opinion

Question: The purpose of this questionnaire is to study your opinion concerning the criteria influencing **analysis of hazard vulnerability for Rakhine State, Myanmar.** Please, answer the questions *from the position of a disaster manager concerning your own field of expertise.* State your own view about general preferences.

Which criterion you think is more important than the other and how much it's importance (in 1 to 9 scale) *in comparison* with the other. To each pair of the attributes select one and assign a number (1 to 9) reflecting their relative importance.

CAUTION

Please consider the **Existing Criteria Scenario** within the study areas while performing the pair wise comparison between two criteria, sub-criteria or sub-sub-criteria.

Pair-Wise Comparison Matrix_01

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Importance of Sensitivity and Resilience for Vulnerability Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Sensitivity	☐	Resilience	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_02

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Importance of Disaster Mechanism, Preparedness and Accessibility for Disaster Resilience Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
	Mechanism		Preparedness	1	2	3	4	5	6	7	8	9
	Mechanism		Accessibility	1	2	3	4	5	6	7	8	9
	Preparedness		Accessibility	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_03

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Sensitivity of Different Age and Gender Groups for Demographic Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Male>18	☐	Female>18	1	2	3	4	5	6	7	8	9
☐	Male>18	☐	Male<18	1	2	3	4	5	6	7	8	9
☐	Male>18	☐	Female<18	1	2	3	4	5	6	7	8	9
☐	Female>18	☐	Male<18	1	2	3	4	5	6	7	8	9
☐	Female>18	☐	Female<18	1	2	3	4	5	6	7	8	9
☐	Male<18	☐	Female<18	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_04

Infrastructure Sensitivity in Respect of Flood Hazard
(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Flood Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance: Equal		Moderate		Strong		Very Strong		Extreme
☐	Concrete	☐	Masonry	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Others	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Others	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Others	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Others	1	2	3	4	5	6	7	8	9
☐	Hut	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_05

Infrastructure Sensitivity in Respect of Cyclone Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Cyclone Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Concrete	☐	Masonry	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Others	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Others	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Others	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Others	1	2	3	4	5	6	7	8	9
☐	Hut	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_06

Infrastructure Sensitivity in Respect of Earthquake Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Earthquake Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Concrete	☐	Masonry	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Others	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Others	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Others	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Others	1	2	3	4	5	6	7	8	9
☐	Hut	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_07

Infrastructure Sensitivity in Respect of Storm Surge Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Storm Surge Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Concrete	☐	Masonry	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Others	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Others	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Others	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Others	1	2	3	4	5	6	7	8	9
☐	Hut	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_08

Infrastructure Sensitivity in Respect of Tsunami Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Tsunami Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Concrete	☐	Masonry	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Others	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Others	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Others	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Others	1	2	3	4	5	6	7	8	9
☐	Hut	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_09

Infrastructure Sensitivity in Respect of Forest/Rural Fire Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Forest/Rural Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
	Concrete		Masonry	1	2	3	4	5	6	7	8	9
	Concrete		Brick-nogging	1	2	3	4	5	6	7	8	9
	Concrete		Wood	1	2	3	4	5	6	7	8	9
	Concrete		Hut	1	2	3	4	5	6	7	8	9
	Concrete		Others	1	2	3	4	5	6	7	8	9
	Masonry		Brick-nogging	1	2	3	4	5	6	7	8	9
	Masonry		Wood	1	2	3	4	5	6	7	8	9
	Masonry		Hut	1	2	3	4	5	6	7	8	9
	Masonry		Others	1	2	3	4	5	6	7	8	9
	Brick-nogging		Wood	1	2	3	4	5	6	7	8	9
	Brick-nogging		Hut	1	2	3	4	5	6	7	8	9
	Brick-nogging		Others	1	2	3	4	5	6	7	8	9
	Wood		Hut	1	2	3	4	5	6	7	8	9
	Wood		Others	1	2	3	4	5	6	7	8	9
	Hut		Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_10

