NATURAL HAZARD ASSESSMENT OF SW MYANMAR - A CONTRIBUTION OF REMOTE SENSING AND GIS METHODS TO THE DETECTION OF AREAS VULNERABLE TO EARTHQUAKES AND TSUNAMI / CYCLONE FLOODING

Barbara Theilen-Willige

Berlin University of Technology (TU Berlin), Institute of Applied Geosciences

Email: Barbara.Theilen-Willige@t-online.de

George Pararas-Carayannis

Tsunami Society, Honolulu, Hawaii, USA

Email: drgeorgepc@yahoo.com

ABSTRACT

Myanmar, formerly Burma, is vulnerable to several natural hazards, such as earthquakes, cyclones, floods, tsunamis and landslides. The present study focuses on geomorphologic and geologic investigations of the south-western region of the country, based on satellite data (Shuttle Radar Topography Mission-SRTM, MODIS and LANDSAT). The main objective is to detect areas vulnerable to inundation by tsunami waves and cyclone surges. Since the region is also vulnerable to earthquake hazards, it is also important to identify seismotectonic patterns, the location of major active faults, and local site conditions that may enhance ground motions and earthquake intensities. As illustrated by this study, linear, topographic features related to subsurface tectonic features become clearly visible on SRTM-derived morphometric maps and on LANDSAT imagery. The GIS integrated evaluation of LANDSAT and SRTM data helps identify areas most susceptible to flooding and inundation by tsunamis and storm surges. Additionally, land elevation maps help identify sites greater than 10 m in elevation height, that would be suitable for the building of protective tsunami/cyclone shelters.

1. INTRODUCTION

The south-western region of Myanmar is vulnerable to numerous natural hazards, such as earthquakes, cyclones, floods, tsunamis and landslides (Fig. 1). The present study was undertaken for the purpose of using remote sensing satellite imagery and methodology to determine Myanmar's vulnerability to disasters and for ways to mitigate losses of lives and improve on disaster preparedness. The assessments described in subsequent sections are based on satellite data of the Shuttle Radar Topography Mission-SRTM, MODIS and LANDSAT and focus on geomorphologic and geologic investigations of the southwest region of Myanmar. The main objective is to detect areas vulnerable to inundation by tsunamis and cyclone surges, but also to identify seismotectonic patterns, the location of major active faults and local site conditions that may enhance earthquake ground motions and seismic intensities. As illustrated by this study, linear, topographic features related to subsurface tectonic features become clearly visible on SRTM-derived morphometric maps and on LANDSAT imageries. The GIS (**G**eo-**I**nformation**S**ystem) integrated evaluation of LANDSAT and SRTM data helps to identify areas most susceptible to flooding and inundation by tsunamis and storm surges. Land elevation maps help identify sites with elevations greater than 10 m that would be suitable for building protective evacuation shelters. However, before proceeding with the analysis of the satellite data, a brief review of the region's disaster exposure is appropriate.

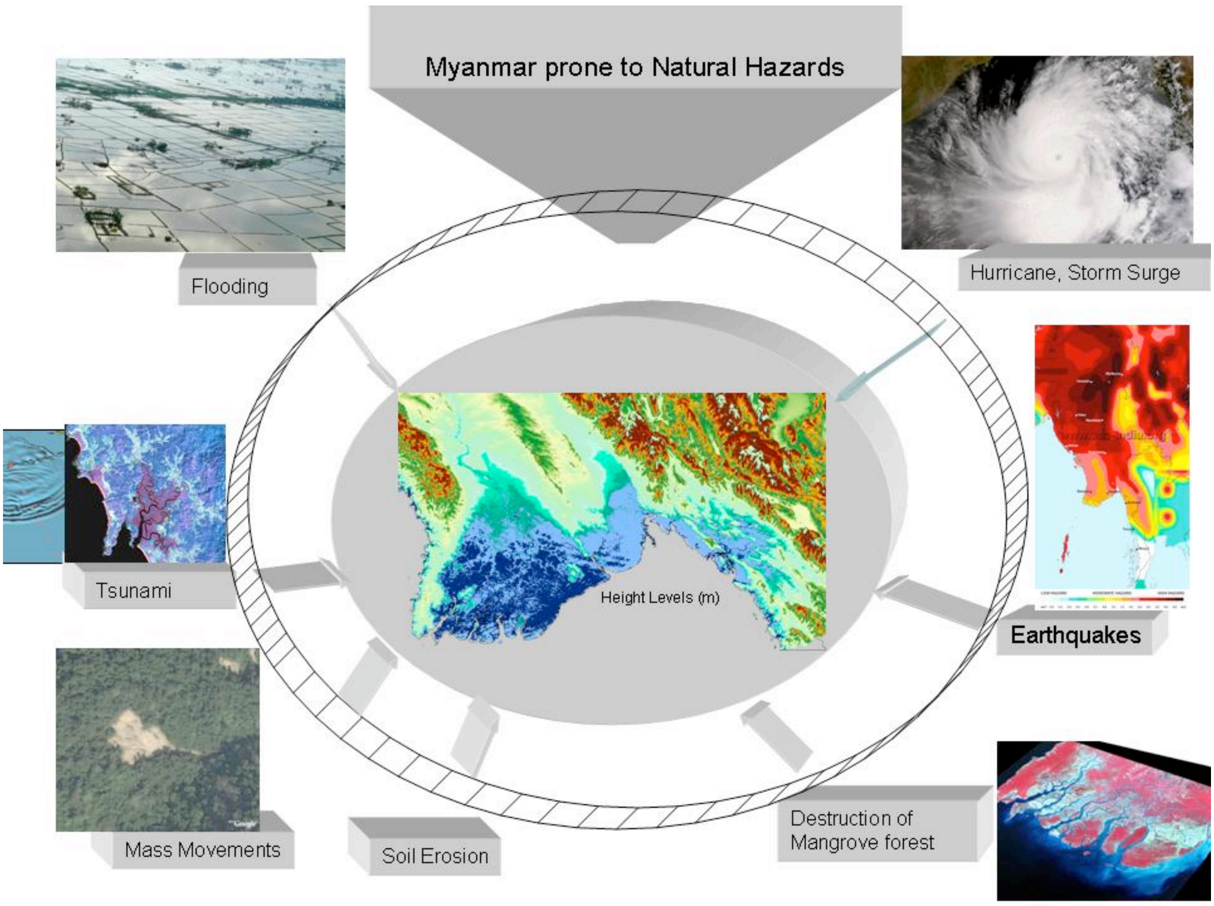

Fig. 1. The vulnerability of southwest Myanmar to natural hazards.

2. MAYNMAR'S VULNERABILITY TO NATURAL DISASTERS

Mynmar's high vulnerability to natural disasters results from its unique geographic and geologic location and geomoprhology. Myanmar borders the Bay of Bengal to the southwest and the Gulf of Martaban and the Andaman Sea along its southern periphery. The country's extensive coastline of about 1,930 (1,199 mi) and its extensive lowland areas make it particularly vulnerable to all types of marine and terrestrial disasters. Its geotectonic evolution and proximity to regions of subduction and major antithetical faulting, make it vulnerable to earthquakes, some of which could be potentially tsunamigenic.

Cyclones and Cyclone Surges - Myanmar is particularly vulnerable to cyclones originating in the Bay of Bengal during pre- and post-monsoon seasons from April to May and from October to November. These cyclones result in heavy rains, floods and storms surges, especially in the coastal region of Rakhine State. Cyclone-related disasters occur in this region every 3 to 4 years.

Additionally to the destruction by high winds, storm surges generated by the cyclones in the region usually flood the low lying and densely populated Ayeyarwady (Irrawaddy) river delta region as well as other coastal regions along the Gulf of Martaban. On May 1-3, 2008, Cyclone Nargis generated in the Bay of Bengal was the deadliest to ever hit the country. It made landfall across the delta of the Irrawaddy River, then continued northeast along the coastline and devastated Myanmar (Fig. 2). Figure 3 shows flooded areas in the Irrawaddy region.

