Hazard Profile of Myanmar

July, 2009

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Jointly Prepared by,

Department of Meteorology and Hydrology
Forest Department
Relief and Resettlement Department
Irrigation Department
Fire Servies Department
} Union of Myanmar

Myanmar Engineering Society (MES)
Myanmar Geosicences Society (MGS)
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Acronyms and Abbreviations

ADPC	:	Asian Disaster Preparedness Center
AMMH	:	ASEAN Ministerial Meeting on Haze
ASEAN	:	Association of South East Asian Nations
CL	:	Central Lowland
DMH	:	Department of Meteorology and Hydrology
EH	:	Eastern Highland
FAO	:	Food and Agriculture Organization
HFA	:	Hyogo Framework for Action
HTTF	:	Haze Technical Task Force
MAPDRR	:	Myanmar Action Plan on Disaster Risk Reduction
MES	:	Myanmar Engineering Society
MGS	:	Myanmar Geosciences Society
MIMU	:	Myanmar Information Management Unit
MOF	:	Ministry of Forestry
MOAI	:	Ministry of Agriculture and Irrigation
NCEA	:	National Commission for Environmental Affairs
NGO	:	Non-Government Organization
NOAA	:	National Oceanic and Atmospheric Association
NSDS	:	National Sustainable Development Strategy
RHAP	:	Regional Haze Action Plan
RRD	:	Relief and Resettlement Department
PGA	:	Peak Ground Acceleration
PONJA	:	Post-Nargis Joint Assessment
PSHA	:	Probabilistic Seismic Hazard Assessment
UN	:	United Nations
UNDP	:	United Nations Development Programme
UNEP	:	United Nations Environment Programme
UNESCAP	:	United Nations Economic and Social Commission for Asia and the Pacific
WFB	:	Western Fold Belt
WMO	:	World Meteorological Organization

Chapter 1

1. Hazard Profile of Myanmar: An Introduction

1.1 Background

The Union of Myanmar is exposed to multiple natural hazards including cyclone, earthquake, floods and fire. It has been periodically hit by natural disasters. Recent major disasters are as follows:

- Cyclone Nargis, 2008 which led to the loss of 84,537 human lives, 53,836 persons missing and damage to property to the tune of approximately 4.1 billion USD[1],
- Cyclone Mala, 2006 led to loss of 37 lives
- Indian Ocean Tsunami, 2004 claimed 61 lives and
- Taungdwingyi Earthquake (M: 6.8 RS), 2003 led to loss of 7 lives

Fire is the most frequent disaster in Myanmar and accounts for 71 percent of the disasters within the country. Storms and Floods account for 11 percent and 10 percent of the disasters respectively while other disasters including earthquake, landslide, etc accounts for 8 percent of the disasters.

Considering the multi-hazard proneness, it is important to profile the hazards of Myanmar as it will help in identification and prioritisation of future disaster preparedness and mitigation interventions.

The Post-Nargis Joint Assessment Report [PONJA] was prepared by the Tripartite Core Group (TCG) comprising the Government of the Union of Myanmar, the United Nations, and the Association of Southeast Asian Nations (ASEAN) to determine the full scale of the impact of the cyclone and requirements for both immediate humanitarian assistance needs and medium to longer term recovery, in the aftermath of the cyclone Nargis 2008. It identified five main pillars namely (a) Risk identification and assessment (b) Strengthening and enhancing emergency preparedness (c) Institutional capacity building (d) Risk mitigation investments and (e) Risk financing and transfer mechanisms along which disaster risk reduction activities can be aligned in Myanmar. Also, the Hyogo Framework for Action [HFA] Priority II ' Know the Risks and Take Action' emphasises that to reduce vulnerability to natural disasters, countries and communities must know the risks they face and take action based on that knowledge.

The 'Hazard Profile of Myanmar' report includes nine frequent hazards of Myanmar using existing information, studies and research on occurrence, causes, impacts, distribution and direction of future studies. The report has been prepared by a team comprising five Government Ministries and Departments and four non-Government Agencies.

1.2 Myanmar Overview

The Union of Myanmar is the largest country of South-East Asia located between 9^{0}32′ N & 28^{0}31′ N Latitude and 92^{0}10′E & 101^{0}11′E Longitude. It has been administratively divided into 7 Divisions and 7 States. The Divisions and States have been divided into Districts which in turn have been divided into Townships.

Myanmar is regarded as an agriculture based country as it accounts for 40.2 percent of the GDP[1]. It has a tropical climate with three seasons namely Rainy (mid-May to mid-October), Winter (mid-October to mid-February) and Summer (mid-February to mid-May). There is large variation in average precipitation as coastal areas receive average precipitation in the range of 4000mm to 5600 mm while central dry zone receives precipitation in the range of 600mm and 1400 mm.

The summary of key indicators of Myanmar is at Table 1.

Table: 1 **Key Indicators of Myanmar**

S/N	Indicator	Value
1	Total area	676,578 kms^2
2	Coastline	2400 kms
3	Number of Districts	67
4	Number of Townships	330
5	Estimated population[2] (2006-07)	56.52 mn
6	Percentage of population in rural areas	70
7	Population density (sq. kms)	77
8	Percentage of work force in agriculture	64.1
9	Gross Domestic Product (2005-06 at current producers price)	12,286,765.4mn kyats
10	Per capital GDP Product (2005-06 at current producers price)	221,799 kyats

1.3 Development of Hazard Profile of Myanmar: Process

The hazard profile report has been developed in consultative and multi-partnership mode. The scope of this report was discussed with Government Ministries and Departments, UN Agencies, ASEAN, Professional Associations and NGOs in briefing-cum-consultation workshops held on 18th–19th December 2008. Based upon observations from the Workshops, Landslides and Drought/Dry zones were included to augment the scope to nine natural hazards. The data was collected from the libraries of Ministries and Departments, UN Agencies and NGOs, research papers on hazards and websites. Also, Annual reports of Ministries and Departments and Country report of Myanmar on Disaster Management were referred.

[1] Myanmar Agriculture at a Glance 2008, Department of Agriculture Planning, Ministry of Agriculture and Irrigation, pg. 14.
[2] Statistical Yearbook, 2006, Central Statistical Organization.

Nine agencies namely Forest Department, Department of Meteorology and Hydrology [DMH], Irrigation Department, Relief and Resettlement Department [RRD], Fire Services Department, Myanmar Engineering Society [MES], Myanmar Geosciences Society [MGS], Myanmar Information Management Unit [MIMU] and Asian Disaster Preparedness Center [ADPC] were involved in preparing this report. They held four meetings between March and June 2009 to discuss review and finalise the report. The draft report was also shared in the Disaster Risk Reduction (Early Recovery) Working group meetings over February to June 2009.

1.4 Objectives and scope

The objectives of 'Hazard Profile of Myanmar' are as follows:

- To compile existing information on nine natural hazards of Myanmar and provide an overview
- To serve as one of the base documents for future in-depth hazard assessment and natural disaster risk profiling of Myanmar
- To give an overview of future areas of interventions in the context of risk assessment of Myanmar

The scope of report covers nine frequent natural hazards namely Cyclones, Droughts/ Dry zones, Earthquakes, Fire, Floods, Forest Fires, Landslides, Storm surges and Tsunamis. Its geographical scope covers the whole of Myanmar.

1.5 Structure of 'Hazard Profile of Myanmar' report

The Hazard Profile of Myanmar report has ten chapters. The hazards have been arranged in alphabetical order.

- **Chapter 2: *Cyclone*** includes Characteristics of the cyclones in the Bay of Bengal and the Frequency of their formation. It also includes a list of major cyclones which have previously hit Myanmar, and the probability of landfall along the Myanmar coastline based upon the past data, Recommendations for cyclone risk mitigation and preparedness have been made.
- **Chapter 3: *Drought/Dry zone*** includes list of 54 Townships spread across Mandalay, Sagaing and Magway Divisions which fall under the Dry zone. The profiling of the Dry zone areas include temperature, humidity, wind, rainfall patterns, vegetation, soil and land use. It also includes a list of factors contributing to the degradation of Dry zone.
- **Chapter 4 : *Earthquake*** includes the main causes of earthquakes within Myanmar, examples of past earthquakes, including their magnitude, location and their impact. It also includes a seismic zonation map for the whole of Myanmar and specifically of the Mandalay–Amarapura area located in central Myanmar. The areas of future research and seismic risk mitigation measures have also been recommended.

- **Chapter 5:** ***Fire*** analyses the trends of fires in terms of frequency and impact over the past 25 years. Fire hazard maps, based upon past data, categorises States and Divisions into High, Medium and Low risk zones and five Divisions have been identified under the High risk zone.
- **Chapter 6 :** ***Floods*** includes the different types of flooding in Myanmar, lists the major floods of Myanmar from 1997 to 2007 along with affected areas & impact which includes affected population, number of deaths and economic losses. The current flood risk reduction and preparedness initiatives in Myanmar and future steps towards risk reduction have been recommended.
- **Chapter 7:** ***Forest Fire*** captures causes of forest fire, its characteristics and hot spots. It also includes impacts of forest fire and risk reduction initiatives for forest fire in Myanmar.
- **Chapter 8:** ***Landslide*** includes causes of landslide, its frequency and impact in Myanmar. It also lists past landslides along with its location and triggering factors. The landslide risk mitigation measures have been identified.
- **Chapter 9:** ***Storm surge*** includes Causes and characteristics of storm surge in the context of Myanmar and their frequency including past occurrences. It also lists observed peak surge height along the cyclone Nargis track and storm surge hazard potential map of Ayeyarwady. The suggestions for Storm surge risk mitigation have been recommended.
- **Chapter 10:** ***Tsunami*** captures the impact of the Indian Ocean Tsunami, 2004 in Myanmar, and it highlights vulnerable locations including preliminary level zoning of Tsunami risks has along three coastal Divisions/State of Myanmar. It also lists a set of recommendations for Tsunami risk reduction.

It is important to note that the each chapter on specific hazard is an independent chapter in itself.

1.6 Limitations

The report does not take into account the climate change impact especially in relation to the hydro-meteorological disasters in the context of Myanmar. The report is purely based on secondary data. The historical data for certain hazards covers limited duration. The report also doesn't take into consideration wider economic and social impacts of these hazards.

It is expected that the report will serve as a base document for future risk assessment studies of natural hazards in Myanmar.

Chapter 2

2. Cyclones

Myanmar is exposed to the threat of cyclones and associated sea waves. Previous frequency of cyclones that made landfall on Myanmar coast was just once in about three years, but since the year 2000, cyclones crossed Myanmar coast every year. The cyclone tracks are unprecedented with respect to the Latitude and pattern of recurvature. Latitude of recurvature becomes lower year after year and drastic change of direction of the course took place within a few hours. In the case of Cyclone Nargis, the impact was extremely severe. It is due to very high vulnerability of the area. Enhancement of strong coordination among the responsible agencies, community participation and capacity building need to be expanded in the context of disaster risk reduction in Myanmar.

2.1 Causes and Characteristics of Cyclones in the Bay of Bengal

Myanmar is situated in the western part of the South-East Asia, bordering the Bay of Bengal and the Andaman Sea with its 2400 km long coast line. It is potentially rich with marine natural resources and also potentially threatened by the waves, cyclones and associated weather. As a tropical agricultural country, the majority of the people live in the fertile plain land which is often inundated by river floods and coastal areas exposed to stormy weather.

The Bay of Bengal of the North Indian Ocean stretches northward from the equator to the river mouths of Bramaputra, Ganges and Magna and eastward from Madras coast of India to Myanmar coast, in the tropical region. Though the area is not so vast, but it is a typical place for the tropical cyclone generation. The life span of cyclone is rather short, less than a week. Cyclones, once generated, move generally westward heading to India and if there is slight re-curvature, it heads towards Bangladesh. If the re-curvature is sudden, then it moves towards the Myanmar coast. The more the degree of re-curvature is drastic, the higher probability of its crossing the Myanmar coast at lower Latitudes. Hence, once there is cyclone formation in Bay of Bengal, at least one country is likely to suffer unless the cyclone filled up in the open sea, which is not often. The cyclone is accompanied by three destructive forces: strong winds (as high as 120 mph), heavy rains (more than 5 inches in 24 hours) and storm surges (higher than 10 feet). Storm surge is the main cause of damage, which depends on the vulnerability of the place of landfall. Annually, there are approximately 10 tropical storms in the Bay of Bengal from April to December. Severe cyclones occurred during the pre-monsoon period of April to May and post-monsoon period of October to December. The tropical storms that form during the monsoon period June to September are weak and have a short life span. In the post-monsoon period, remnants of typhoons in the South China Sea regenerate into storms in the Bay of Bengal. Hence, the Bay of Bengal has two cyclone seasons annually about a month before and three months after the South-West monsoon.

2.2 Frequency and Impact

During the period 1887 to 2005, 1248 tropical storms were formed in the Bay of Bengal, of which 80 storms (6.4 percent of total) hit the Myanmar coast. May and April account for 30 and 18 percent of the cyclones, respectively, while October and November each accounts for 18 percent cyclones that hit Myanmar. The month-wise break-up of cyclone formed in Bay of Bengal from 1887 to 2005 is at Table 2.