Infrastructure Sensitivity in Respect of Landslide Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Landslide Sensitivity of Different Building Typology for Infrastructure Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Concrete	☐	Masonry	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Concrete	☐	Others	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Brick-nogging	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Masonry	☐	Others	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Wood	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Brick-nogging	☐	Others	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Hut	1	2	3	4	5	6	7	8	9
☐	Wood	☐	Others	1	2	3	4	5	6	7	8	9
☐	Hut	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_11

Livelihood Sensitivity in Respect of Flood Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Flood Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_12

Livelihood Sensitivity in Respect of Cyclone Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Cyclone Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_13

Livelihood Sensitivity in Respect of Earthquake Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Earthquake Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_14

Livelihood Sensitivity in Respect of Storm Surge Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Storm Surge Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_15

Livelihood Sensitivity in Respect of Tsunami Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Tsunami Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_16

Livelihood Sensitivity in Respect of Forest/Rural Fire Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Forest/Rural Fire Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Pair-Wise Comparison Matrix_17

Livelihood Sensitivity in Respect of Landslide Hazard

(Please select (√) the relatively important criterion and assign a number (1-9) reflecting their relative importance and Circle (O) it for each pair of attributes)

Relative Landslide Sensitivity of Different Livelihood Groups for Livelihood Sensitivity Analysis in Rakhine State, Myanmar				Intensity of Importance								
				Equal		Moderate		Strong		Very Strong		Extreme
☐	Agriculture	☐	Fisheries	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Agriculture	☐	Others	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Livestock	1	2	3	4	5	6	7	8	9
☐	Fisheries	☐	Others	1	2	3	4	5	6	7	8	9
☐	Livestock	☐	Others	1	2	3	4	5	6	7	8	9

[2, 4, 6 and 8 are intermediate values between the two adjacent judgments]

Comments/Suggestions

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CHAPTER E: DAMAGE ESTIMATION FOR SELECTED HAZARD

Damage estimation is an essential step in the risk assessment process since it will facilitate the emergency response, recovery, and reconstruction planning in an event of a future disaster. Furthermore economic implication both immediately after the disaster and long term are hinging on the level of damage caused by the disaster.

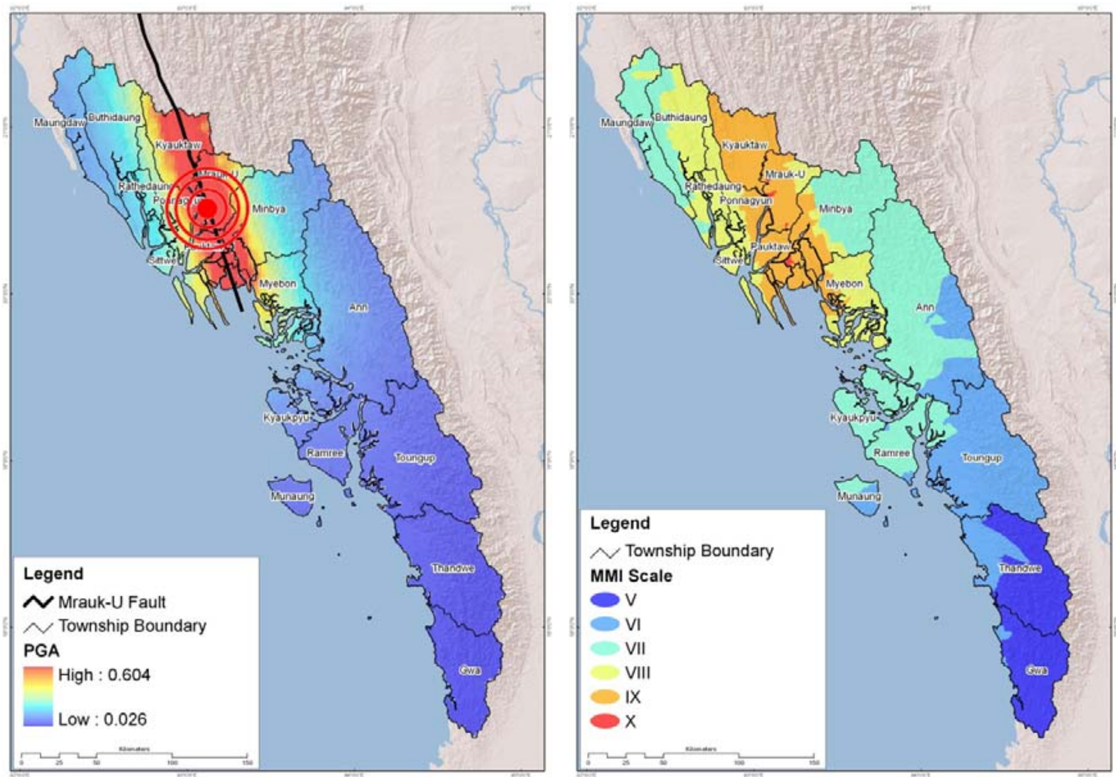
Damage estimation can follow different schemes, ranging from a purely judgmental approach to a strictly analytical approach. The process itself is very complicate and would require multi-disciplinary collaboration. For example in term of an earthquake damage estimation, geologists and seismologists need to provide an outlook of the possible earthquake as well as the intensity of the earthquake at various locations. Structural and geotechnical engineers will then take the information and assess the direct physical impacts on the foundation and structure of the buildings and other infrastructures. Social workers may assess the social damage from the earthquake. Finally economists will look into translating the direct physical and social damage into economic impacts, both short term and long term.