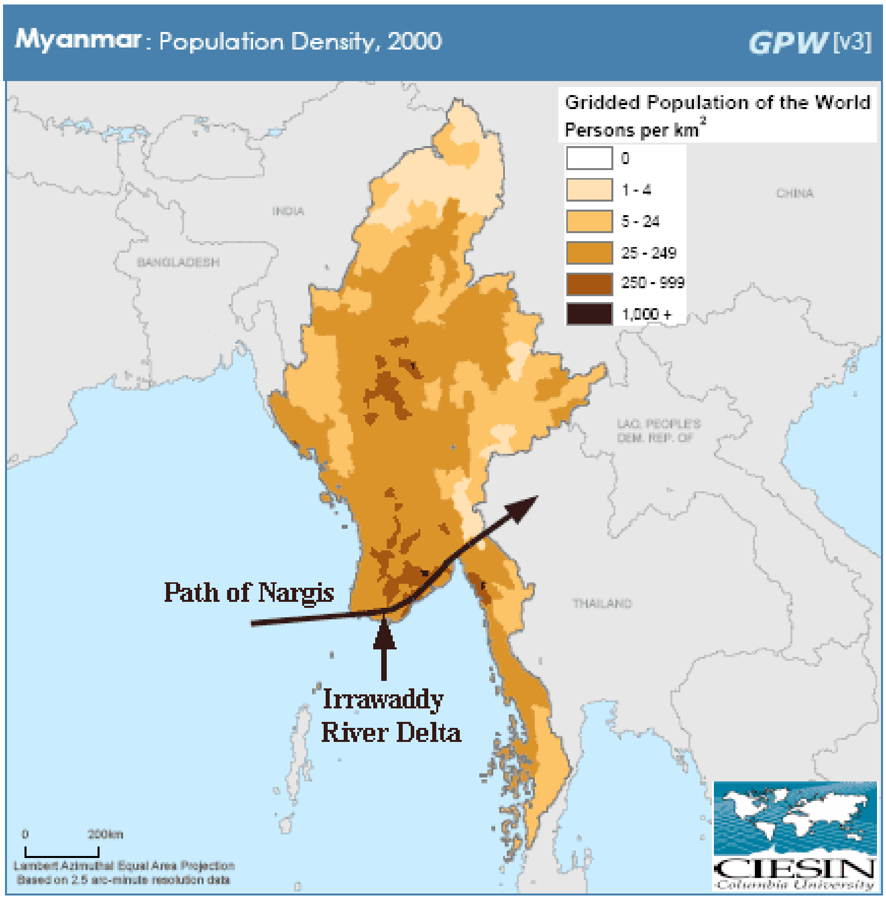

Fig. 2. Cyclone Nargis Path over the Irrawaddy River Delta Region (web graphic)

Fig. 3. Flooding by Cyclone Nargis surge at the Irrawaddy Delta. Non-flooded land of higher elevation seen as islands from NASA satellite.

Maximum reported flooding by Nargis' surge was at least 4 meters (13 feet). The cities of Yangon, Irrawaddy, Pegu and the states of Karen and Mon Worse were the most severely affected regions (Pararas-Carayannis, 2008). The cyclone was responsible for unprecedented loss of life and destruction. It is estimated that more than 100,000 people lost their lives As illustrated by the May 5 MODIS image, the entire coastal plain was flooded. The image from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite uses a combination of visible and infrared light to make floodwaters visible (Fig.4). Based on data of the RADAR satellites TerraSAR-X (DLR/Infoterra) and ALOS/PALSAR (JAXA), the Center for Satellite Based Crisis Information (ZKI) at DLR produced maps of the affected areas (DLR, ZKI, 2008).

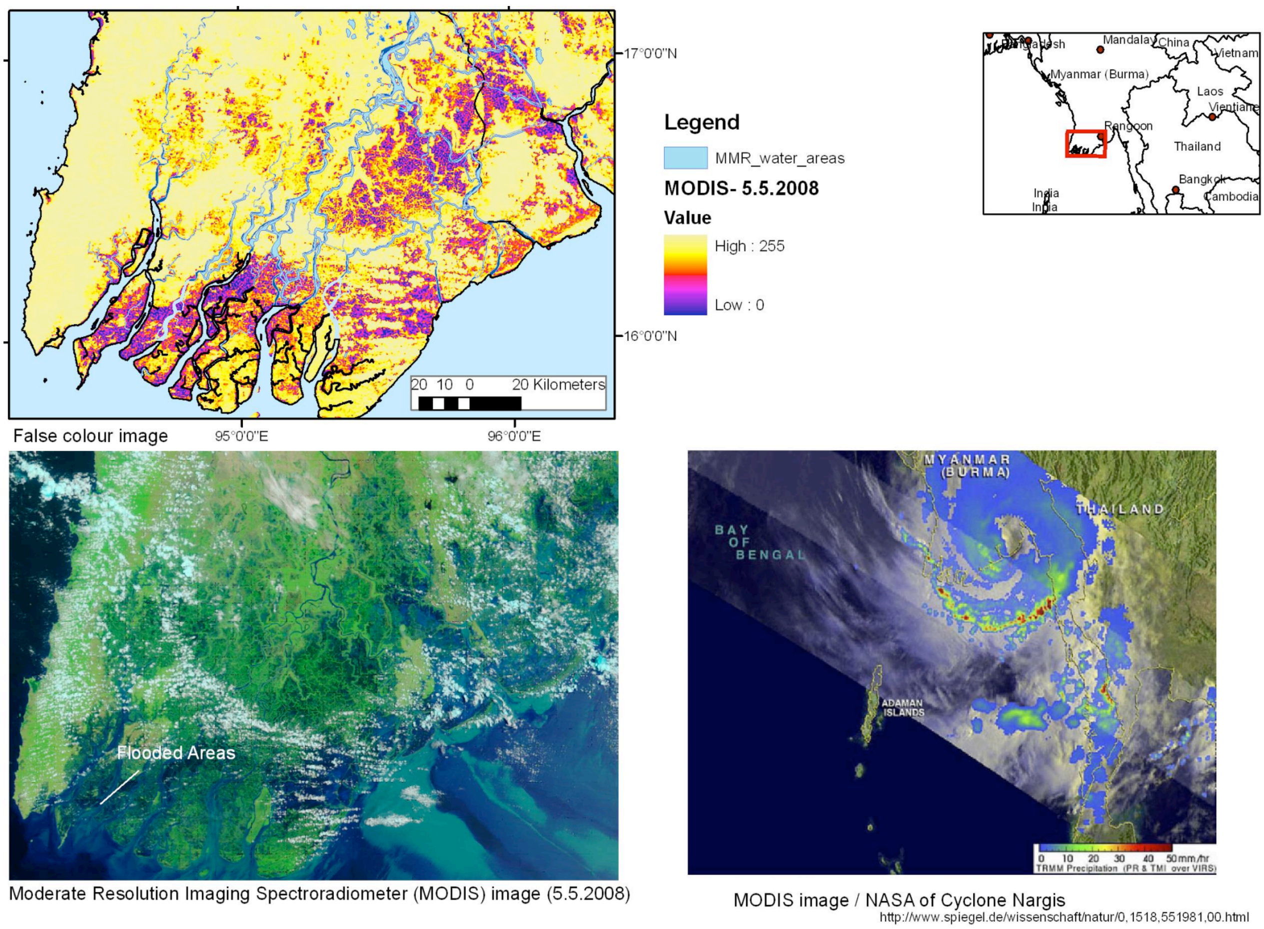

Fig. 4. MODIS image from the flooded areas (NASA)
Water is blue or nearly black, vegetation is bright green, bare ground is tan, and clouds are white or light blue. The wetlands near the shore are a deep blue green. The colour-coded image above shows the flooded areas in blue-reddish and grey tones.

Floods - Four major rivers flowing southward traverse southwest Maynmar. Sometimes, during the heavy monsoon season, rainfall in the north causes the rivers to exceed maximum levels and result in destructive flooding of adjacent towns and villages. The lowland, delta regions are also vulnerable to similar disastrous floods during the monsoon season, particularly when the high tide and the high river water flow occur at the same time. Although earthen dykes have been built to protect the lowlands, there have been times when the dykes have failed and great floods have resulted in great losses of life and property. Fig. 4 and 5 show NASA and Google Earth images of Southwest Myanmar that are also vulnerable areas to both annual and extreme floods (Asian Disaster Reduction Center, Country Report Myanmar, 2003), particularly the central plain area bounded by the two major rivers - the Irrawaddy to the west and the smaller Sittang to the east.

Tsunamis - Large earthquakes have generated tsunamis that have struck the coast of Myanmar. The country is vulnerable to tsunamis originating from earthquakes along the Andaman or the Northern Sumatra segments of the great Sunda Arc (Pararas-Carayannis, 2007a&b). Although not as severe as in other regions and apparently underreported, the December 26, 2004 tsunami impacted Maymar and was responsible for extensive loss of life (Pararas-Carayannis, 2005). The December 26, 2004 tsunami devastated the long southern coastline of the country (Democratic

Voice of Burma, 2005 McKeon et al., 2008). Worst impacted was the Irrawaddy Delta region, which is largely populated by subsistence farmers and fishermen. Fig. 5 shows Google Earth images of devastated areas several months after the tsunami struck.

Fig. 5. Destroyed buildings in the delta area of the Irrawaddy River as documented by Google Earth images.

Local tsunami generation is also very possible. Most of the local seismicity originates along the Sagaing transform which apparently undergoes a right lateral slip – a movement that is not particularly conducive to the traditional mechanism of tsunami generation but which could result in folding and deformational future seismic events with the potential to generate local tsunamis directly or by collateral mechanisms of folding, en-echelon bookshelf failures, particularly within the thick sedimentary stratigraphic layers of the Northern Andaman Sea or of the Gulf of Martaban (Pararas-Carayannis, 2009).