Table 2 Month-wise break-up of cyclone formed in Bay of Bengal

Month	No. of Cyclone formed in Bay of Bengal along with % of total	No. of Cyclone which hit Myanmar along with % of total
JAN	16 (1%)	2 (2%)
FEB	3 (0%)	1 (1%)
MAR	8 (1%)	-
APR	32 (3%)	15 (19%)
MAY	89 (7%)	24 (30%)
JUN	111 (9%)	1(1%)
JUL	180 (15%)	-
AUG	192 (15%)	-
SEP	209 (17%)	-
OCT	190 (15%)	14 (18%)
NOV	141 (11%)	14 (18%)
DEC	77 (6%)	9 (11%)
Total	**1248 (100%)**	**80 (100%)**

As 24 out of 89 cyclones crossed Myanmar coast, the Department of Meteorology and Hydrology assumes the month of May as the highest possible period for the cyclone to cross Myanmar coast. However, the post-monsoon period is not less important, considering the fact that the cyclone in November 1970 in Bangladesh claimed 300,000 people.

During the period of 1947 to 2007, 34 cyclones crossed Myanmar coast, of which 7 cyclones claimed lives, mainly due to the accompanying storm surge. The maximum death toll was 1037 during Sittwe Cyclone in May 1968. The Ayeyarwady Division was affected by the cyclone of May 1975 when 304 people died and Mala Cyclone of April 2006 claimed 37 lives.

The details of cyclones in Myanmar from 1947 to 2008 are at Table 3.

Table 3 **Devastating Cyclones of Myanmar (1947 -2008)**

S/N	Dates of TRS in the Bay of Bengal	Place of Landfall	Loss of human lives and property
1	6-8 October 1948	Sittwe	A few people dead, 10 million kyat damaged.
2	22-24 October 1952	Sittwe	4 dead in Yangon, damage in Sittwe and Pathein estimated 10.0 million kyat.
3	15-18 May 1967	Kyaukpyu	Damage in Pathein District 10 million kyat and in Kyaukpyu District 20.0 million kyat.
4	20-24 October 1967	Sittwe	2 dead with 90% houses destroyed, more than 10.0 million kyat lost in Sittwe, 90% houses destroyed in Rathey Taung and Kyauktaw, more than 100 people dead and more than 1000 heads of cattle lost with damage estimated at 5.0 million kyat in Monywa District, Water level of Upper Chindwin River rose 10 feet over night.
5	7-10 May 1968	Sittwe	1037 dead, 17537 cattle lost, 57663 Houses destroyed, estimated damage 10.0 million kyat.
6	5-7 May 1975	Pathein	303 dead, 10191 cattle lost, 246700 homes destroyed, estimated loss 446.5 million kyat.
7	12-17 May 1978	Kyaukpyu	90% destroyed, estimated damage 200.0 million kyat.
8	1-4 May 1982	Gwa	90% destroyed in Gwa, 27 dead in States and Divisions, damage estimated 82.4 million kyat.
9	16-19 May 1992	Thandwe (Sandoway)	27 dead in Man-Aung, Rambre, Kyaukpyu, Thandwe, Taungote and damage cost more than 150.0 million kyat.

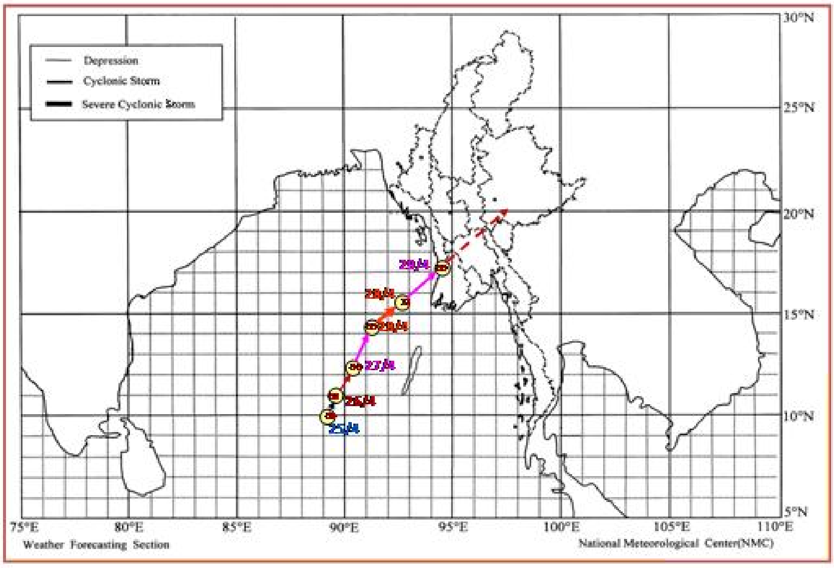
10	2 May 1994	Maundaw	Estimated damage 59.0 million kyat.
11	25-29 Apr. 2006 (Cyclone Mala)	Near Gwa	37 people dead and damage cost 428.56 million kyat[7]
12	28 Apr. 3 May 2008 (Cyclone Nargis)	Ayeyarwady & Yangon	138,373 people missing or dead, 300,000 cattle killed, houses and over 4000 schools in more than 6000 villages destroyed, damage cost 13 trillion kyat[8]

2.3 Comparative Analysis of Two Recent Cyclones

The tropical storms comprise approximately 10% of the disasters of Myanmar as per the data from 1996 to 2005. The cyclone track is very important as even for the same intensity of cyclones, the damage varies depending on the vulnerability and capacity of the areas falling under the cyclone.

The track of cyclone Mala is shown at Figure 1. The cyclone direction of movement has the eastward component since the cyclone was in its initial stage near Lat 10^0 N. With a little increase east component, the cyclone took landfall near Gwa on the 29 April 2006 with minimum central pressure of 960 hPa. The cyclone impact was direct on the thinly populated, rugged coastal strip and slightly felt by the northern part of Ayeyarwady delta.

Figure: 1 **Track of Cyclone Mala, 2006**

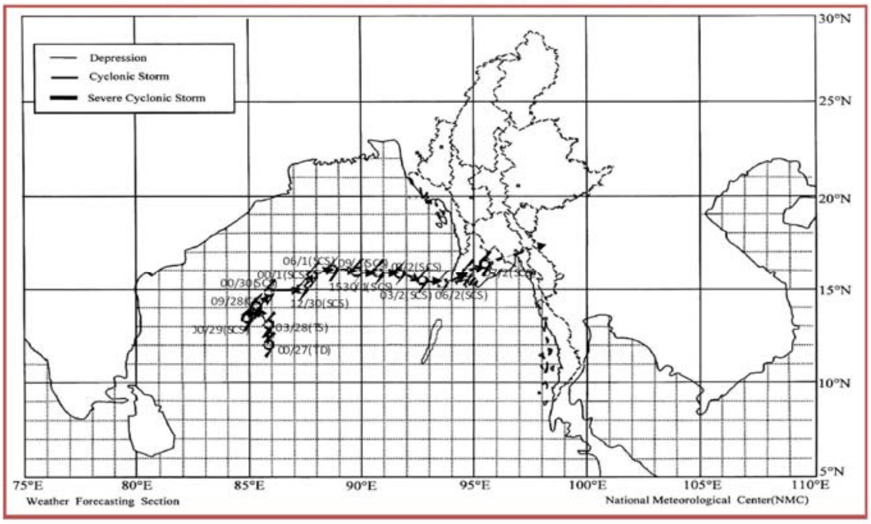


7 Relief and Rehabilitation Department (2009)
8 Department of Meteorology and Hydrology (2009)

However, the cyclone Nargis initially moved north for a few degrees up to Lat. 16^0 N and re-curved suddenly to the east and it skirted along delta coasts of Ayeyarwady and Yangon Divisions for more than 24 hours, without practically weakening. The track of cyclone Nargis is at Figure 2.

Figure: 2 Track of Cyclone Nargis, 2008

Track of severe cyclone "NARGIS" in May 2008 in the Bay of Bengal



Note that the cyclone track eastwards is the lowest latitude ever taken by the cyclones before.

The death toll and damage have been extremely high in the case of Cyclone Nargis in 2008 compared to the previous cyclones. The comparative analysis of cyclone Mala of 2006 and cyclone Nargis of 2008 is at Table 4.

Table: 4 Cyclone Mala vis-à-vis Cyclone Nargis

S/N	Indicator	Cyclone Mala	Cyclone Nargis
1	Life span	25-29 April 06	28 Apr-3 May 08
2	Re-curvature pattern	Steadily re-curving north-east	Suddenly turned from the north to the east
3	Early warning	Issued timely	Issued timely
4	Duration of landfall	10 hrs	24 hrs
5	Maximum wind at landfall	150 mph	100-150 mph
6	Maximum surge height	4.57m	7.02 m
7	Population density	Thin	Very dense
8	Additional hazard next to strong winds, storm surge and heavy rain	Tornado	Multitudes of flood occur from multitude of estuaries and rivers in delta along the cyclone track
9	Knowledge of storm surge	By experience	Practically poor

10	Topography good for shelter	Available within a short distant from the sea shore	Not available within a hundred km from the sea shore
11	Route for evacuation	Relatively less difficult	Difficult
12	Death toll	37	138373 (Includes 53,836 missing people)
13	Damage and losses	428.56 million kyat	4.5 trillion kyat

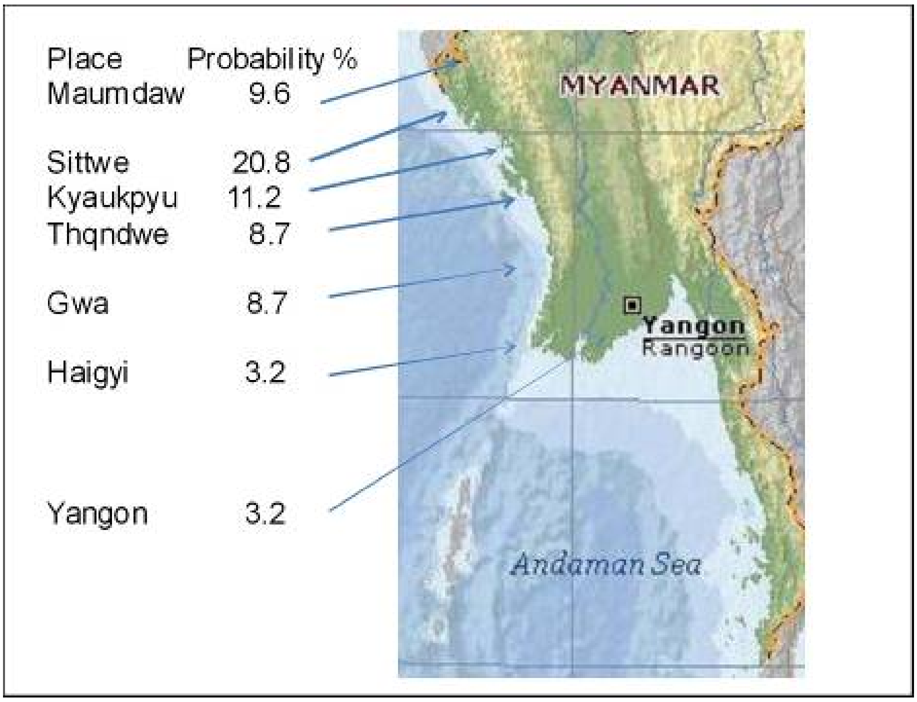
The significant differences between the two cases are: the high population density, poor knowledge of storm surge in the community, the topography i.e. flat land, and almost no place which can act as cyclone and storm surge shelter and the evacuation route.

The eleven elements of vulnerability, as per Dr. Tun Lwin (2008), are namely the severity of storm while crossing coast, moving along the coast line, across a very low lying area, one of the most populated region, with many tributaries, no storm shelter and high ground, no hazard map and risk assessment had done yet, no past experience and extremely hard to convince local people, low risk knowledge of disaster especially on storm surge, poor mobility (mostly water ways along small canals by boats) and the non-linear interaction between the wind induced waves, topography and high tides of the area is extremely high.

2.4 Looking Forward

According to the 1947-2008 data, 35 cyclones have made landfall on Myanmar coast with the highest probability, in percentage terms, at Sittwe (20.8%), followed by Maundaw (9.6%) and decreasing towards south (3.2% at Ayeyarwady delta). Figure 3 illustrates the probability (9 in percentage terms) of cyclone landfalls at various sites along Myanmar coasts. The Bay of Bengal cyclones have never hit the southern coast in Mon State and Tanintharyi Division in living memory of Myanmar.

Figure 3 Cyclone landfall probability along Myanmar Coast (1947-2008)



However, because of the southward shifting of the cyclone track (eg. the Cyclone Nargis), there is uncertainty that cyclone will not cross the southern coastal zone of Myanmar in near future. The maximum observed storm surge height was 7 m at Pyinsalu and 6.7 m at Kyonkadun of Ayeyarwady delta due to cyclone Nargis and along Rakhine coast approximately 4 m was observed.

In order to mitigate cyclone risk and make coastal communities of Rakhine State, Ayeyarwady Division and Yangon Division safer, there is in need of short term, medium term and long term plans through structural and non-structural measures.