This chapter provides only a glimpse of the damage estimation process. It focuses on estimating the damage caused by a scenario earthquake to housing in Rakhine State.

Scenario Earthquake

Earthquake may seem to be a distant threat to Rakhine State due to its inactivity in recent history. This is a misleading and very dangerous perception. Geological evidence and paleoseismic data have shown that there are in fact several earthquake sources in and nearby of Rakhine State. Some of which are capable of producing very destructive earthquakes. As a result, earthquake was selected as a hazard type to be undergone damage estimation in this study as an example application of the risk assessment. In this regard, a rupture of the Mrauk-U fault, located in the northern part of the state and cut through the Kyauktaw, Mrauk-U, Pauktaw, and parts of Minbya and Myebon townships, was assumed. The rupture of this fault results in a magnitude-8 earthquake. This scenario earthquake represents a worst-case scenario that could happen along this seismic fault.

The location of the fault line as well as the Peak Ground Acceleration (PGA) estimated at the surface from this scenario earthquake is illustrated in Figure 43a. The PGA values were then converted into a qualitative measure of the seismic intensity, which is the Modified Mercalli Intensity (MMI) scale. A formula used for the conversion can be found in Chapter A. The MMI map is depicted in Figure 43b. An explanation for different values of the MMI scale can be found in Chapter A. It was revealed that this scenario earthquake resulted in an MMI-X (intense shaking) in several village tracts including Na Kan, Lay Hnyin Thar, Wet Hla, Bar Nyo, and Tha Baw of Mrauk-U township, Kywe Tet, Aing Wan, and Ba Li Pauk of Minbya township, and Na Ga Yar of Kyauktaw township.



(a) (b)

Figure 43: Spatial Distribution of Intensity of the Scenario Earthquake, (a) Peak Ground Acceleration, (b) Modified Mercalli Intensity Scale