Furthermore, backarc seismicity results along the Shan scarp which is presumed to be a normal fault zone dissecting the Shan plateau of the SE Asian plate against the Burmese lowlands (Mukhopadhyay, 1992). However, there is also a high potential for a major tsunamigenic earthquake in the future as the western region may be representing a seismic gap where stress may have been building up as a result of recent seismic activity along Sumatra and the Andaman Sea and the northward, oblique movement of the Indian tectonic plate (Pararas-Carayannis, 2005a&b; 2007).

The geomorphology of the Gulf of Martaban enhances the occurrence of flooding disasters. The geological conditions and shallow sea off the coast of Myanmar stretching 15 to 20 miles obviously influence the intensity of flooding (Fig. 6).

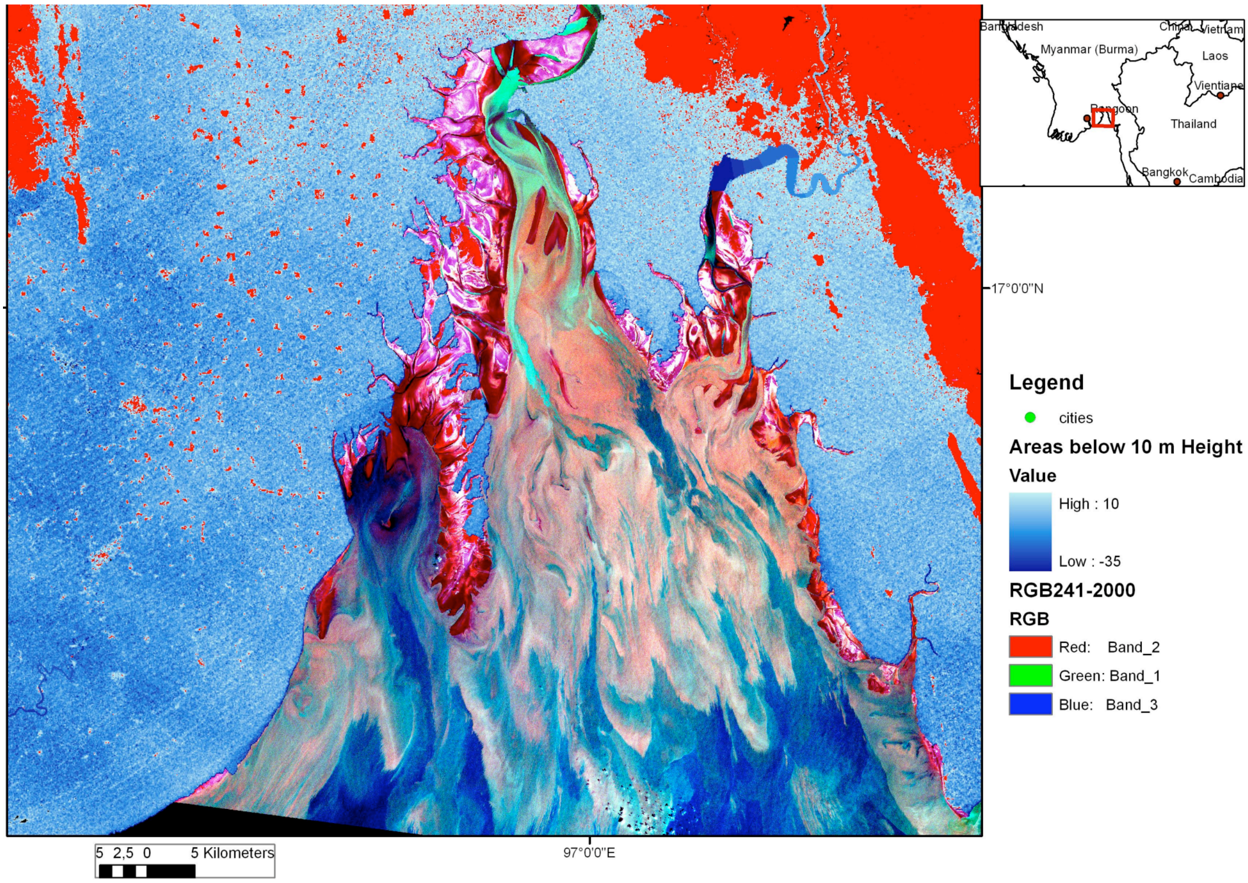

Fig. 6. Visualizing sea surface water currents and streaming in the Gulf of Martaban - based on a LANDSAT ETM false-colour composite (3.5.2000)

Earthquakes - Also, Myanmar is seismologically unstable and vulnerable to earthquakes because of its proximity to boundaries of major interacting tectonic plates. Specifically, the eastern Himalayan belt marks the collision boundary of the Indian tectonic plate underthrusting the Eurasian plate. The approximately North-South trending Indo-Burmese Arc extends southward to join the Andaman segment of the great Sunda Arc (Fig. 7). Continuous collision and movement of the northward-moving Indian plate, at an average rate of 5.5 cm/yr, results in active subduction underneath the smaller Burma plate (part of the Eurasian plate) – the latter moving northward from a spreading center in the Andaman Sea at an average rate of 2.5 – 3.0 cm/yr (Kyaw Kyaw Lin, 2008; Tun, 2008; Pararas-Carayannis, 2007). The movement of the Indian plate movement with respect to Eurasia is highly oblique along the margin of the subduction zone. Northward-trending, antithetical right-lateral shear motion occurs along the Great Sumatra fault and extends into the rift system of the Andaman

Sea (Asian Disaster Reduction Center, Country Report Myanmar, 2003; Pararas-Carayannis, 2005a and b). Very large over thrusts along the Western Fold Belt have resulted from past movements along the Sagaing and related faults.

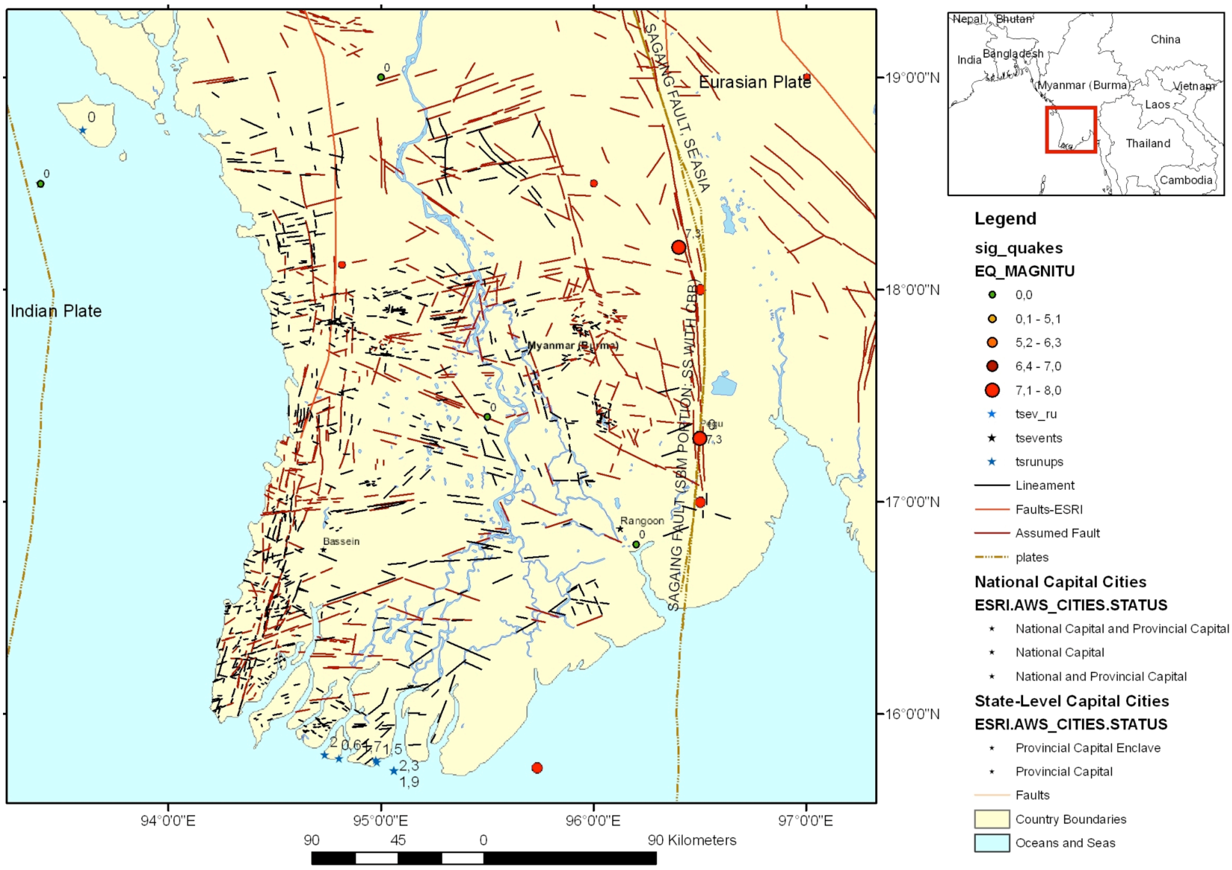

Fig. 7. Geotectonic position of Myanmar
(based on NOAA data, ESRI-data and LANDSAT and SRTM evaluations)

Across Maynmar’s lowlands, the Sagaing transform fault defines another plate boundary between the Burma and the Southeast Asean tectonic plates. The seismicity of Maynmar’s coastal area is relatively low, perhaps because of a fossil plate boundary. However, occasionally, sudden, intermittent movements along these major active faults have resulted in earthquakes that have affected the region. The historic records show that at least 15 major earthquakes with magnitudes $M \geq 7.0$ have occurred in Myanmar in the last hundred years. Destructive earthquakes occurred in 1930 at Bago, in 1970 at Yangon and in 1975 at Pagan.