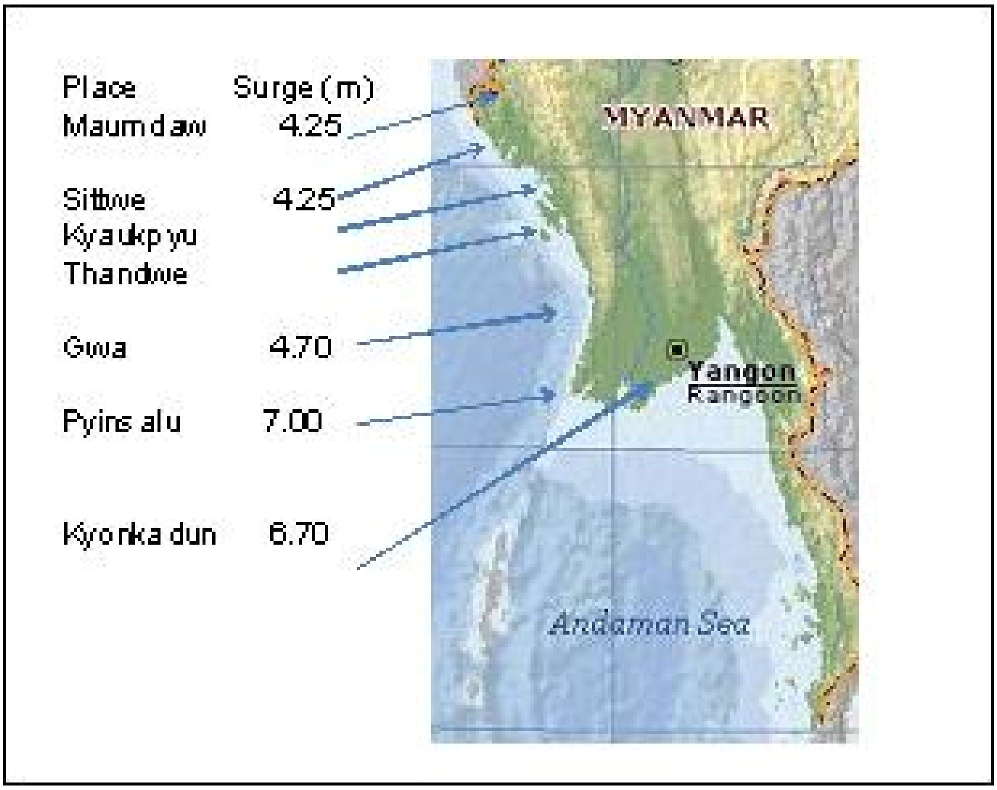
The local communities should be encouraged or supported to create the following structural measures:

- Identification or construction of safe shelters, which include religious monument etc. for each community within the easy access of community. It can serve as a community center for various activities during normal times and storm shelter during stormy weather and floods,
- Tree plantation around the village which can act as wind breaker to reduce the severity of wind and as well as floods during the stormy weather,
- Community should be educated and encouraged to live in storm resistant houses and engineered building,

- Patches of mangrove forests should be created along the water front of the sea and rivers,
- Residential areas should be allowed only at a safe distance from the water front of the sea and river,
- Mass awareness on do's and don'ts of cyclone should be periodically undertaken,
- Volunteer youth force should be created and trained in disaster management,
- Joint study/ research schemes by Myanmar and international institutions may be considered for cyclone in the context of capacity building and human power development,
- Cyclone risk map of Myanmar should be developed.

The Natural Disaster Management Committee of Myanmar Engineering Society can play a catalyst role in coordination with related government agencies of Myanmar particularly Department of Meteorology and Hydrology and also with the international organizations such as World Meteorological Organization (WMO), UNESCAP, ASEAN, ADPC and other UN Agencies.

Figure 4 Storm surge observed along Myanmar Coast (1947-2008)



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CHAPTER 3

3. Drought/Dry zone

3.1 Introduction

Myanmar is regarded as an agriculture based country as it accounts for 40.2 percent of GDP and employs 64.1 percent of the work force[9]. Its geographical area can be divided into five major physiographic units[10] namely:

I. The Indo-Burman (Myanmar) Ranges
II. The Arakan (Rakhine) Coastal Lowlands
III. The Sino-Burman (Myanmar) Ranges
IV. The Inner Burman (Myanmar) Basin
V. The Eastern Himalayas

The first four units run more or less north to south while the fifth unit i.e. the Eastern Himalayas runs west to east in the northern part of the country. The S-shaped Indo-Burman (Myanmar) Ranges starts from east of the lowlands of Ganges and Brahmaputra and extends 2000 km. to the south upto the Andamans. It decreases in altitude and spreads towards south. The narrow Arakan (Rakhine) Coastal Lowlands on Bay of Bengal are geographically part of the Indo-Burman (Myanmar) Ranges. The Sino-Burman Ranges is in eastern parts of the Myanmar. The Inner Buman (Myanmar) Basin lies between the Indo-Burman (Myanmar) Ranges and Sino-Burman (Myanmar) Ranges and it widens towards south.

3.2 The Dry zone

The Dry Zone is a part of the Central Inner Burman (Myanmar) Basin located between 19^0 to 23^0 N and between 94^0 to 96^0 E. It covers an area of 67,700 sq km, 10 percent of country, partially over Sagaing, Magway and Mandalay Divisions. It is 403 km. north-south while 120 km. east-west. The dry zone is surrounded on three sides by mountain ranges and opens towards South. It consists of undulating plateau with elevation of 150-200 m and a number of steep hilly chains rise above the plateau with peaks of hill reaching altitude of 300-400m.

3.2.1 Zonation Index[11]

The arid and semi-arid zones are characterized by an extreme diversity such as soils, geomorphology, vegetation, water balance and human activities, so it is difficult to make

[9] Sanyu Consultants Inc.
[10] FAO, Yangon, Myanmar
[11] HDI-III, UNDP, FAO, Yangon, June 2001

classification. Several indexes such as Rainfall index by Le Houerou-1973, Thornthwaite classification, Papadakis climatological classification, etc. have been developed. As per the Thornthwaite classification, the dry zone predominantly falls under the arid zone, while Papadakis classifies region between Magway and Myin Gyan (central dry zone). Le Houerou-1973, classification based on mean annual rainfall categories into semi-arid zone. Overall, the dry zone falls under arid zone to semi-arid zone.

The dry zone comprises 54 townships in 13 districts spread across 3 Divisions namely Sagaing (Lower), Mandalay and Magway as per the Dry zone Greening Department. Division-wise list of districts and townships under the central dry zone is at Table 5.

Table : 5 Dry zone Divisions, Districts and Townships

Sr. No.	Division	District	Township
1	Magway	Magway	Magway
2			Taungdwingyi
3			Natmauk
4			Myo Thit
5			Yaenanchaung
6			Chauk
7		Min Bu	Min Bu
8			Salin
9			Pwint Phyu
10			Nga Phe
11		Thayet	Thayet
12			Sinpaungwe
13			Mindon
14			Kan Ma
15			Aung Lan
16			Min Hla
17		Pakkoku	Pakkoku
18			Seik Phyu
19			Pauk
20			Yesagyo
21			Myaing
22	Mandalay	Nyaung Oo	Nyaung Oo
23		Myin Gyan	Taung Thar
24			Nga Zun
25			Kyauk Padaung
26			Nadoegyi
27			Myin Gyan
28		Meikhtila	Meikhtila

29			Mahlaing
30			Wan Twin
31			Tharzi
32		Yamaethin	Yamaethin
33			Tat Kone
34			Pyaw Bwe
35		Kyauk Se	Kyauk Se
36			Tadar Oo
37			Myit Thar
38	**Sagaing**	Mon Ywa	Mon Ywa
39			Palae
40			Salingyi
41			Butalin
42			Chaung Oo
43			Yinmarpin
44			A Ya Daw
45		Sagaing	Sagaing
46			Myin Mu
47			Myaung
48		Shwe Bo	Shwe Bo
49			Kant Balu
50			Wet Let
51			Khin Oo
52			Depaeyin
53			Yae Oo
54			Ta Sei

However, based on isohyets (region below 40" isohyets) 60 townships in Magway, Mandalay and Sagaing have been identified under Dry zone[12]. Some of these towns are fully under while a few are partially in Dry zone. Division-wise number of townships under dry zone is at Table 6.

Table: 6 Divisions and Townships, and extent of dry zone

Division	Total Townships	Townships in Dry zone	Percentage of Division in dry zone	Are of Township in Dry zone (sq. mile)
Sagaing	38	19	20.22	7,388.5
Mandalay	39	23	68.00	8,872.0
Magway	25	18	56.47	9,819.5
Total	**102**	**60**	**-**	**26,080**

[12] Proceedings of the National Workshop on Integration of Myanmar's Agriculture into the ASEAN, 17-18 March 2004, TCP/MYA/2902, Yangon Myanmar (page 86)

3.2.2 Temperature, Humidity and Wind in Dry zone

The temperature of dry zone is very high and April and May are the hottest months. Some of the locations record temperature over 43^0 C, while the highest mean temperature is around 32^0 C and range between maximum and minimum temperature is 15^0 C. The average annual humidity is 63 percent but in hottest months (April and May) it drops to 42 percent, while in wettest months it shoots up to 80 percent.

The southwest monsoon[13], without monsoon winds, starts in late March or early April with local turbulence that includes tornadoes and cyclones, which causes havoc with their spiraling winds up to 200-300'. It is laden with sand and top soil and one of the important causes of the loss of top soil in dry zone. The south and southwest monsoon arrives by April end or early May laden with moisture from the sea. The monsoon period starts from mid June. From October end to mid-March, is the season for northeast monsoon, which is dry and cool.

3.2.3 Precipitation pattern in Dry zone

The precipitation in dry zone is controlled by the monsoon circulation system. The mountain ranges running north-south present effective barriers to the South-West monsoon in summer and North-East monsoon in winter, thus the central region falls under rain shadow zone. The annual precipitation in dry zone is less than 750 mm, while the national average precipitation is 2353.06 mm. The dry zone receives 3.2% of the country's total rainfall, while geographically it comprises 10% of the total area of the country. The annual average precipitation over 10 years in dry zone at selected stations is at Table 7.

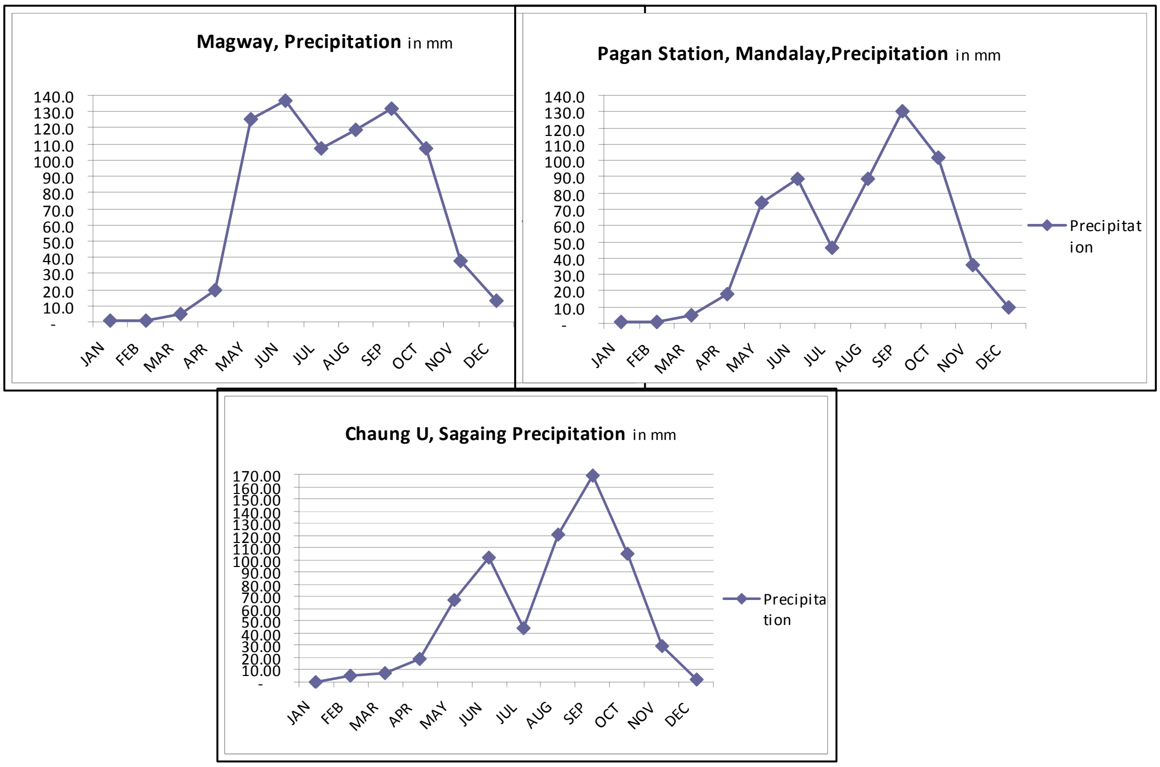
Table: 7 Annual average precipitation in Dry zone

Division	Station	Average annual precipitation *in mm*
Magway	Seikpyu	612.90
Magway	Myaing	509.02
Magway	Chauk	635
Magway	Sale	553.72
Magway	Aunglan	980.44
Average Magway		***658.22***
Mandalay	Nayung Oo	624.84
Mandalay	Mandalay	830.58
Mandalay	Meikhtila	845.82
Mandalay	Myingyan	655.32
Mandalay	Hlaingtet	914.4
Average Mandalay		***774.19***
Sagaing	Monywa	820.42
Sagaing	Shwebo	904.24
Average Sagaing		***862.33***
Average of precipitation of dry zone		**740.56**

[13] See Chapter "Cyclone"

The precipitation is concentrated in May to June and August to November[14]. In July, relatively dry spell exists when dry desiccating winds blow from the south. On average, this dry spell lasts from 21st June to 20th July. Also, the length of dry spell is variable. The month-wise precipitation at three townships/stations in three dry zone divisions are at Figure 5.

Figure: 5 Month-wise rainfall in Dry zone Division



3.2.4 Vegetation in Dry zone

The natural floras are dry shrubby thickets (dry savanna), with small thorny acacias and Euphorbia, cacti and short grasses. Apart from the short grasses, there is no herbaceous vegetation and it dies in the dry season. The margins of the Dry zone have an almost continuous ring of dry tropical shrub savanna, with grasses and deciduous trees. The slopes of Mount Popa are covered with dense forests as precipitation is considerably higher compared to surrounding plains.