Housing Typology

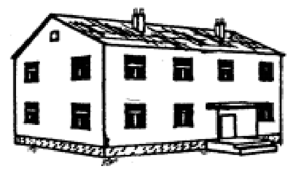
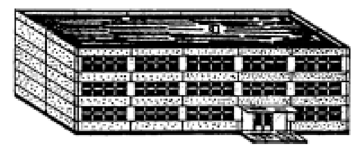
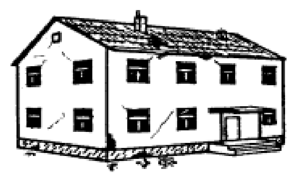
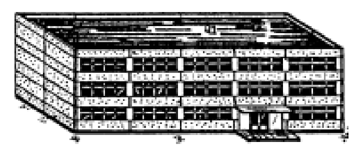
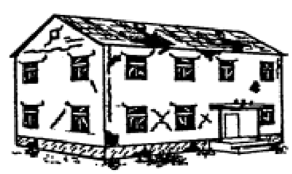
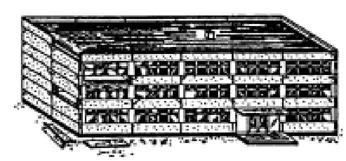
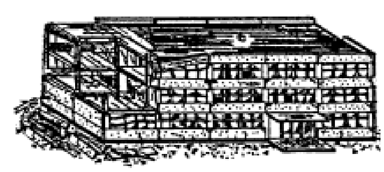
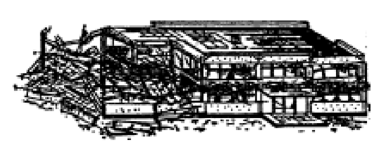
The entire housing ensemble in Rakhine State was classified according to the construction material of the main structural components. They are classified into concrete, wood, masonry, brick-nogging, and hut (bamboo-type). The breakdown of the housing classes was obtained from field survey data, secondary data from Rakhine State government, and statistical analyses from the settlement areas of each village tract. Details are presented in Chapter 3.

Housing Damageability to Earthquakes

Seismic damage curves (fragility curves) are used to estimate the degree of damage that a building type can experience as a result of certain levels from earthquake intensity. The damage curves can be derived from various means. In the case that damage data from past earthquakes in the area is abundant and reliable, the damage curves can be generated from that data. On the other hand, in an area that buildings are constructed according to the engineering design, and that there are supporting structural laboratory and field test results on the buildings, the damage curves may be developed analytically by means of computer simulations. However, for Rakhine State, none of the above was available. As a result, a set of seismic damage estimation scheme from another region was adopted with modification to reflect the local contexts.

The European Macroseismic Scale of 1998 or EMS-98 (Grünthal, 1998) was established by a working group under the European seismological Commission, comprising of many esteemed earthquake experts from all over Europe. EMS-98 classifies the degree of damage into 5 distinct classes and call them 'Damage Grade'. Table 33 illustrates the damage grades for masonry and concrete buildings.

Table 33: Damage Grades for Masonry and Concrete Buildings as defined by EMS-98 (Grünthal, 1998)

Damage Grade	Damage Description	Illustration of Damage	
		Masonry Building	Concrete Building
1	**Negligible to Slight Damage** (no structural damage, slight non-structural damage)		
2	**Moderate Damage** (slight structural damage, moderate non-structural damage)		
3	**Substantial to Heavy Damage** (moderate structural damage, heavy non-structural damage)		
4	**Very Heavy Damage** (heavy structural damage, very heavy non-structural damage)		
5	**Destruction** (very heavy structural damage)		

The European Macroseismic Scale also defines 6 vulnerability classes, A to F, with the vulnerability class A being the most vulnerable class. Depending on the type of construction materials (wood, brick, concrete, etc.), the buildings are assigned to a vulnerability class. Adapting the approach from EMS-98, a vulnerability table mapping the building types in Rakhine with the vulnerability classes is shown below. It is important to understand how the building type is mapped to the vulnerability class, so it is worthwhile to provide an example. According to the table, the concrete buildings in Rakhine State are most likely to be categorized as a Vulnerability Class C, sometimes they are probably Vulnerability Class B, and in some exceptional cases they can be categorized as Vulnerability Class A and D. Table 34 depicts mapping scheme between the EMS Vulnerability Class and the building typology in Rakhine State.