3. METHODS AND OBJECTIVES

To further delineate Southwest Maynmar’s disaster vulnerability, the present study evaluated remote sensing data from LANDSAT ETM, MODIS and SRTM. **G**eo-**I**nformation**S**ystem (GIS) integrated, comparative analysis of remote sensing data with available geoscientific data was carried out as well as evaluation of reference data. Available geological and geophysical data were collected and integrated as layers into the **G**eo-**I**nformation**S**ystem using ArcView GIS 9.2

and ENVI 4.3 software. Various digital image processing tools delivered by ENVI / CREASO software were tested, to determine the best suited LANDSAT Enhanced Thematic Mapper (ETM) band combinations or contrast stretching parameters. The imageries were merged with the panchromatic Band 8 of LANDSAT ETM to get a spatial resolution of 15 m. For the extraction of tectonic features, standard approaches of digital image processing were used, such as classification for land use and vegetation information. The thermal Band 6 was used to derive and process surface temperature information.

Subsequently, the digital, topographic sets of data were merged and overlain with LANDSAT ETM data. SRTM data provided by the **S**huttle **R**adar **T**opography **M**ission (90 m resolution, interpolated to 50 m) was used to get an overview of the geomorphology of the region and for structural analysis. SRTM data derived image products were used - such as shaded relief and slope degree maps (Theilen-Willige, 2008). The main objectives were to identify more accurately areas vulnerable to floods and suitable locations to build protective shelters.

For the delineation of the tectonic patterns in Southwest Myanmar, the study also considered the support provided by spatial databases. The neotectonic movements were traced by drainage and sedimentological patterns or displacements of strata mapped as linear features (lineaments). Causal or preparatory factors influencing earthquake ground intensity that can be derived by remote sensing and GIS methods were represented as layers in the GIS, in order to detect local site conditions and possible enhancement effects.

4. EVALUATION OF SRTM AND LANDSAT DATA FOR THE DETECTION OF AREAS SUSCEPTIBLE TO FLOODING BY TSUNAMI AND STORM SURGE

In evaluating digital topographic data provided by the Shuttle Radar Topography Mission (SRTM, 2000) one can visualize that the flooding susceptibility is very high in southwest Myanmar since most of the delta region is situated at an elevation almost below 10 m above sea level. Figure 8 provides an overview of the geomorphologic setting. The height level map enhances the V-shaped basin-morphology with large areas below the 10 m elevation from sea level.

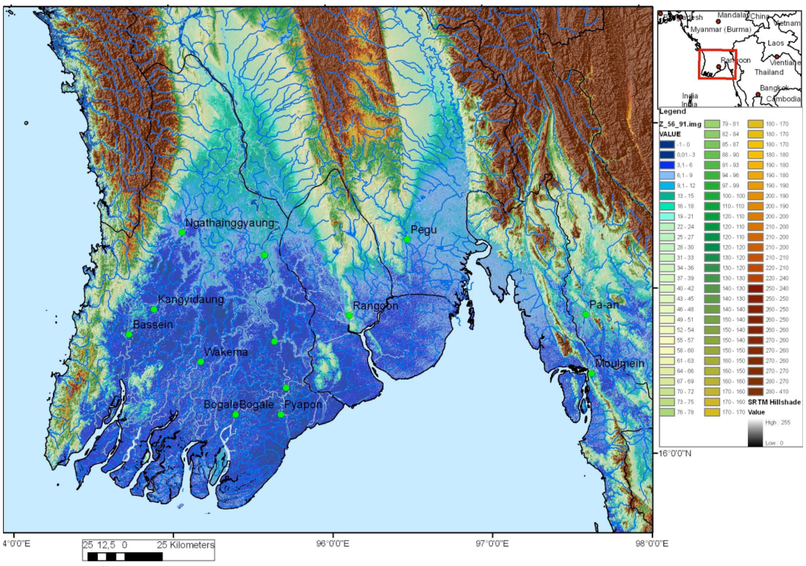

Fig. 8. Height level map (heights in m) of SW-Myanmar

(Note:The ArcGIS 9.2 integrated **flow accumulation** function was applied to calculate surface runoff and lateral flow toward streams using a two-compartment distributed delay function. It routes the flow of water, finding a flow direction for every cell of the elevation grid, following the steepest paths. Flows from cell to cell on the same flow path result in a flow accumulation map in which the value for each cell represents the accumulated flow along a particular path).

Based on the SRTM DEM data, the flow accumulation and the drainage patterns can be calculated as shown in Figure 9. The flow accumulation map provides information of the areas susceptible to flooding.

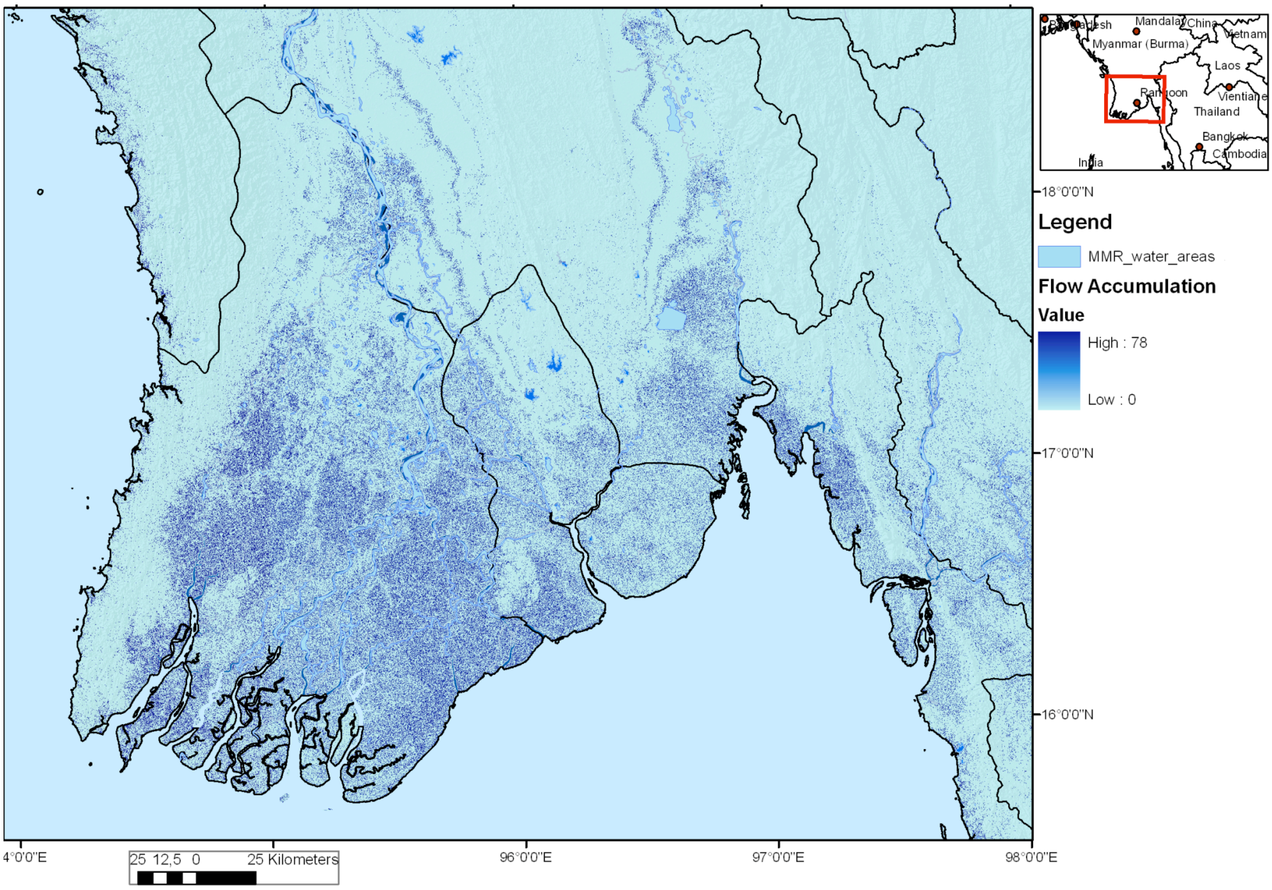

Fig. 9. Flow accumulation map indicating in dark-blue colours the areas most susceptible to flooding.