The landscape of dry zone is a mixture of the woodlands, bushes, grazing lands and arable lands which occur as separate forms of land use. Trees are hardly grown on the agriculture land. The secondary vegetation such as shrubs and grasses can be found on the stony volcanic plateau of Lagyi and west of Songon, Mandalay (Kyaukpandaung Township). Eucalyptus and white-bark Acacia are along the main roads, planted under the reforestation

[14] FAO, Yangon, Myanmar

'Greening of the Dry zone' program. Toddy palms can be found throughout and sometimes on field limits, which are used for jaggery and toddy wine.

3.2.5 Soil types

Geologically, the Dry zone is relatively recent with an estimated age of 15 million years. The strong winds and other factors, the top soil has eroded, thus exposing the underlying bedrock which is predominantly sedimentary. The common rock types are sandstones, shale, and slates. The resulting sandy loams and loamy sands are thin and poor in nutrient. The rich volcanic soils can be found near Mount Popa, which is an extinct volcano.

Following soils can be found across the dry zone:

- Yellow-brown forest soil
- Dark compact clays
- Red brown stony dry savannah soils
- Gravelly compact soils
- Alluvial soils
- Mountain red-brown forest soils
- Mount Popa soil

3.2.6 Land use

In Myanmar, 12 percent of the land is under cultivation, 16 percent under fallow and 74 percent under forests and others. Approximately 35 percent of the cultivable land is in dry zone. Paddy being the main crop is cultivated on approximately 60 percent of the cultivable land. Other gain crop like millet and maize cover 5 percent, oil crops account for 15 percent, legumes for 7 percent and rest include fruits, rubber, tea, etc.

Dry zone is the most important vegetable oil production region, which includes sesame and sunflower. Other important crops are rice, millet, cotton and tobacco. All suitable land is cultivated and there is hardly any scope for expansion. The farmers of this zone are mainly commercial, cultivating a variety of crops in a double cropping and rotational system. Intercropping is widely practiced in Chaung U, Sagaing and Kyaukpandaung, Mandalay while less in Magway.

3.3 Soil Degradation

The soils have eroded to varying degree and at some places it has completely removed by water and wind erosion. The soil erosion is intensive and rapid as a result of heavy shower and low degree of compaction of rocks. The surface runoff has been estimated to be 30 percent. Removal of the natural savanna vegetation quickly leads to erosion, which is more intensive at the start of the monsoon rains on bare soils.

3.4 Wind Erosion

Wind erosion is a problem of arid and semi-arid regions with a dry season of more than 6 months. In such areas, natural vegetation is steppe-like with large parts of bare soil. The fine participles of the soil such as clay, silt and organic matter are blown away by strong winds while coarse materials are left behind. The wind erosion starts at a wind speed of 25 km/hour. Sand gains of 0.5- 2 mm are rolled, fine sands of 0.1-0.5 mm are transported over few metres and finer particles such as clay, silt and organic matter go into suspension in the air. In Magway, dust cloud or 'Red sky' during March and April is due to this suspension.

3.5 Deforestation[15]

The Dry zone was once a heavily forested region. The heavy cutting of forests to fire brick kilns for construction of stupas and pagodas are said to be primary cause of forest destruction since 11 AD. The inevitable consequence of forest destruction was drastic change in climate, gradually moving from bad to worse. Other main causes of deforestation in Dry zone can be grouped into the following heads:

- Population growth
- Agricultural encroachment
- Increasing livestock population
- Increasing demand for fuel wood

The population, as well as population density, increased in all three Dry zone divisions. The population density from 200 persons per sq. miles in 1941 increased to 442 persons per sq. miles in 1993. It led to encroachment on reserves and protected areas. The increased population led to extension of agriculture field and thus encroachment of reserved and protected forests. In addition, it also led to increased demand for domestic fuel as well as industrial usage.

The increase in livestock population led to increased grazing browsing which are destructive to plantation and plant growth. The natural regeneration is destroyed through trampling. The 99.6 percent of the national sheep herd, 71 percent of goats and 40 percent of cattle are located in Dry zone. The jaggery production from palm tree is very common and it requires 0.342 million tons of wood annually.

[15] Proceedings of the National Workshop on Integration of Myanmar's Agriculture into the ASEAN, 17-18 March 2004, TCP/MYA/2902, Yangon Myanmar (page 90)

3.6 Concluding remark

The Dry zone of Myanmar is located in central part of the country in Magway, Mandalay and Sagaing (lower) Divisions and covers approximately 10 percent of total area of the country. It falls under arid to semi-arid zone as per different zonation, criteria. As it is located in rain fed area, the average annual precipitation is below 1000mm. Fifty-four Townships spread across 13 Districts in 3 Divisions falls under the Dry zone as per the Dry Zone Greening department. Some other reports have identified 60 Townships under dry zone.

The deterioration of natural resources such as soil erosion and deforestation has made the agricultural production base unstable. The main reasons include increased human as well as cattle population and demand of fuel wood for domestic as well as industrial use. The natural resources of Dry zone are being depleted more rapidly than nature can renew itself. The Dry zone map is at Figure 6.

Figure 6 Dry zone map, Myanmar

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Chapter 4

4. Earthquake

4.1 Causes and Characteristics

Geographically, a larger part of Myanmar lies in the southern part of the Himalaya and the eastern margin of the Indian Ocean, hence exposed to bigger earthquakes. Myanmar is earthquake-prone as it lies in one of the two main earthquake belts of the world, known as the Alpide Belt that starts from the northern Mediterranean in the west, and then extends eastwards through Turkey, Iran, Afghanistan, the Himalayas, and Myanmar to finally Indonesia. The seismotectonics of Myanmar is at Figure 7.

Earthquakes in Myanmar have resulted from two main sources namely:

- The continued subduction (with collision only in the north) of the northward-moving Indian Plate underneath the Burma Platelet (which is a part of the Eurasian Plate) at an average rate of 3.5 cm/yr; and
- The northward movement of the Burma Platelet from a spreading centre in the Andaman Sea at an average rate of 2.5–3.0 cm/yr (Bertrand et al., 1998; Curray, 2005).

Very large over thrusts along the Western Fold Belt have resulted from the former movement, and the Sagaing and related faults from the latter movement. Intermittent jerks along these major active faults have caused the majority of earthquakes in Myanmar. These seismotectonic processes are still going on. The occurrence of intermediate-focus earthquakes (focal depth 70 – 300 km) along the Western Fold Belt is due to the subduction, and that of shallow-focus earthquakes (focal depth 0 – 70 km) along the Central Lowlands and Eastern Highlands is mainly due to shallow-depth strike-slip (e. g., Sagaing Fault) and other faulting (Figure 8). Generally, the shallow earthquakes tend to be more destructive than intermediate ones for the same magnitude.

The major seismotectonically important faults in Myanmar are some unnamed major thrust faults in north-western Myanmar, Kabaw Fault along the Kabaw Valley in western Myanmar, the well-known Sagaing Fault, and the Kyaukkyan Fault situated west of Naungcho.

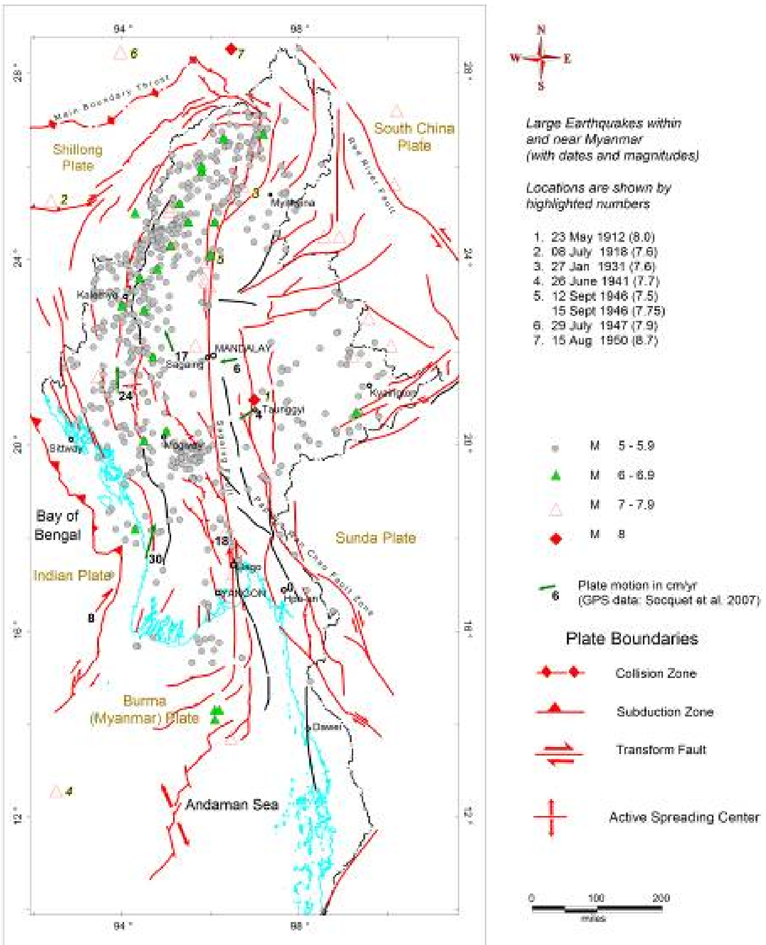
The well-known and seismologically very active Sagaing Fault (Win Swe, 1972 & 1981; Vigny et al., 2003; Soe Thura Tun, 2006) is the most prominent active fault in Myanmar, trending roughly north – south. It has been an originator of a large proportion of destructive earthquakes in Myanmar. This is due to the fact that many large urban centres lie on or near this fault. In fact, of the five major source zones in Myanmar, three lie around this large and dangerous fault. As shown at Figure 7, it is a right lateral strike-slip fault extending from south of Putao, west of Katha, through Sagaing, along the eastern flank of Bago Yomas, then through Bago, and finally into the Gulf of Mottama for a total distance of about 1500 km.

The earthquakes generated by sea-floor spreading in the Andaman Sea, however, are mostly small to moderate and shallow-focus.

4.2 Frequency and Extent of Earthquakes

As shown in epicentral map (Figure 9) and with reference to the seismotectonic map (Figure 7), the majority of the earthquakes in Myanmar are mainly confined to three zones.

Figure7 Seismotectonic map of Myanmar and surrounding regions*

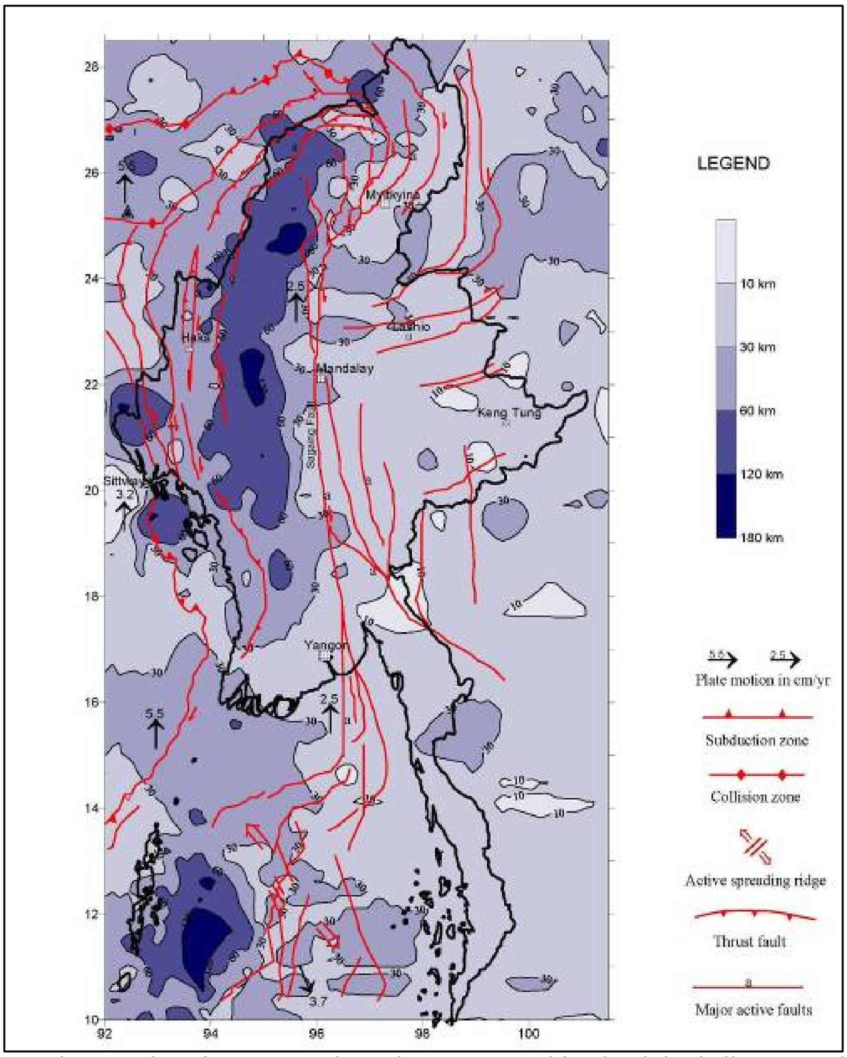


*Active faults are shown in red lines (Earthquake data: ANSS Catalogue for the period 1950-2008; from other sources for 1912-1949; data are in Richter Magnitude)

The zones are as follows:

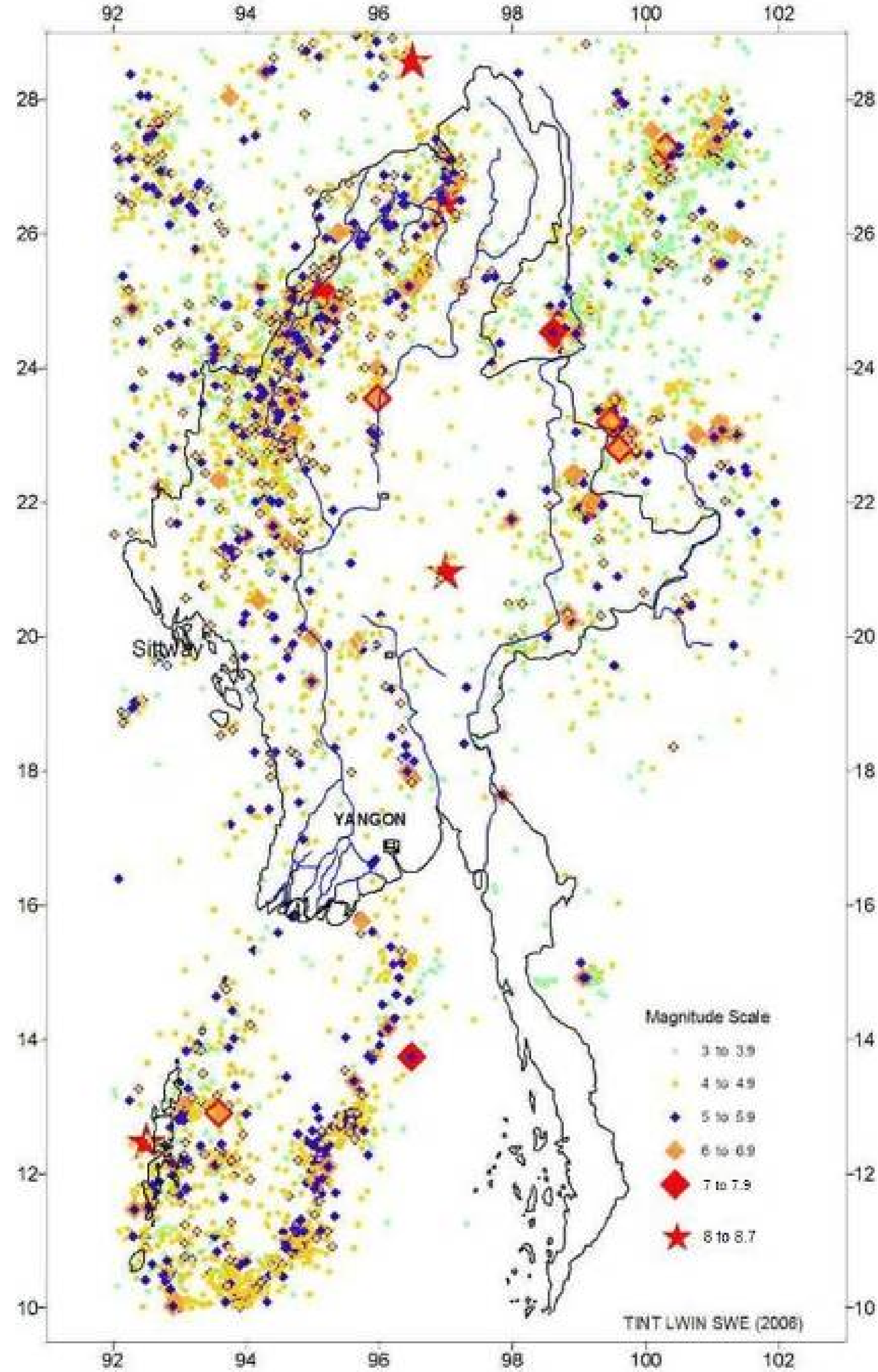
1. The zone along the western fold belt of Myanmar with mostly intermediate-focus earthquakes; earthquake frequency is much higher in the northern part.
2. The zone along the Sagaing Fault, including the offshore part with shallow-focus earthquakes; the earthquake frequency is higher in three segments, namely (from south to north), Bago-Taungoo, Sagaing-Tagaung, and Myitkyina-Putao Segments.
3. The zone in the north-eastern part of Myanmar, which is continuous with the earthquakes in southern Yunnan.

Figure : 8 Earthquake focal depth contour of Myanmar for the period 1964-2004**



**Intermediate earthquakes occur only in the Western Fold Belt while shallow crustal earthquakes in other parts of Myanmar. The locations of major faults are superimposed on the focal depth zones. (Maung Thein and Tint Lwin Swe, 2006)

Figure 9 **Earthquake occurrences in the Myanmar region*****



***Earthquake data: from NEIC for 1964 – 2004; from other sources for 1912 – 1963; data are in Richter Magnitude (modified after Tint Lwin Swe, 2006)

The seismic records show that there have been at least 16 major earthquakes with Richter Scale (RS) ≥ 7.0 within the territory of Myanmar in the past 170 years. The frequency with respect to time may be summarized at Table 8.

Table 8 Earthquakes in Myanmar

Type of Earthquake	Richter Scale	Frequency	Time Range	Data Source
Great	> 8	1	1839-2008	Historical record and NEIC
Major	7-7.9	15	1839-2008	Historical record and NEIC
Strong	6-6.9	25	1950-2008	ANSS Catalogue
Moderate	5-5.9	549	1950-2008	ANSS Catalogue

4.3 Earthquake Prone Locations

The seismic zone map of Myanmar is at Figure 11, which is a probable intensity zoning map. It is partly a deterministic map as past earthquake data and spatially correlated peak ground acceleration (PGA) values for some earthquakes are used.

The highest intensity zone designated for Myanmar is the Destructive Zone (with probable maximum range of ground acceleration 0.4 – 0.5 g), which is equivalent to Modified Mercalli (MM) class IX. There are four areas in that very vulnerable zone; namely, Bago-Phyu, Mandalay-Sagaing-Tagaung, Putao-Tanaing, and Kale-Homalin areas. Although the latter two have major earthquake hazards, they may be less vulnerable as are sparsely populated. Important cities and towns that lie in Zone IV (Severe Zone, with probable maximum range of ground acceleration 0.3 – 0.4 g) are Taungoo, Taungdwingyi, Bagan-Nyaung-U, Kyaukse, Pyin Oo Lwin, Shwebo, Wuntho, Hkamti, Haka, Myitkyina, Taunggyi, and Kunglong. Yangon straddles the boundary between Zone II and Zone III, with the old and new satellite towns in the eastern part in Zone III, and the original City in Zone II.

About 75 percent of the Myanmar people are living in the rural areas. Most of their dwellings are still non-engineered structures, which are vulnerable to moderate to high intensity earthquakes. The rate of urban growth increases in some large cities like Yangon and Mandalay. Due to urbanization the vulnerability increases in cities and the level of disaster from earthquake would increase in major cities. On the other hand, some large segments of the active faults have not exhibited any significant seismic activity in the past 50 to 75 years, indicating that the faults are apparently locked and stress is accumulating in those segments (e.g., the southern segment of the Sagaing Fault that is close to Yangon and Bago cities, and the central segment that is close to Mandalay and Sagaing cities). This suggests that a national emergency plan for earthquakes and related disasters is in need, which should also include operating procedure for disaster preparedness and mitigation with strong support of scientific foresight. Vulnerable locations of the country can be studied also on seismotectonic map in which seismically active faults are shown in red lines in comparison with earthquake records (Figure 9).

4.4 Past Earthquake Events in Myanmar

4.4.1 Historical earthquakes

In recent months, some geoscientists (Cummins, 2007; Sieh, 2007) speculated that there is possibility of a giant tsunamigenic earthquake in the northern Bay of Bengal (that includes the Rakhine Coast) in future. Their speculations were based partly on the Megathrust tectonic setting and stress and crustal strain observations, and partly on the historical account of a large earthquake that occurred on 2 April 1762 in northern Bay of Bengal (Chhibber, 1934). Both authors refer to the account given by Halstead (1843) that was recorded some eighty years after the said event. Halstead recorded raised marine terraces in six different localities along the Northern Rakhine Coast with heights ranging from 3 m to 7m that were probably related with great earthquakes.

Chandra (1978) (in Satyabala, 2003) located the epicenter of 1762 earthquake at 22° N and 88° E, i. e., north of Kolkata. On the other hand, Ganse and Nelson (1982) located the epicenter at 22° N and 92° E, i.e., east of Chittagong where the damage was severe. Recent paleoseismological studies by the joint Myanmar-Japanese teams in the northern Rakhine Coast (Than Tin Aung et al., 2008) reveal the presence of at least three raised marine terraces with radiocarbon dates ranging from 1400 BC to 1860 AD, indicating that there were at least three great earthquakes (including 1762 earthquake) in that general region in the past 3400 years. On the basis of an average recurrence interval of about 1000-1800 years, the authors suggested that the chance of next large earthquake in the near future may be low.

Local historic records of tragic events indicate that the Sagaing fault is the principal source of seismic hazards in Myanmar. Myanmar royal capitals were incidentally located along the Sagaing fault zone. These capitals were perhaps the most crowded areas in the country in those days. Historical records gave accounts of costly and terrifying earthquake disasters in earlier times of Myanmar.

The Mandalay area is the site of former royal capitals of Myanmar. These are Amarapura, Ava (Innwa), just south of Mandalay, and Sagaing, opposite to Ava across the Ayeyarwady River. On the 23 March, 1839, the new capital Amarapura and the older capital Ava were severely devastated by a large earthquake at Ava. The banks of the Myitnge River between Amarapura and Ava rent in many places, presenting chasms of 5 to 20 feet in width, and large quantities of water and sand of black appearance were ejected. Causalities were estimated at 300 to 400, including a large number of monks buried under the collapsed brick monasteries. The unfinished colossal Mingun Pagoda was severely damaged and shattered.

Another notable earthquake of higher magnitude (8.0 RS), but contrast to the 1839 Ava earthquake in devastation, occurred on the 23 May, 1912, in the area about 20 miles north of Taunggyi, which is the largest ever instrumentally recorded earthquake in Myanmar. It was felt over 375,000 square miles in Myanmar and adjoining Thailand, Yunnan, and northeastern India. It was recorded by seismographs throughout the world. The maximum intensity of this earthquake, IX on Rossi-Forel scale, was recognized in the vicinity of the Kyaukkyan fault, extending north-south in the east of Pyin Oo Lwin (Maymyo).

The Bago (Pegu) earthquake (7.3 RS) of 5 May 1930, which caused widespread destruction of the town, is considered as a devastating disaster by Chhibber (1934). It killed approximately 500 people in Bago and 50 in Yangon, that is situated at some 30 miles southwest of the epicenter – 30 miles south of Bago. The maximum intensity, IX on Rossi-Forel scale was felt in an area of 375 square miles of the deltaic alluvial plain south of Bago where large cracks in the ground and extruded sand and water indicate liquefaction in the epicentral area.

The epicentres of both the Bago (1930) and the Ava (1839) earthquakes are sited on the Sagaing Fault zone, and both areas happened to be located on the flat alluvial plains covered by rice paddy fields, whereas the epicenter of the Pyin Oo Lwin (Maymyo) earthquake of 1912 seemed to be situated on the Kyaukkyan fault zone in the western part of the Eastern Highlands, indicating that the Kyaukkyan fault is also an active structure. Table 9 summarizes important historical and recent earthquake that have occurred in Myanmar, and a few instances of destruction are illustrated at Figure 9.

4.4.2 Recent earthquakes in Myanmar

The Sagaing Earthquake (7.0 RS) of 16 July 1956 caused rather large damage to ancient structures. The Mingun Pagoda that is one of the largest brick building in the world partly collapsed again because of the liquefaction effect during the earthquake. The records indicate at least 50 people were killed and most of the stupas in the Sagaing area fell down.

The most memorable recent earthquake that ever struck the Myanmar territory is the Bagan earthquake of 8 July 1976 in central Myanmar. Its magnitude was of 6.8 RS, but its destruction horrified the peoples of Myanmar, because it devastated Myanmar's royal capital of the 11^{th} to 13^{th} Centuries very severely.

On 22 September 2003, an earthquake with moment magnitude 6.8 occurred in central Myanmar, causing severe damage to rural houses and religious buildings. The earthquake had happened in the midnight of 21 September 2003 near Taungdwingyi City, about 360 kilometres north of Yangon. The location of the epicentre was at the western boundary of the

Bago Yoma anticlinorium and the alluvial plain composed of the water-saturated silts and sandy loam. Scientists believe that the earthquake, showing a transpressional nature in its USGS fault plane solution, occurred due to the buried southern extension of Gwegyo thrust, which is well exposed near Mt. Popa Volcano north of the present location (Soe Thura Tun et al., 2003). That earthquake damaged or destroyed many non-engineered brick structures and rural houses, and extensive liquefaction failure of building foundations. About 180 rural houses, including some primary school buildings, were severely damaged (Myanmar Earthquake Committee, 2003). Fortunately it occurred in the midnight, so most of the community centres and school buildings were empty, and that greatly reduced casualty in the affected area (7 deaths and 43 injured). Figure 10 shows some records of damages of 20th Century earthquakes in Myanmar.