Table 34: Mapping Table of the EMS Vulnerability Class and Rakhine State's Building Typologies

Rakhine State Building Type	EMS Vulnerability Class					
	A	B	C	D	E	F
Hut	100%					
Brick	25%	75%				
Wood	5%	90%	5%			
Concrete	5%	25%	65%	5%		

Finally, EMS-98 defines the earthquake intensity scale in a similar manner as in the Modified Mercalli Intensity (MMI) scale; that is the EMS scale also ranges from I to XII (1 to 12). It also provides an expectation of the building damage associated with each intensity scale. Musson et. al. (2010) stated that the MMI scale and EMS-98 intensity are interchangeable.

A Damage Probability Matrix (DPM) provides the probabilities of reaching different Damage Grades providing specific levels of the EMS (or MMI) scale. Each DPM is specific for a Vulnerability Class. Table 35 to Table 40 summarize the DPM derived for Rakhine State.

Table 35: Probability of Reaching Damage Grades for EMS Vulnerability Class A

EMS Scale	Damage Grade					Equivalent MMI Scale
	1	2	3	4	5	
V	10%					V
VI	35%	10%				VI
VII			35%	10%		VII
VIII				35%	10%	VIII
IX					35%	IX
X					75%	X
XI					100%	XI
XII					100%	XII

Table 36: Probability of Reaching Damage Grades for EMS Vulnerability Class B

EMS Scale	Damage Grade					Equivalent MMI Scale
	1	2	3	4	5	
V	10%					V
VI	35%	10%				VI
VII		35%	10%			VII
VIII			35%	10%		VIII
IX				35%	10%	IX
X					35%	X
XI					75%	XI
XII					100%	XII

Table 37: Probability of Reaching Damage Grades for EMS Vulnerability Class C

EMS Scale	Damage Grade					Equivalent MMI Scale
	1	2	3	4	5	
V						V
VI	10%					VI
VII		10%				VII
VIII		35%	10%			VIII
IX			35%	10%		IX
X				35%	10%	X
XI				75%	35%	XI
XII					100%	XII

Table 38: Probability of Reaching Damage Grades for EMS Vulnerability Class D

EMS Scale	Damage Grade					Equivalent MMI Scale
	1	2	3	4	5	
V						V
VI						VI
VII	10%					VII
VIII		10%				VIII
IX		35%	10%			IX
X			35%	10%		X
XI				35%	10%	XI
XII					75%	XII

Table 39: Probability of Reaching Damage Grades for EMS Vulnerability Class E

EMS Scale	Damage Grade					Equivalent MMI Scale
	1	2	3	4	5	
V						V
VI						VI
VII						VII
VIII						VIII
IX		10%				IX
X		35%	10%			X
XI			35%	10%		XI
XII					75%	XII

Table 40: Probability of Reaching Damage Grades for EMS Vulnerability Class F

EMS Scale	Damage Grade					Equivalent MMI Scale
	1	2	3	4	5	
V						V
VI						VI
VII						VII
VIII						VIII
IX						IX
X		10%				X
XI		35%	10%			XI
XII					75%	XII

Damage Estimates

The damage on hosing in Rakhine State has been estimated using the information provided in the previous sections. The number of houses suffering various levels of damage Grade was summarized for all townships (Table 41). It was estimated that close to 200,000 houses would suffer some level of damage as a result of this magnitude-8 Mrauk-U earthquake scenario. Out of this number, more than 100,000 would be severely damaged or destroyed. The housing damage is concentrated in the Maungdaw, Sittwe, and Buthidaung townships.

It is important to note that these estimates are based on the housing statistics derived from the field survey and secondary sources as of 2011. They present only a rough overview of the potential damage from a worst-case-scenario earthquake from the Mruak-U fault.