When comparing satellite data of the western coasts of Myanmar before and after the December 26, 2004 Tsunami, it becomes obvious that the areas below 10 m elevation were particularly vulnerable to flooding (Fig. 10), however, generally not the areas above the 10 m elevation. These areas seen in greenish colours on the LANDSAT scene, which were acquired in 2002, appear in light tones on the image received in April of 2006, because erosion, abrasion and sedimentation caused by the 2004 tsunami. As these images suggest, bays, river mouths, broader riverbeds and estuary plains have probably been more vulnerable to tsunami inundation. Bays and river mouths where tsunamis can enter and inundate are illustrated in Figure 11.

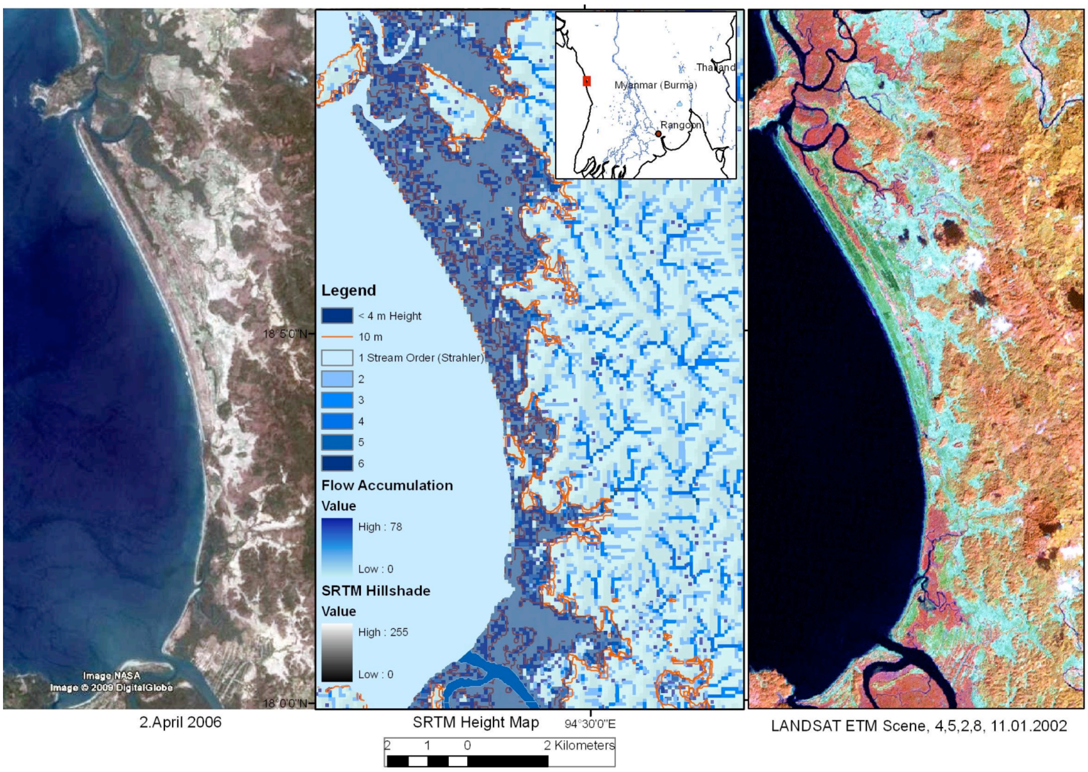

Fig. 10. Comparative analysis of a Google Earth Scene (after the Dec. 26, 2004 Tsunami), SRTM and LANDSAT ETM data (before the Dec. 26, 2004 Tsunami)

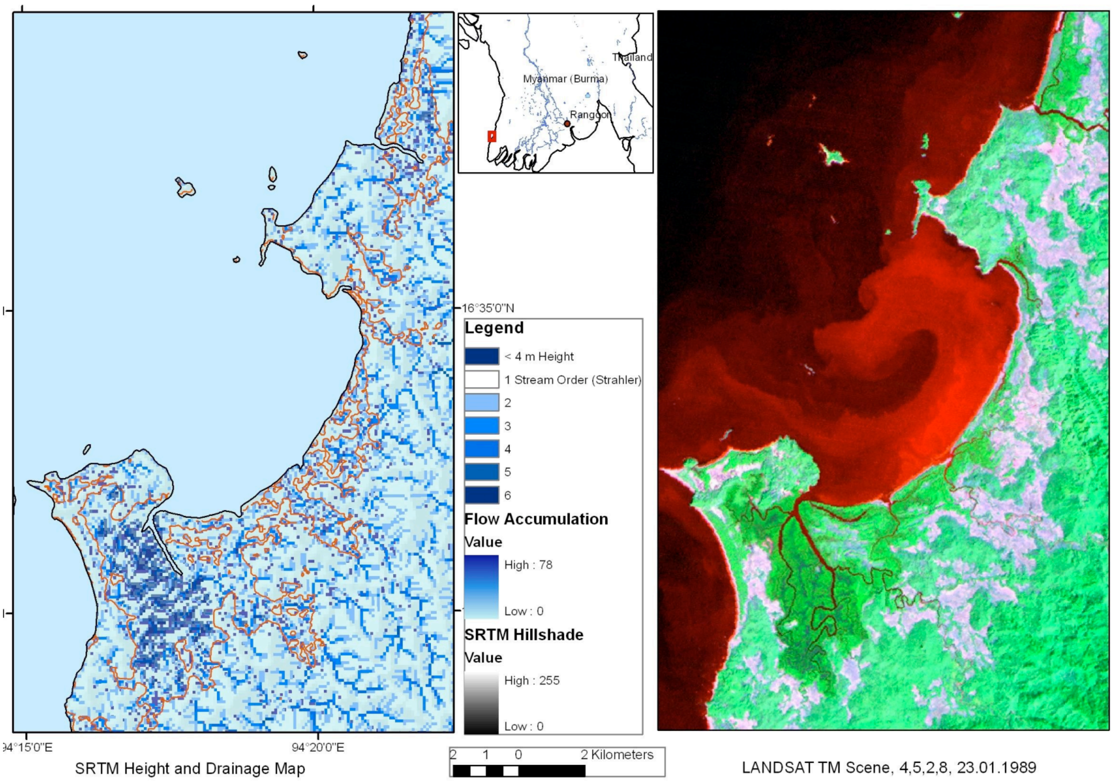

Fig. 11. Streaming pattern at the west coast of Myanmar as seen on LANDSAT imageries

The flooding by Cyclone Nargis had shown that areas above the 10 m elevation had not been flooded (see maps of DLR, ZKI, 2008). Also, evaluation of the satellite data (Fig. 12) indicates that coastal areas above the 10 m elevation were not inundated by the December 26, 2004 tsunami. Therefore, in planning emergency measures such as shelters or evacuation routes, the 10 meter elevation should be considered as being a relatively safe elevation. Figure 13 shows this 10m contour elevation and the areas lower than 4 m above sea level. Based on SRTM height data (interpolated to 50 m ground resolution), LANDSAT ETM data (15 m resolution) and on available high resolution Google Earth data, areas above 10 m were further investigated.