Table 9 Summary of historical and recent earthquakes in Myanmar ****

Date	Location	Magnitude and/or brief description
868	Bago	Shwemawdaw Pagoda fell
875	Bago	Shwemawdaw Pagoda fell
1429	Innwa	Fire-stopping enclosure walls fell
1467	Innwa	Pagodas, solid and hollow, and brick monasteries destroyed
24 July 1485	Sagaing	3 well-known pagodas fell
1501	Innwa	Pagodas, etc. fell
13 Sept. 1564	Bago	Pagodas including Shwemawdaw and Mahazedi fell
1567	Bago	Kyaikko Pagoda fell
1582	Bago	Umbrella of Mahazedi Pagoda fell
9 Feb 1588	Bago	Pagodas, and other buildings fell
30 Mar 1591	Bago	The Great Incumbent Buddha destroyed
23 June 1620	Innwa	Ground surface broken, river fishes were killed after quake
18 Aug. 1637	Innwa	River water flush
10 Sept. 1646	Innwa	
11 June 1648	Innwa	
1 Sept. 1660	Innwa	
3 April 1690	Innwa	
15 Sept. 1696	Innwa	4 well-known pagodas destroyed
8 Aug. 1714	Innwa	Pagodas, etc. fell; the water from the river gushed into the city
4 June 1757	Bago	Shwemawdaw Pagoda damaged
2 April 1762	Sittwe	M=7 RS; very destructive violent earthquake felt over Bengal, Rakhine up to Calcutta.
27 Dec 1768	Bago	Ponnyayadana Pagoda fell
15 July 1771	Innwa	
9 June 1776	Innwa	A well known pagoda fell
26 Apr 1830	Innwa	
21 Mar 1839	Innwa	Old palace and many buildings demolished;

23 Mar 1839	Innwa	pagodas and city walls fell; ground surface broken; the river's flow was reversed for sometime; Mingun Pagoda shattered; about 300 to 400 persons killed
6 Feb 1843	Kyaukpyu	eruption of mud volcanoes at the Rambye (Ramree) Island
3 Jan 1848	Kyaukpyu	The civil line and other buildings were damaged
24 Aug 1858	Pyay	Collapsed houses and tops of pagodas at Pyay, Henzada, and Thayetmyo and felt with some damages in Innwa, Sittwe, Kyaukpyu and Yangon
8 Oct 1888	Bago	Mahazedi Pagoda collapsed
6 Mar 1913	Bago	Shwemawdaw Pagoda lost its finial
5 July 1917	Bago	Shwemawdaw Pagoda fell
10 Sep 1927	Yangon	
17 Dec 1927	Yangon	M=7 RS; extended to Dedaye
8 Aug 1929	Near Taungoo	Bent railroad tracks, bridges and culverts collapsed, and loaded trucks overturned (Swa Earthquake)
5 May 1930	Near Khayan	M=7.3 RS, Imax=IX; in a zone trending north-south for 37 km south of Bago (on the Sagaing Fault line); about 500 persons in Bago and about 50 persons in Yangon killed
3 Dec 1930	Nyaunglebin	M=7.3 RS; railroad tracks twisted (Pyu Earthquake); about 30 persons killed
27 Jan 1931	East of Indawgyi	M=7.6 RS, Imax=IX; numerous fissures and cracks (Myitkyina Earthquake)
10 Aug 1931	Pyinmana	
27 Mar 1931	Yangon	
16 May 1931	Yangon	
21 May 1931	Yangon	
12 Sept. 1946	Tagaung	M=7.5 RS
12 Sept.1946	Tagaung	M=7.75 RS
16 July 1956	Sagaing	M=7.0 RS; Several pagodas severely damaged (40 to 50 persons killed)
8 July 1976	Bagan	M=6.8 RS; Several pagodas in Bagan Ancient City were severely damaged (only 1 person killed)
22 Sept. 2003	Taungdwingyi	M=6.8; RS Severe damaged to rural houses and religious buildings (7 persons killed)

****most of them along the Sagaing Fault

Figure 10 Damages during past Earthquakes, Myanmar

Top portion of the Shwemawdaw Pagoda, Bago fell down in the 1917 earthquake (Top).Collapsed primary school during the Taungdwingyi earthquake (6.8 RS) and cracks in the dam closed to the epicenter (Bottom).

4.5 Work on Earthquake Hazards

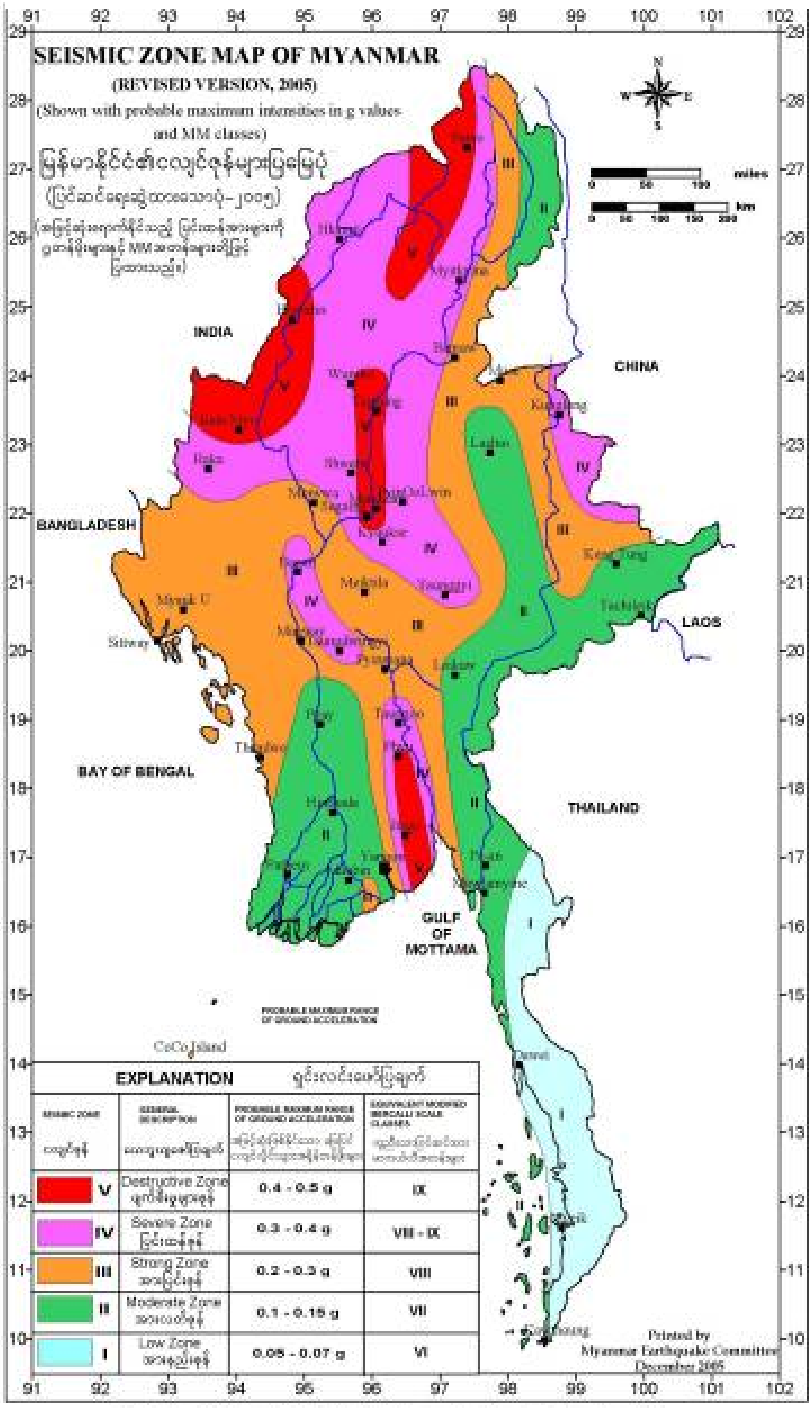
4.5.1 Seismic Zoning Map

The seismic zone map of Myanmar (2005) was prepared by a team led by Dr Maung Thein during 2003 to 2005 with several detail observations and brainstorming. Tectonic activities in connection with earthquake information from external sources are applied in the development of the map (Maung Thein and Tint Lwin Swe, 2006), deterministically and some intuitively.

As shown in the map (Figure 11), five seismic zones are demarcated and named (from low to high) Zone I (Low Zone), Zone II (Moderate Zone), Zone III (Strong Zone), Zone IV (Severe Zone), and Zone V (Destructive Zone), mainly following the nomenclature of the European Macroseismic Scale 1992. (It should be mentioned that in some countries, there are zones higher than **Zone V** as used here). For each zone, a probable maximum range of ground acceleration in g values and equivalent Modified Mercalli (MM) Scale classes are given. In near future, the Probabilistic Seismic Hazard Assessment (PSHA) map, indicating the level of earthquake loading of 10 % in 50 years is going to be developed.

Figure 11 **Seismic zone map of Myanmar**

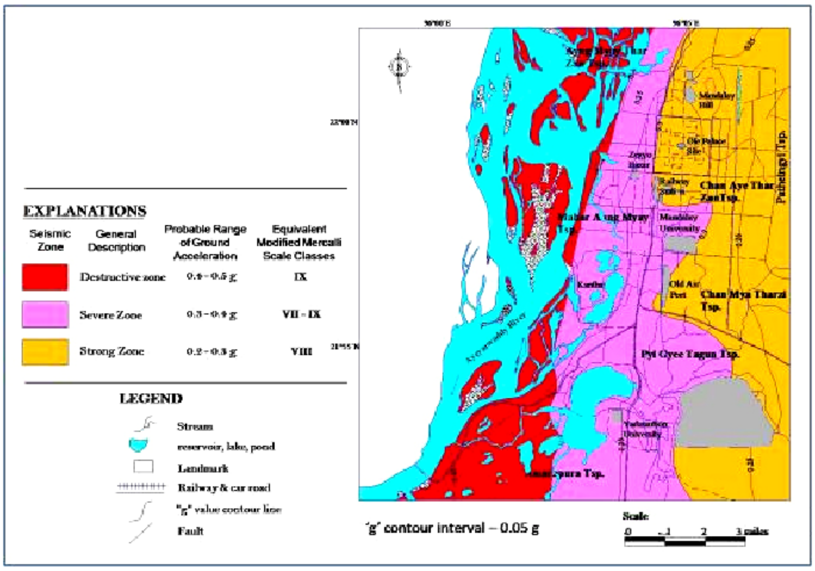
(modified Maung Thein and Tint Lwin Swe, 2006)



Revised by Dr. Maung Thein, U Tint Lwin Swe and Dr. Sone Han (December 2005)

During the years of 2005 to 2007, the Myanmar Geosciences Society, in collaboration with the MEC, sponsored some graduate students of the University of Yangon, for the preparation of preliminary seismic micro zoning maps for four seismically hazardous cities. These are deterministic maps. As an example the seismic microzoning maps of Mandalay-Amarapura area in central Myanmar is shown at Figure 12. The terminology for zonation is in accordance with that used in the seismic zone map of Myanmar (Figure 11).

Figure 12 Seismic micro zone map of the Mandalay-Amarapura area
(Shown with PGA in 'g' values, in upper 30 m) (Eyn Keey, 2006)



The MEC has been trying to establish an earthquake microzoning map including landslide potentials of the Yangon City, since 2004. The geological map of Win Naing (1973) is being revised by scientists of the Yangon University to support the hazard mapping, and field surveys in particular areas where exposures are present at new construction sites have been carried out occasionally. The team expects to draft the map before the end of 2009.

4.5.2 Earthquake resistant design code

In development of Building Code (Than Myint *et al.*, 2007), the study of that of the other countries like Thailand, India, Indonesia and the UBC (Uniform Building Code of United States) are very helpful, but the background geological setting as well as the surface composition of geologic material, especially technical characteristics and distribution of rock and soil deposits of Myanmar, is quite different from that of other countries. For earthquake safety of buildings, seismic demand from various sources should be analysed by means of ground motion attenuation models and used as a seismic coefficient which is then applied in calculating base shear of the structure. Earthquake ground motion and intensity levels can be obtained from the proper installation of network of the seismological stations covering well-defined seismogenic sources.

However, the number of seismological stations in Myanmar is limited for acquiring earthquake information and establishing database and need to be upgraded not only instrumentation but also in technical concerns.

For application of seismic design code, levels of earthquake intensities are mainly based on the earthquake – zoning map. During the development of building code in Myanmar, the requirement of modern seismological instrumentation and technical improvement in the field of engineering seismology and earthquake engineering shall be enhanced by cooperative works among the scientists and engineers from various organizations.

Table 10 Composition of seismic zone (in %) of Myanmar's States and Divisions

State or Division\Zone	I	II	III	IV	V
Bago Division		35	30	20	15
Chin State			55	22	23
Irrawaddy Division		95	5		
Kachin State		18	27	32	23
Kayah State		98	1		
Kayin State	30	50	20		
Magway Division		15	50	35	
Mandalay Division			45	40	15
Mon State	20	70	10		
Rakhine State		15	85		
Sagaing Division			10	65	25
Shan State		40	40	20	
Tanintharyi Division	85	15			
Yangon Division		40	23	20	17

4.6 Future Studies/Research

The seismotectonic research division of the Myanmar Earthquake Committee has been studying regional and local earthquakes, and active faults in Myanmar in collaboration with international researchers. In this connection, the following issues can be considered for future work and research.

- Possibility of subduction-related earthquakes in Rakhine coast is rather low. After the Sumatra Earthquake (2004), Stein and Okal (2005) expressed no immediate danger of a tsunamigenic earthquake on this segment of the plate boundary as strain accumulated from subduction of Indian Plate beneath Burma Plate on the northern part of the rupture has also been released since such earthquakes should be at least 400 years apart. During the years 2005 to 2008, a Myanmar -Japanese team organized by MEC studied in northern Rakhine coast found evidence of at least three major ancient earthquakes were found for estimating earthquake recurrence. The estimate for the last major earthquake in this segment is 800±200 years. Also, we believed that there were aseismic movements along the northern Rakhine especially around Kyaukpyu area thus, the possibility of strain accumulation sufficient for large earthquake is low.