Table 41: Number of Houses suffering various Damage Grades in each Township

Township	Damage Grade				Total
	2	3	4	5	
Maungdaw	3,478	19,215	6,086	249	29,029
Sittwe	1,234	9,143	12,126	2,747	25,250
Buthidaung	788	6,854	12,124	2,923	22,688
Mrauk-U	22	550	5,716	9,861	16,149
Kyauktaw	2	338	5,889	7,764	13,992
Minbya	106	722	5,284	6,789	12,901
Ponnagyun	119	2,142	5,785	4,625	12,670
Pauktaw	87	1,305	5,363	5,220	11,974
Myebon	39	465	4,383	4,832	9,719
Kyaukpyu	5,546	3,433	535	-	9,514
Ann	4,663	3,835	734	-	9,233
Ramree	3,880	3,986	853	-	8,719
Rathedaung	2,350	3,191	1,711	280	7,531
Munaung	2,474	1,119	171	-	3,764
Toungup	2,989	329	32	-	3,349
Thandwe	2,785	-	-	-	2,785
Gwa	271	-	-	-	271
Total	30,831	56,628	66,791	45,289	199,539

Considering different building typologies, the breakdown of the housing damage can be depicted in Figure 44.

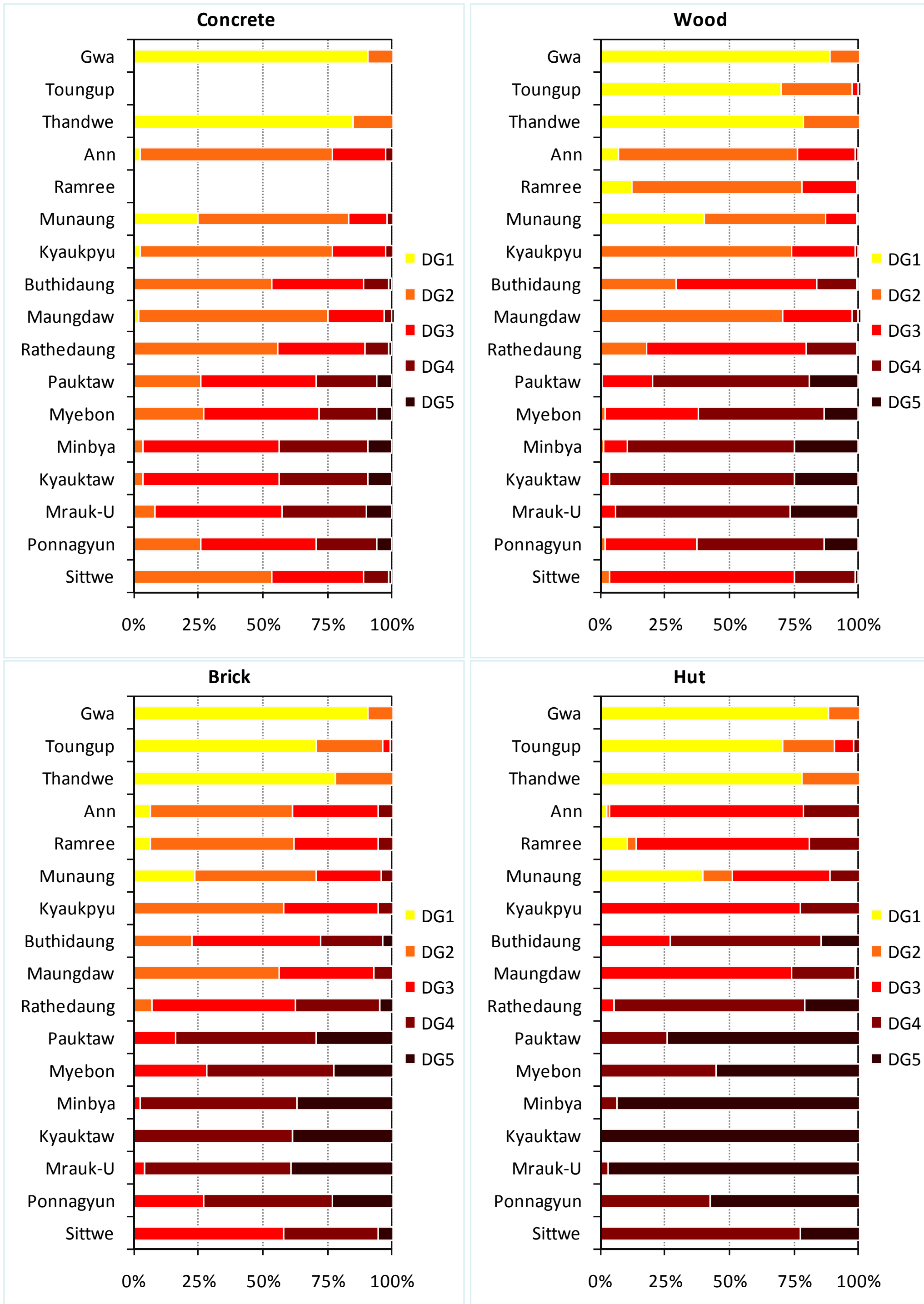


Figure 44: Breakdown (in percents) of Housing Damage by Township for (a) Concrete, (b) Wood, (c) Brick, and (d) Hut

Figure 45 shows damage estimates of the houses in Rakhine State from the scenario earthquake in terms of the percents of destroyed houses, calculated at the village tract level.