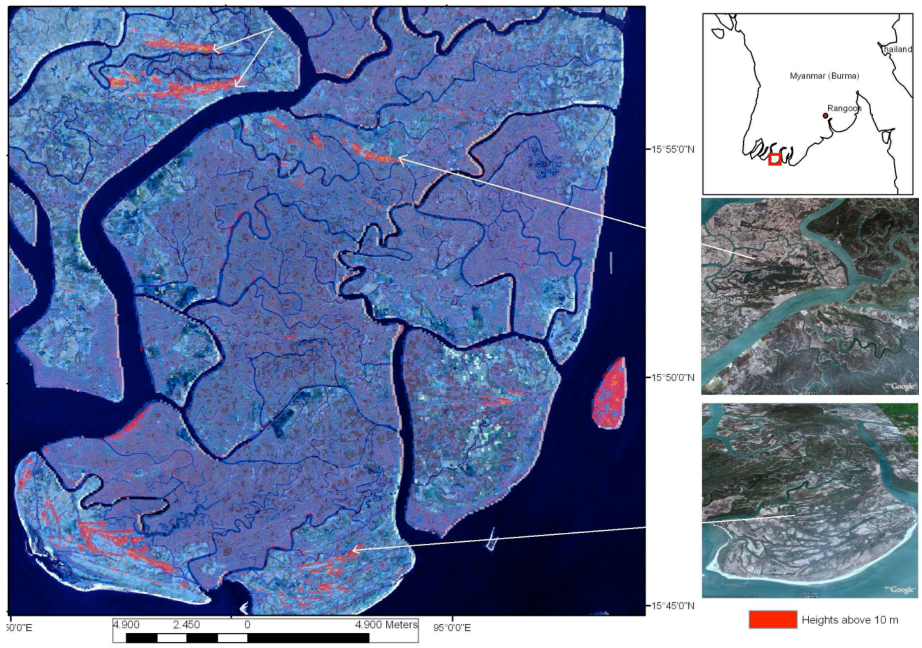

Fig. 12. Areas above 10 m height level

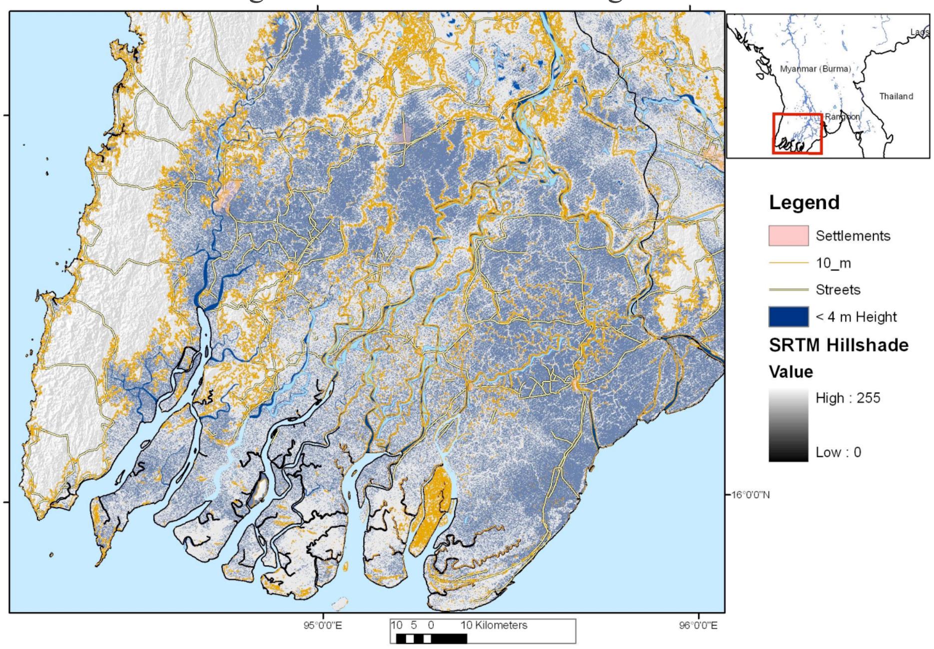

Fig. 13. Elevations below 4 m and 10 meters.

Surveys of the impact of severe and catastrophic floods, such as those caused by Cyclone Nargis, found that small scale flood protection measures such as raising the elevations of houses and shelters should be part of emergency planning (Thomalla et al., 2008). Also necessary is coordination of resources, technical assistance and proper hazard assessment. Measures to be taken should include: flood shelters, evacuation roads above flood levels, planning that takes into account all flood risks and actions that reduce the economic vulnerability of households to flood losses. Criteria for the selection of flood shelter locations should include:

- Elevation heights above 10 m;
- siting on a morphological watershed;
- a distance greater than 1 km from larger rivers;
- separation of shelters not to exceed 3 to 4 km (if possible).

Analysis of satellite imageries makes it obvious that in flat delta areas with dense river patterns the selection of locations to build shelters is difficult. However, analysis of the drainage patterns can help select small "islands" with elevations greater than 10 meters that could be used for such shelters. Thus, the best-suited locations for shelters were mapped in Figures 14 and15 and distances to each other were calculated (Fig. 16). However, with often-limited financial resources, a possible low or no cost emergency solution would be to construct such shelters with earth-bags (Fig. 17).

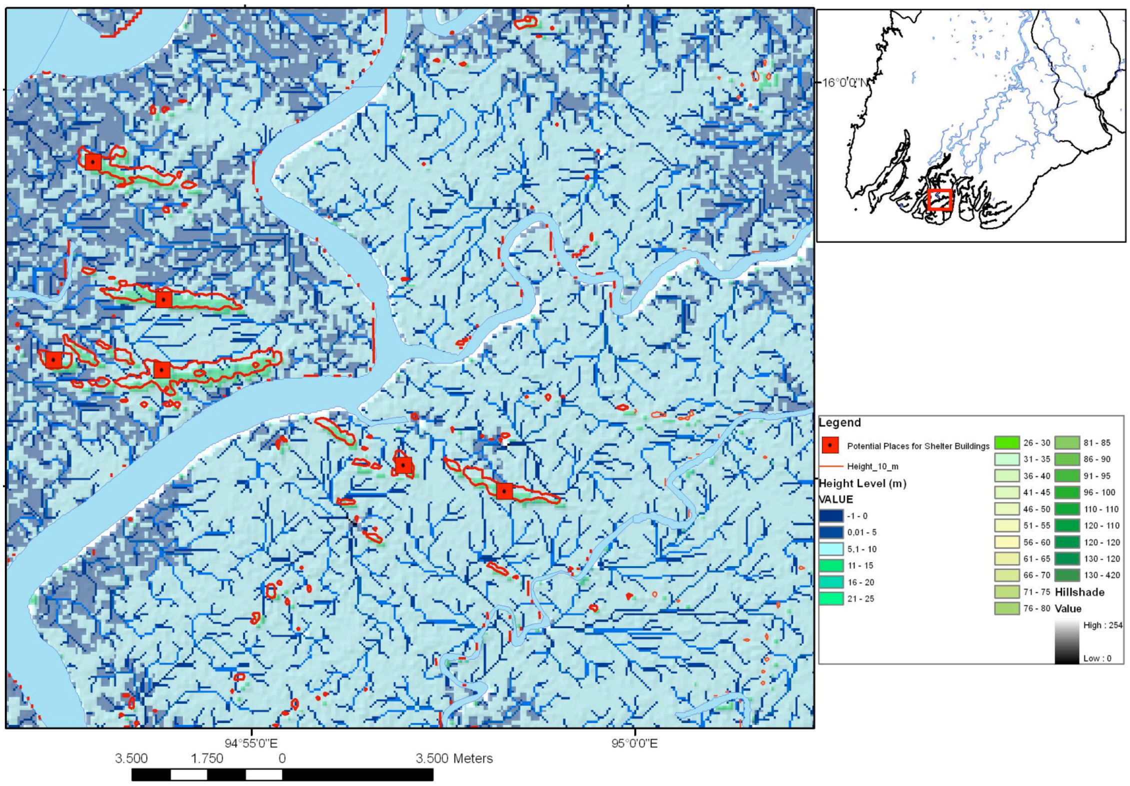

Fig. 14. Possible flood shelter locations with elevations above 10 m in height.
The drainage pattern was calculated based on SRTM data (interpolated to 50 m Grid resolution)

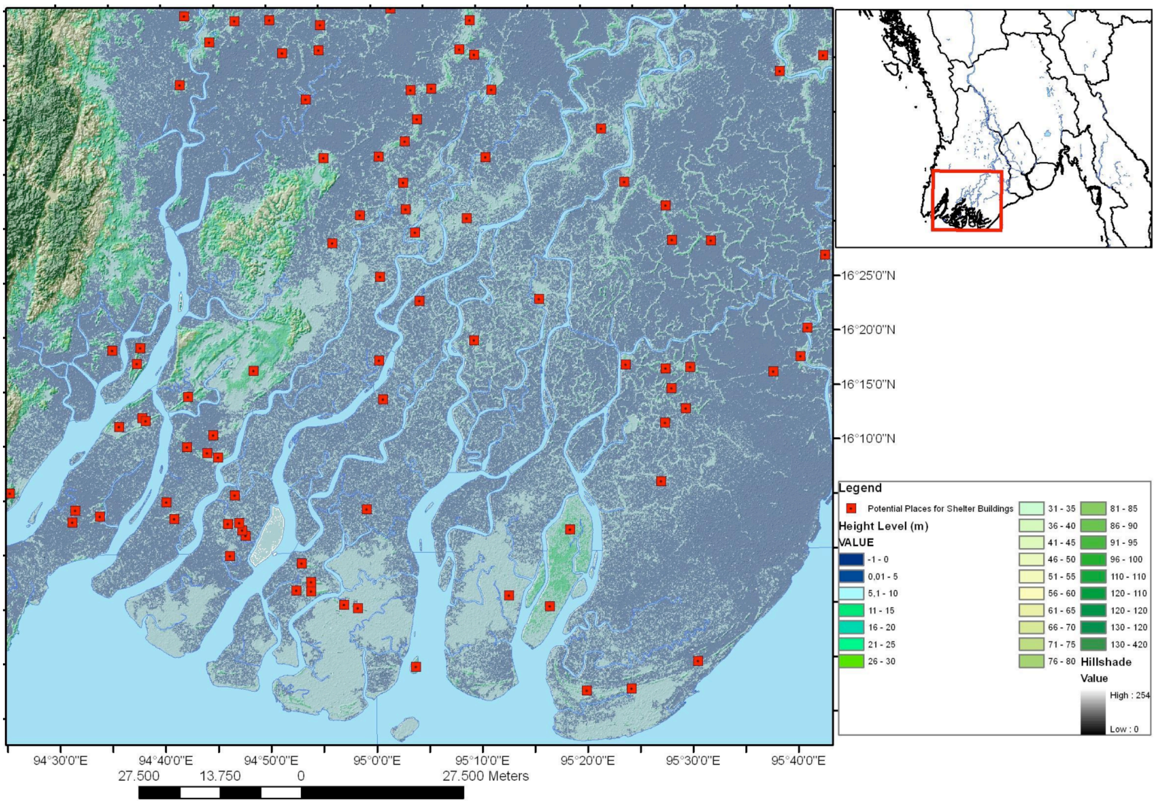

Fig. 15. Distribution of possible tsunami and cyclone surge shelter locations in the Irrawaddy delta area.