- Possibility of strong and major earthquakes along the Sagaing Fault is considerable. As already described in the text, two important segments of the fault (Taungoo - Bago and Sagaing – Tagaung) displayed no seismic activity for more than half a century. GPS observations of the French-Myanmar team showed strain loading in the Mandalay area (Vigny et al., 2003). Recently, active fault study project in Bago area detected possibility of strain loading in the offset Payagyi ancient city wall to a certain extent.
- Seismic activity of Kyaukkyan – Papun Fault is considerable but the movement along is too much slower than that of the Sagaing Fault. Though the largest magnitude earthquake of Myanmar occurred in 1912, the apparent recurrence interval seems to be more than 200 years (known by checking geomorphic features between Lawksauk and Inlay Lake by our researchers).
- Possibility of moderate to strong earthquakes in central Myanmar basin, especially along the transpressional faults is still high. Strong earthquakes in every two decades are not negligible at least two thrust fault lines.

4.7 Looking Forward

Myanmar is an earthquake-prone country due to its location in the active Alpide seismotectonic belt, the young Alpine-Himalayan-Sumatran orogenic belt. Myanmar forms a local segment, the Myanmar arc, of this major arc commonly referred to as the Sunda arc. The arc has two important tectonic features- earthquake sources, one within Myanmar and the other in her neighbourhood to the west. These are the active Sagaing fault, trending north – south across the entire length of central Myanmar, and the Sunda subduction megathrust zone running through off-shore southwest and west of the Myanmar coast and on-land to the west and northwest of Myanmar. The Sagaing Fault passes through the most populated areas of Myanmar where large cities have been built, active fault studies with characterization of earthquake response spectrum on engineering structures and design code for buildings are necessary.

It is suggested that the following activities should be undertaken to mitigate the seismic risks.

- Continuation, extension, and expansion of the neotectonic and active fault studies along the Sagaing, Kyaukkyan and Kabaw faults.

- Preparation of the probabilistic seismic zone map of Myanmar (which may be used as a seismic risk map)
- Regular precise GPS measurements along the Sagaing Fault, especially between Bago and Mandalay.
- Training of some seismologists and earthquake engineers, preferably in Japan.
- Upgrading of the existing seismological stations, and then installation of some more modern-type seismological stations in some suitable locations, such as Hpa-an, Pathein, Bago, Pyinmana, Magway, Kalemyo, and Muse.

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CHAPTER 5

5. Fire

5.1 Introduction

Myanmar has a long history of fire and fire fighting, as there are some historical evidences of constitution of fire fighting forces since 11th century in Bagan, Myanmar. The traditional fire hooks and fire beater flats are common in rural areas. Fire is the most frequent disaster of Myanmar as on average, approximately 900 cases are reported every year in Myanmar[16]. Fire Services Department, under the Ministry of Social Welfare, Relief and Resettlement maintains a record of fire cases.

5.2 Fire Cases (1983-2007)[17]

Fire hazards account for 70 percents[19] of disasters of Myanmar and annual losses are approximately 1billion kyats.

5.2.1 Fire cases from 1983 to 1989

The number of fire showed an increasing trend in the decade of 1980's as in 1989 the number of fire cases were 1,394 against 1,096 cases in 1983, which is an increase of 27 percent. The estimated losses also showed an increasing trend and in 1989 estimated losses were of the tune of 991 million kyats, which is 493 percent more than the 1983 losses. The total fire cases from 1983 to 1990 were 9,853 causing an estimated loss of 2.75 billion kyats. The annual fire cases along with estimated losses are at Table 11.

Table: 11 Fire case and losses in 1980s

Year	No. of Fire cases	Estimated losses *in Kyats*
1983	1,096	167,089,302
1984	1,078	390,525,046
1985	1,255	166,222,975
1986	1,281	471,973,149
1987	1,243	145,524,527
1988	1,187	418,712,922
1989	1,394	991,418,278
Total	**8,534**	**2,751,466,199**

16 Country Report, 2003, Myanmar
17 Fire service Department
19 Relief and Resettlement Department,

The fire cases during 1983-89 were concentrated mostly in Yangon, Ayeyarwady, Mandalay and Bago. The break-up is at Table 12.

Table: 12 **Fire case in selected Divisions/State**

Division/State [D/S]	No. of Fire cases	% of total fire cases	Total loss *in kyat*	% of total loss
Yangon	1770	21	167,729,839	6.10
Mandalay	1374	16	593,917,547	21.59
Bago	1162	14	106,675,279	3.87
Ayeyarwady	1041	12	163,199,884	5.93
Total in 4 Divisions/States	**5347**	**63**	**1031,522,549**	**37.49**
Total in Myanmar	**8534**	**100**	**2751,466,199**	**100.00**

The major cause of fire has been kitchen related fire and negligence and other causes are arson and electrical fire. Kitchen and negligence are causes of 81 percent of fire for 1983-89. The break-up of two major causes is at Table 13.

Table: 13 **Major causes of fire**

Year	Total Fire cases	Kitchen	% of total	Negligence	% of total fire
1983	1,096	423	39	501	46
1984	1,078	394	37	470	44
1985	1,255	442	35	554	44
1986	1,281	512	40	509	40
1987	1,243	513	41	522	42
1988	1,187	426	36	498	42
1989	1,394	491	35	658	47
Total	**8,534**	**3201**	**38**	**3,712**	**43**

The fire led to loss of human lives, cases of injury, animals, gutting down of factories and gowdowns and overall impacting people. During 1983-89, 339 human lives were lost, 417 injuries, loss of 42,061 animals and overall affecting approximately 0.4 million people.

5.2.2 Fire cases from 1990 to 1999

The decade of 1990s overall reflected the decreasing trend of fire cases, as during the first half total number of cases were 7690, while 5042 cases were reported in second half. The losses due to fire also showed decreasing trend and total losses in second half is less than 11 percent against the first half of 1990s. The annual fire cases along with estimated losses are at Table 14.

Table: 14 **Fire case and losses in 1990s**

Year	No. of Fire cases	Estimated losses *in Kyat*
1990	1,519	320,617,350
1991	1,815	1,222,414,399
1992	1,620	379,114,377
1993	1,464	496,540,753
1994	1,272	316,367,217
1995	1,177	404,320,545
1996	902	301,059,209
1997	1007	415,158,394
1998	1,098	343,626,523
1999	847	968,158,010
Total	**12,721**	**5,167,376,777**

The fire cases during the decade of 1990's, were mainly concentrated in four divisions/states namely Yangon, Ayeyarwady, Mandalay and Bago. These four divisions/states constitute 63 percent of the fire cases and accounting for approximately 38 percent of estimated losses. The break-up is at Table 15.

Table: 15 **Fire cases in selected Divisions/States, 1990-99**

Division/State [D/S]	No. of Fire cases	% of total fire cases	Total loss *in kyat*	% of total loss
Yangon	2791	22	461,919,377	8.94
Ayeyarwady	1327	10	373,548,959	7.22
Mandalay	2509	20	1294,468,930	21.59
Bago	1385	11	269,152,888	5.20
Total in 4 D/S	**8012**	**63**	**2,399,090,154**	**37.49**
Total in Myanmar	**12721**	**100**	**5,167,376,777**	**100.00**

The two major causes of fire have been kitchen related fire and negligence and together it accounts for 85 percent of fire causes in the decade of 1980s. The two other causes are arson and electrical fire and together it accounted for 12.97% of cases. The break-up of two major causes is at Table 16.

Table: 16 **Major causes of fire, 1990-99**

Year	Total Fire cases	Kitchen	% of total fire	Negligence	% of total fire
1990	1,519	557	37	749	49
1991	1,815	594	33	947	52
1992	1,620	494	30	876	54
1993	1,464	451	31	831	57
1994	1,272	377	30	710	56
1995	1,177	344	29	665	56
1996	902	230	25	538	60
1997	1007	265	26	591	59
1998	1,098	314	29	623	57
1999	847	224	26	496	59
TOTAL	12,721	3,850	30	7,026	55

The fire led to loss of 358 human lives and injury to 661 in 1990s and overall affecting approximately 415,000 people.

5.2.3 Fire cases from 2000 to 2007

In first eight years of the decade of 2000, the total number of fire cases is reported to be 6915. The number of cases in first four years [2000-2003] is a little less than the cases in next four years [2004-2007], which are 3347 and 3568 respectively. The annual fire cases along with estimated losses are at Table 17.

Table: 17 **Fire cases and losses in 2000-2007**

Year	No. of Fire cases	Estimated losses *in Kyats*
2000	876	368,722,816
2001	868	4,830,391,573
2002	843	523,009,154
2003	760	714,741,185
2004	956	1,045,319,258
2005	835	2,000,543,067
2006	833	859,595,480
2007	944	969,433,941
Total	6,915	11,311,756,474

The number of fire cases in 2000-2007 have been concentrated in three divisions in the order of Yangon, Mandalay and Sagaing and accounted for 64 percent of fire cases and approximately 23 percent of estimated losses in the country. The break-up is at Table 18.

Table: 18 **Fire cases in selected Divisions, 2000-2007**

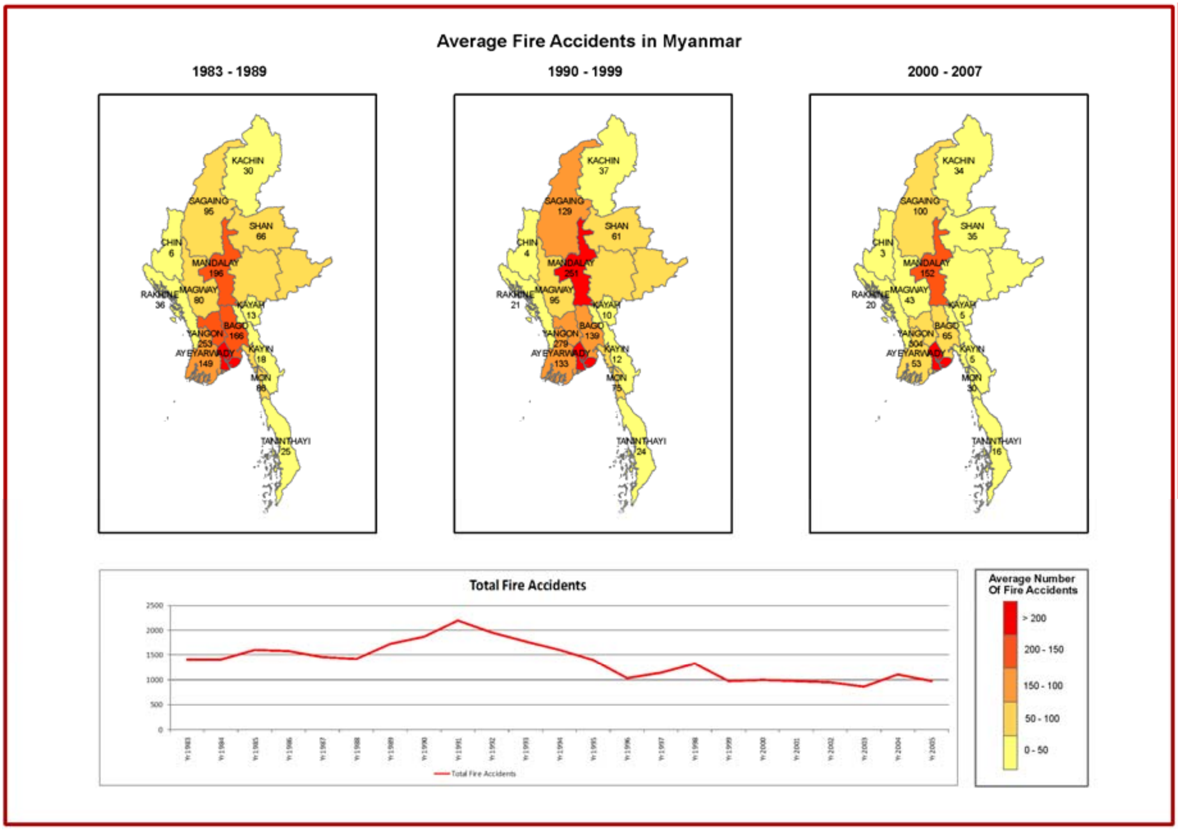
Division	No. of Fire cases	% of total fire cases	Total loss *in kyats*	% of total loss
Yangon	2431	35	1611682459	14
Mandalay	1214	18	688446883	6
Sagaing	800	12	318528513	3
Total in 3 Divisions	**4445**	**64**	**2618657855**	**23**
Total in Myanmar	**6,915**	**100**	**11,311,756,474**	**100.00**

The two major causes of fire are kitchen related fire and negligence and together account for 78 percent of fires. Overall in 2000-2007, fires led to loss of 298 lives, injury to 607 and affected 135,127.