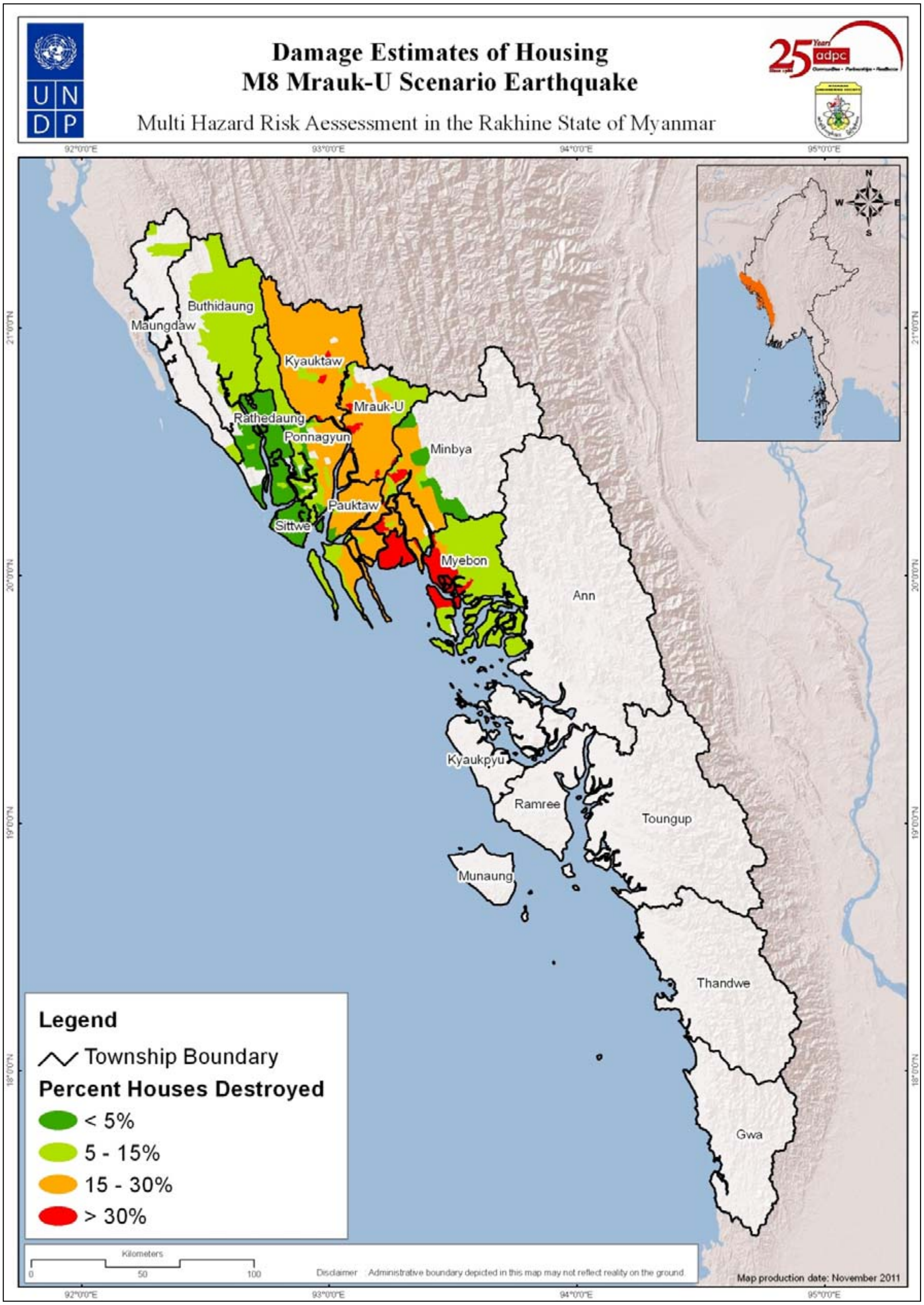


Figure 45: Map depicting the Percentage of Houses Destroyed by the Scenario Earthquake

Loss Estimates

The final step in the damage estimation would be to assess the economic impact of the scenario earthquake. Costs of construction for the different types of housing in Rakhine State are needed for this purpose. However, due to the lack of reliable construction cost data in Rakhine State, the project team employs the construction costs that were collected from the Chittagong Hill Tract region of Bangladesh, located adjacent to Rakhine State. It is highly recommended that further research be conducted to build a database of buildings in Rakhine State and their values.

Table 42: Average Cost of Houses (taken from Chittagong Hills Tract region of Bangladesh)

Building Types	Average Cost per House (USD)
Concrete	1,600
Brick Masonry	667
Wood	587
Hut	280
Brick Nogging	560

Assuming that the Damage Grades 1 to 5 are corresponding to 5, 25, 50, 75, and 100 percents of the total cost of the house, the total direct physical loss to the housing sector due to this Mrauk-U earthquake scenario would be US$ 54.6 million. The loss breakdown is presented in Table 43.

Table 43: Breakdown of Expected Losses (US Dollar)