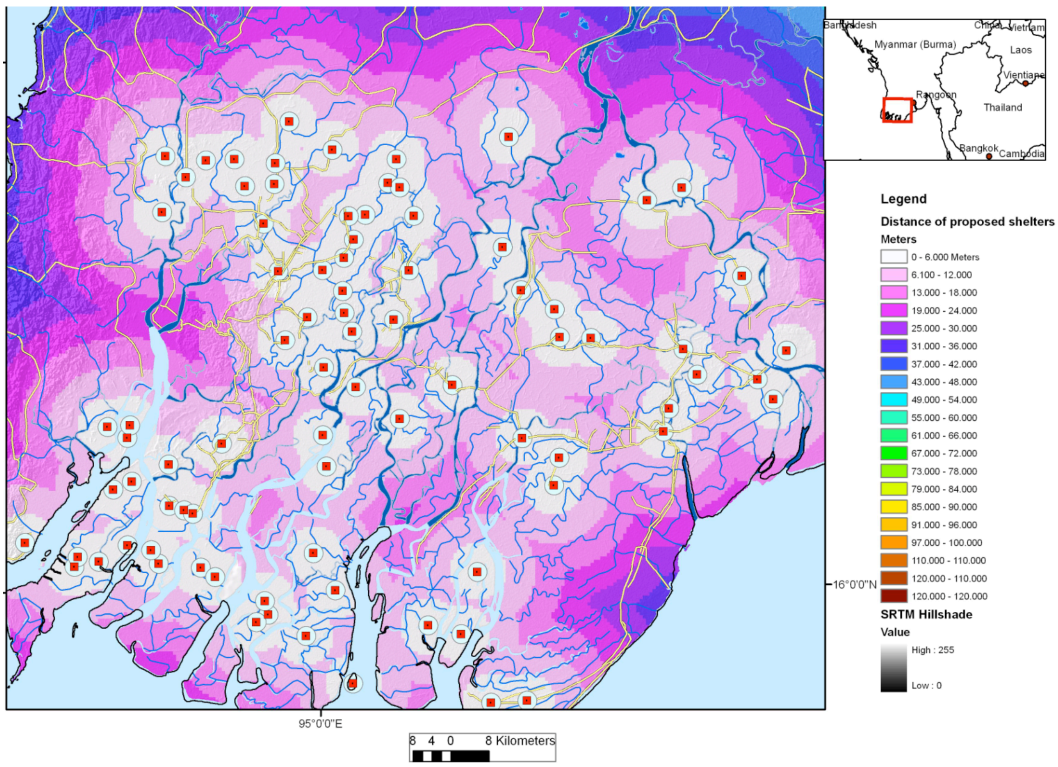

Fig. 16. Distance of potential shelter locations to each other.

Fig. 17. Proposed low cost shelter buildings (from Khalili and Hart, http://www.earthbagbuilding.com/articles/earthbagbuilding.htm)

Sandbags have long been used to form strong, protective barriers or for flood control. For this reason sandbags could be useful to create housing or shelters. The walls of such structures are massive, strong and resist severe weather and fire. Such structures can be erected simply and quickly with readily available components. Burlap bags have been traditionally used for this purpose, and they work fine until they rot. For more permanent structures, such bags should be covered with some kind of protective plaster (according to Khalili, see link in caption of Fig. 15). Still fire is one of the main causes of disasters in Myanmar as most homes, normally in close proximity to each other, are build with bamboo and thatch roofing – which are the cheap and readily available traditional building materials. (http://www.adrc.or.jp/countryreport/MMR/2002/CR_MMR2002.htm).

5. EVALUATION OF LANDSAT DATA FOR THE DETECTION OF ENVIRONMENTAL CHANGES

Since environmental conditions play a significant role in assessing flooding vulnerability, remote sensing data was used to analyze the distribution of vegetation and land use changes. The destruction of huge areas of coastal mangroves around the Irrawaddy River delta in Myanmar in the last few decades has amplified the flooding risk and has worsened potential devastation in this region. As people have been pushing closer towards coastal areas, the combination of new settlements and the ongoing deforestation for the creation of fishponds and farmland, has increased significantly the vulnerability to flooding by severe tsunamis or cyclones (UNOSAT, 2008). Lumbering operations have also reduced forest density. A comparative analysis of the LANDSAT imageries from the Irrawaddy-Delta clearly shows the decrease of the mangrove forest (red colours) between 1978 and 2000 (Fig. 18). Coastlines that have lost mangroves have also lost their protection from future tsunamis.

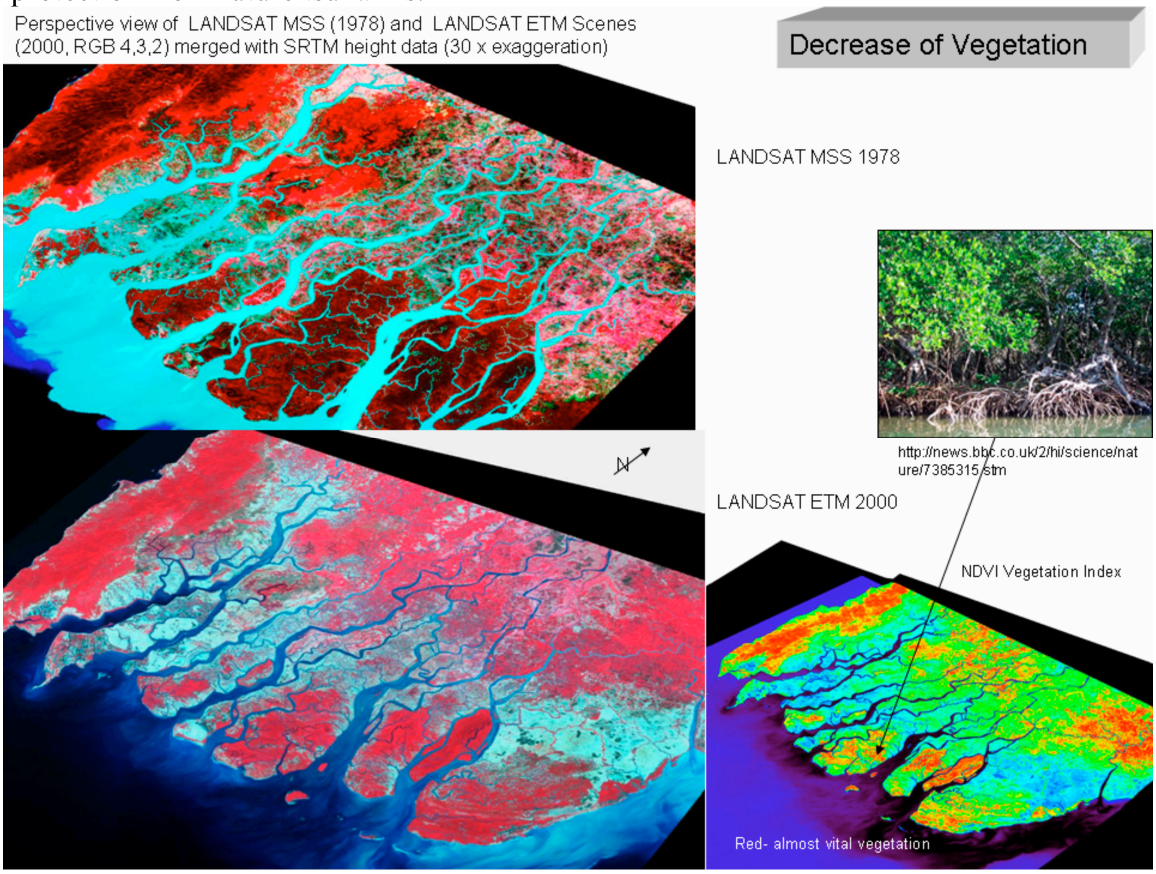

Fig. 18. LANDSAT imageries from 1978 and 2000 showing the decrease of forests

6. EVALUATION OF SRTM AND LANDSAT DATA FOR THE DETECTION OF AREAS SUSCEPTIBLE TO HIGHER EARTHQUAKE INTENSITIES AND TO EARTHQUAKE INDUCED SECONDARY EFFECTS

One important factor that must be accounted for in local earthquake hazard studies is a site's surface and subsurface conditions and expected response in the form of ground motions. Earthquake damage may vary locally, since it depends on the types of structures that are built and the subsurface ground conditions, proximity to faults and fractures, lithology, and the ground water table (Gupta, 2003). Remote sensing data can be used to map factors that are related to the occurrence of higher earthquake intensities and earthquake-induced secondary effects, such as liquefaction or landslides.