Township	Expected Losses in US Dollar				
	Concrete	Wood	Brick	Hut	Total
Sittwe	1,001,491	3,064,458	1,104,190	2,371,240	7,541,379
Mrauk-U	126,910	3,608,265	40,703	2,198,119	5,973,997
Kyauktaw	42,316	3,642,260	80,721	1,593,830	5,359,127
Minbya	6,045	3,275,837	126,663	1,423,626	4,832,171
Maungdaw	71,506	762,501	229,252	3,715,529	4,778,787
Buthidaung	5,953	597,311	183,572	3,839,464	4,626,300
Pauktaw	116,259	2,358,248	443,392	1,353,843	4,271,742
Ponnagyun	44,245	2,201,323	135,168	1,617,456	3,998,193
Rathedaung	2,323,223	8,595	1,177,240	76,899	3,585,957
Myebon	56,837	417,039	70,576	2,038,847	2,583,299
Kyaukpyu	2,828	1,361,400	51,531	300,399	1,716,159
Ann	404	1,154,174	20,739	455,145	1,630,462
Ramree	-	941,018	5,576	561,375	1,507,968
Munaung	22,626	444,405	207,525	83,191	757,747

Township	Expected Losses in US Dollar				
	Concrete	Wood	Brick	Hut	Total
Toungup	-	702,114	1,446	35,913	739,473
Thandwe	4,215	393,123	81,954	112,012	591,304
Gwa	209	80,150	232	10,803	91,394
Total	3,825,068	25,012,221	3,960,481	21,787,691	54,585,461

Reference

Grünthal, G. (editor), (1998). European Macroseismic Scale 1998. Cahiers du Centre Européen de Géodynamique et de Séismologie,Vol. 15, Luxembourg, 1-99.

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