Past earthquakes indicate that damage and loss of life are mostly concentrated in areas that are underlain by deposits of soft soils and high ground water tables - as exemplified by the Mexico City earthquake of 1985 (Steinwachs, 1988; Pararas-Carayannis, 1985). Soft soils tend to amplify shear waves and ground shaking. Wetlands have a higher damage potential during earthquakes due to longer and higher vibrations. The fundamental phenomenon responsible for the amplification of ground motions over soft sediments is the trapping of seismic waves due to differences between sediments and the underlying bedrock. With horizontal stratigraphy, the trapping affects body waves, which travel up and down through the surface layers. When the structure is either two or three-dimensional, lateral heterogeneities are present (such as thickness variations in sediment-filled valleys), this trapping also affects the surface seismic waves. The interferences between the trapped waves lead to resonance patterns, the shape and the frequency of which are related with the geometrical and mechanical characteristics of the structure (Ehret & Hannich, 2004).

For example, although the epicenter of the 1985 earthquake was more than 300 Km away from Mexico City, the downtown area experienced surface seismic waves with accelerations of up to 17% g. with peaks concentrated at 2 sec. period. The maximum estimate of the Modified Mercalli intensity was IX. The extreme liquefaction and damage to new buildings which occurred in downtown Mexico City was attributed to the monochromatic type of seismic wave with a predominant period which caused 11 harmonic resonant oscillations of buildings and caused many to collapse (Pararas-Carayannis, 1985). The ground accelerations were enhanced within a layer of 30 ft. of unconsolidated sediments (of silt and volcanic clay) underneath downtown Mexico City, which had been the site of the historic Lake Texcocoa in the 15th Century. These example illustrate that indeed earthquake damage can be amplified by focused seismic waves along fault zones or layers of sediments. Seismic waves travelling in the subsurface might be refracted at sharp discontinuities such as faults and may have a cumulative effect that influences their intensity and therefore cause greater damage. Similarly, fault segments, their bends and intersections are more likely to concentrate stress and amplify intensity. Intersecting fault zones could cause constructive interference of multiple seismic wave reflections at the boundaries with surrounding rocks**.** The highest risk occurs at junctions of differently oriented, intersecting ruptures. Dense fault zones consisting of distinct segments can be considered to be more dangerous in terms of seismic risk than those where active ruptures are scattered over a larger area. Such aareas can be expected to experience greater earthquake intensities because of focused seismic wave amplification along intersecting fault zones and additional soil amplification. Lineament analysis can help detect near-surface faults and fracture zones and thus provide clues as to where cumulative effects can be expected. Fig. 19 shows the areas with the highest density of linear features assumed to be related to fault zones in South-western Myanmar.

Finally, the Irrawaddy delta was formed by deposition of sediments carried by major rivers and tributaries. The distribution of the sedimentary cover in this region can be correlated with areas having a slope gradient of less than 5°. By extracting elevations below the 4 m level, the location of areas with high ground-water tables can be determined. Slopes with higher slope gradient (> 20°) are generally more vulnerable to mass movements. Slope gradient maps help detect areas where such mass movements are likely to occur. Areas with intersecting, larger lineaments are probably exposed to relatively higher earthquake intensities by the stronger earthquakes.

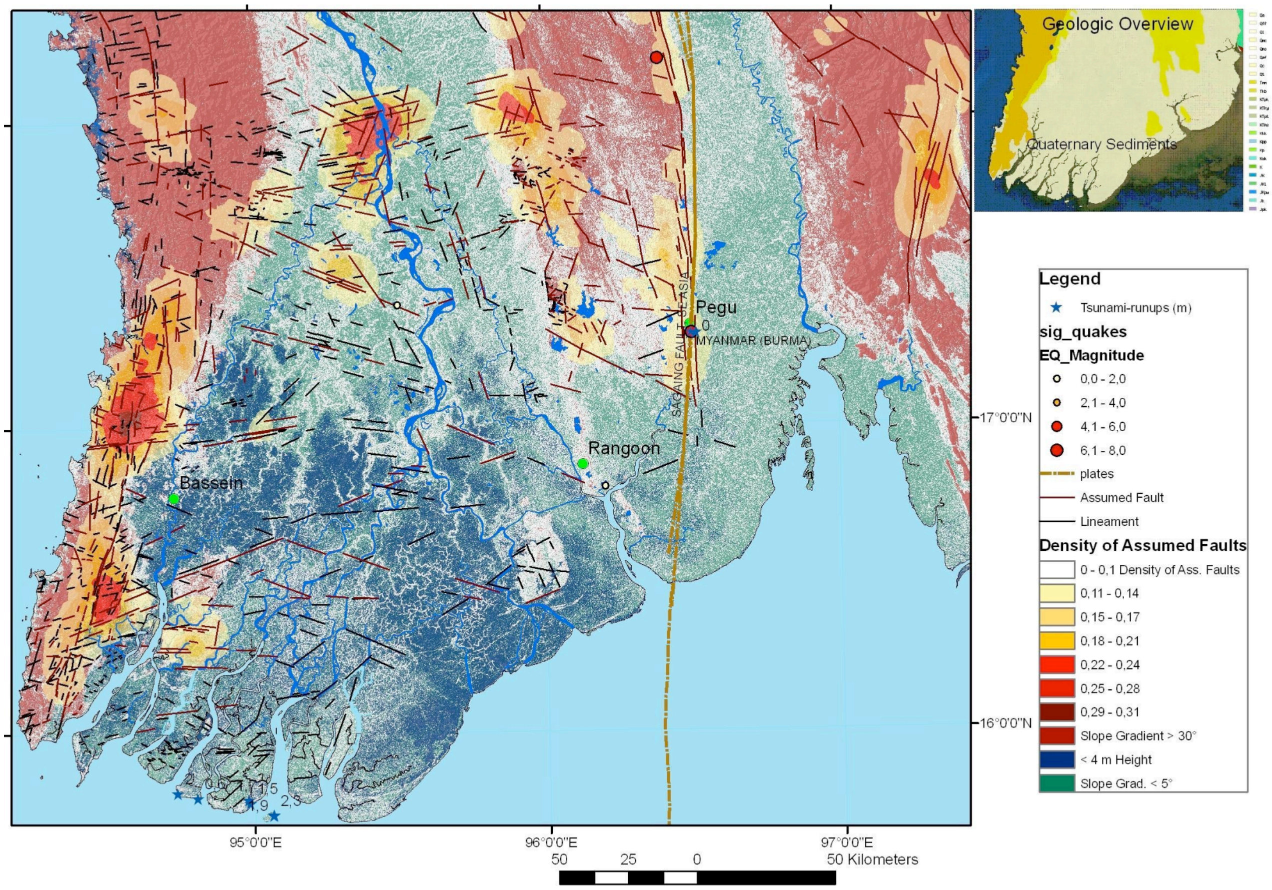

Fig. 19. Areas probably susceptible to higher earthquake intensities due to unconsolidated, sediments, near surface fault density and higher groundwater tables
Linear geomorphologic features are mapped as lineaments, often related to subsurface structures.
Geologic Overview according to One Geology Portal (http://portal.onegeology.org/)

7. CONCLUSIONS

The use of satellite SRTM, LANDSAT and GOOGLE EARTH data, integrated into GIS methodology, helped map the areas most susceptible to flooding in the southwest region of Burma/Myanmar. The analysis helped identify coastal areas that are vulnerable to potential tsunami and storm surge inundation. Such collection of data represents a promising new tool for examining and identifying suitable locations for cyclone flooding and tsunami shelters. The use of the described GIS methodology can help visualize some of the factors that influence local earthquake intensities or are capable of generating secondary hazards. The methodology can also help determine probable fault zones, areas of higher earthquake damage risk, areas with higher groundwater tables and higher slope gradients where mass movements could occur.

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ADDITIONAL NOTE

It was possible to use satellite data for mapping areas most susceptible to flooding using SRTM, LANDSAT and GOOGLE EARTH data, integrated into a GIS. Coastal areas can be identified that are prone to tsunami risk and storm surge.

These data form a promising tool for examining and identifying suitable locations for flood shelters. When converted into Google Earth kml-data format the proposed shelter points can be included directly into Google Earth and, thus, be used for planning purposes without costs for data and software.

Some of the factors influencing local site effects during earthquakes and earthquake induced secondary effects can be visualized using GIS methods and, thus, can contribute to the detection of areas of relatively higher earthquake damage such as areas with the highest groundwater tables, higher slope gradients or probable fault zones."