5.3 Inferences and causes

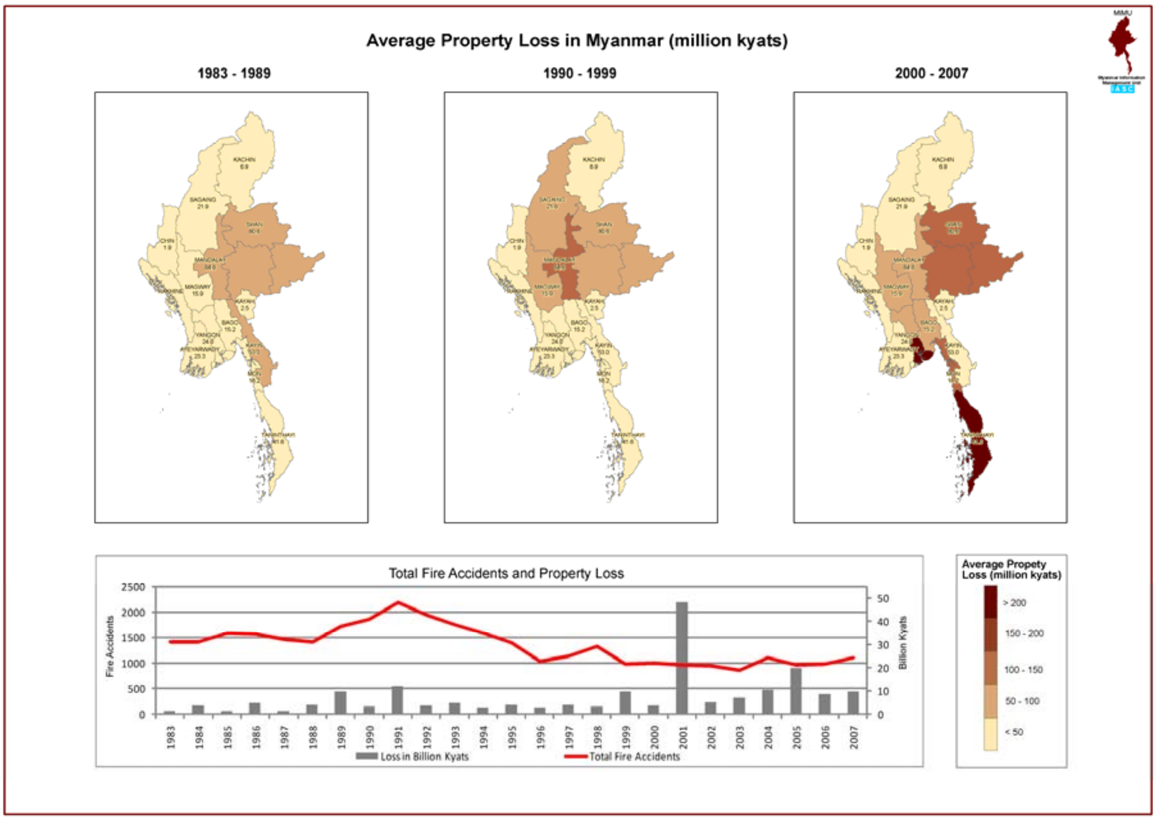
The fire cases of last 25 years (1983-2007) reflect decreasing trend at Figure 13.

Figure : 13 **Annual Average Fire Cases**



The average annual financial loss reflects increasing trend at Figure 14.

Figure: 14 **Average Annual Financial Losses due to Fire**



The high incidences of fire in Myanmar are due to climatic conditions including temperature, use of flammable construction materials, unplanned development and other social factors. The hot season is from mid–February to mid-May. Unlike those countries that lie within the Equatorial Climatic Zone, Myanmar does not receive rainfall all the year round. It has instead a wet period that lasts for about five months and a dry spell for the remaining seven months. Also, the mean temperature ranges from 32° C in the Coastal and Deltaic areas and maximum temperatures reach up to 40° C in the central Dry Zone during the peak hot season[20].In rural areas, people prefer to live in bamboo houses with thatched roof made of bamboo shaves and Nipa palm leaves *(Dha-Ni)*, which are highly inflammable. As these materials are locally and readily available, do not require sophisticated technology, and are not expensive, and above all suit the local weather condition, hence much preferred. The uncovered cinders left after cooking with wood and charcoal, candles left lit even after use, exposure of naked flames and unattended mosquito coils to diesel, petrol and engine oils also led to fire cases.

[20] IFFN No. 20 - March 1999

5.4 Conclusion

The Fire hazard is the most frequent hazard and it also accounts for approximately 70 percent of the disasters. The number of fire cases is decreasing while the losses due to fire is showing increasing trend. The fire cases are mainly in Yangon, Mandalay, Ayeyarwady, Sagaing and Bago. These divisions account for 63 percent of the total fire cases of the country, while the financial loss is approximately 38 percent. The main causes of fire are kitchen related fires and negligence which account for 83 percent of the fire cases. The period from January to May is the high season for fires as per the Fire Services Department[21]. The average annual fire cases are 900, which leads to loss of properties to the tune of 1 billion kyats or 0.91 million USD[22].

Based on the fire incidents from 1983-2007, the States and Divisions have been categorized into High, Medium and Low Fire Risk Zones. Following criteria has been used for zoning:
High Risk Zone : More than 100 average annual fire cases
Medium Risk Zone : Between 100 and 50 average annual fire cases
Low Risk Zone : Less than 50 average annual fire cases

The fire risk-wise Divisions/ States, Number of Districts, Townships, Area and Population are at Table 19.

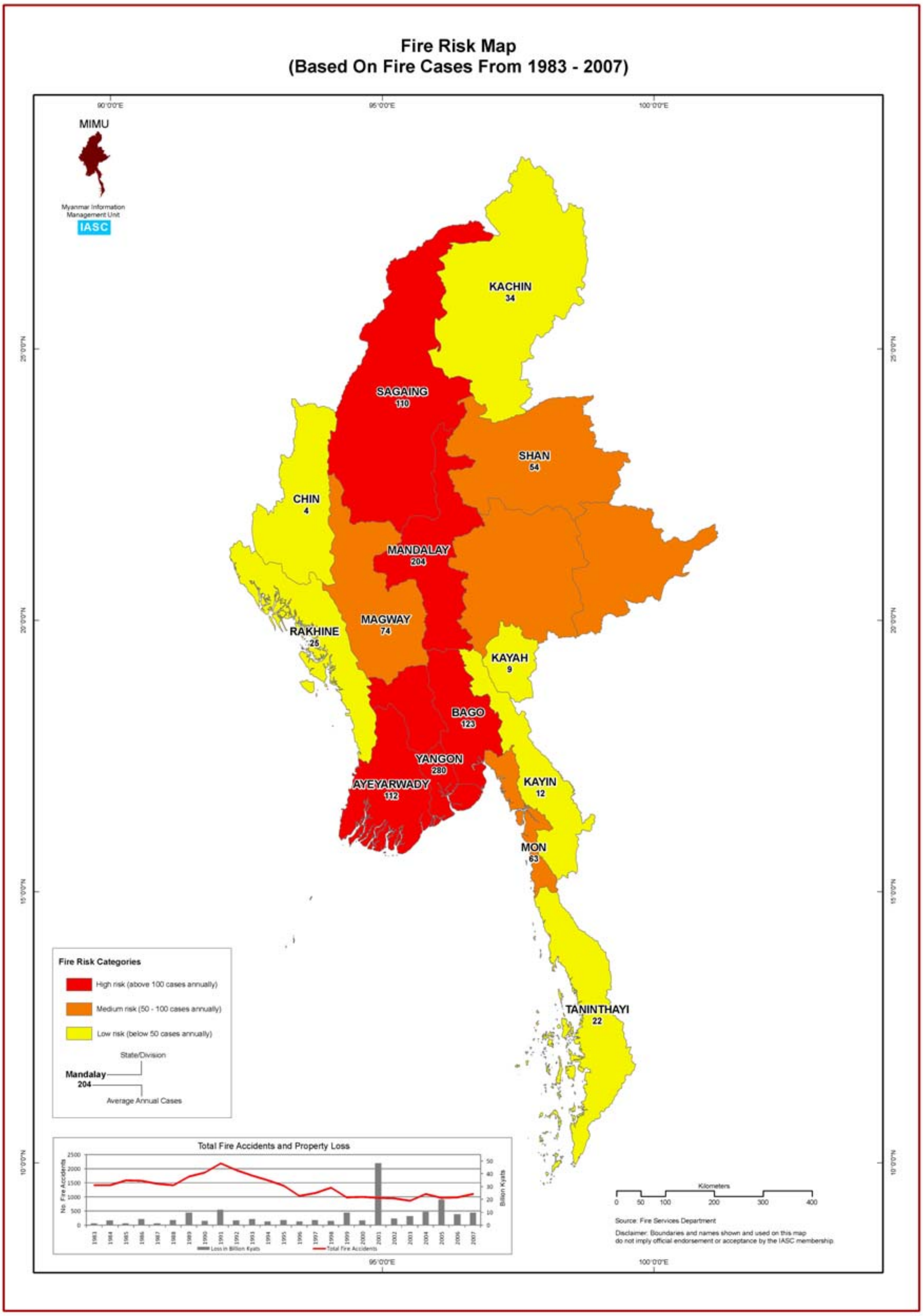
Table 19 **Area[23] & Population[24] in Fire Risk Zone**

Fire Risk Zone	Divisions/ States	[25]No. of Townships	Area *In sq. miles*	% total area	Population	% of total population
High	Yangon, Bago, Ayeyardwady Mandalay Sagaing	167	83,538	32	33,431,000	60
Medium	Magway Mon, Shan	89	82,208	31	13,361,000	24
Low	Rakhine Kachin, Kayah Kayin, Chin Tanintharyi	68	96,812	37	8,604,000	16
Total		**324**	**261,228**	**100**	**55,396,000**	**100**

The Fire Risk Map, based on the fire cases of last 25 years, categorizing Divisions/States into High Risk, Medium Risk and Low Risk zones is at Figure 15.

21 Myanmar Times
22 An exchange rate of 1100 kyat=1 US Dollar has been used.
23 http://www.myanmars.net/myanmar/myanmar-states-divisions.htm
24 Central Statistical Organisation,
25 Ministry of Home Affairs, Myanmar

Figure 15 Fire Risk Map (Based on Fire Cases from 1983 to 2007)



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Chapter 6

6. Floods

6.1 Introduction

In Myanmar, majority of big cities and towns, economically strategic places in the country, usually situate along four major rivers, namely Ayeyarwady, Chindwin, Sittaung and Thanlwin. The topography of the country varies from hilly and mountainous areas in the north and east, semi-arid dry zone in the central region, coastal area in the western parts and alluvial plains in the southern delta where Ayeyarwady flows into the Andaman sea.

Figure 16 Major Rivers and Cities

While the existing intricate river systems provide easy access of water transportation, creating prosperous urban centers along the waterways, the flooding in these rivers devastate the lives of the inhabitants[26]. Though water retaining and flood control structures are being built in areas considered vulnerable to floods, with the increased population in the big cities, development of living quarters and settlement lands has been encroaching upon natural catchment areas.

6.2 Flooding in Myanmar

Flooding has always been one of the major hazards in Myanmar, accounting for 11% of all disasters, second only to fire. Between 1910 and 2000, there were 12 major floods. The Ayeyarwady River basin alone, the largest in the country, covers 404,200 square kilometer of the country. Over 2 million people are exposed to flood hazard in Myanmar every year.

Flooding leads to loss of lives and properties, damage to critical infrastructure, economic loss and health related problems such as outbreak of water borne diseases when the lakes, ponds and reservoirs get contaminated. The country receives practically all its rainfall between mid-May and October, the rainy season, during which flooding and landslides are common.

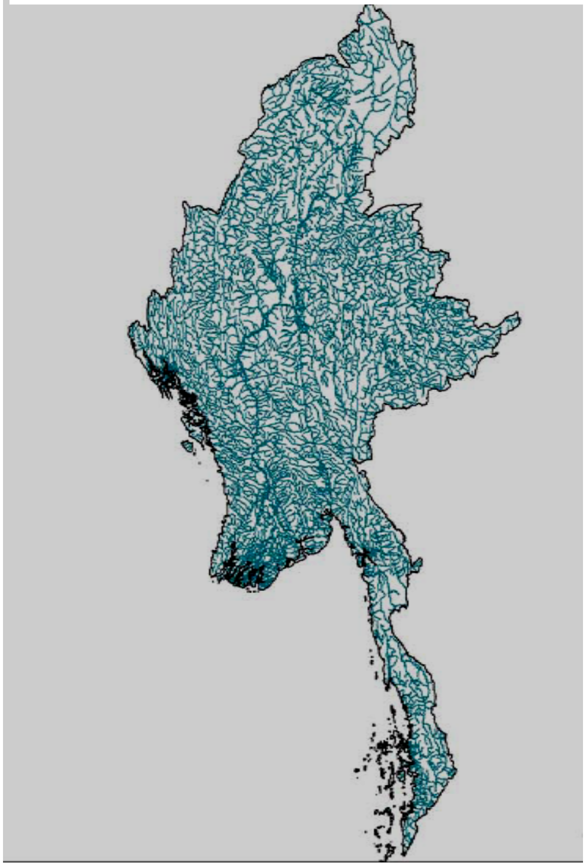
[26] "Figure 23 Source: www.mapsofwprld.com/myanmar/myanmar-river-map.html

In Myanmar, the threat of flooding usually occurred in three waves each year: June, August and late September to October with biggest danger arriving in August as peak monsoon rains occurred around that time.

Different types of floods can be seen in different areas of Myanmar:

- ***Riverine floods*** in the river delta;
- ***Flash floods*** in the upper reaches of the river systems, normally the mountainous areas, caused by the heavy rainfall striking at head water region for considerable period of 1-3 days.
- ***Localized floods*** in urban area due to a combination of factors such as cloudburst, saturated soil, poor infiltration rates and inadequate or poorly built infrastructure (such as blocked drains) and in rural areas due to the breakage of water resistance structures as dams, dykes and levees
- ***Flooding due to cyclone and storm surge*** in the coastal areas[27].

Figure 17: Distribution of rivers and Streams in Myanmar



Riverine floods are most common among all and they happen when the monsoon troughs or low pressure waves superimpose on the general monsoon pattern resulting in intense rainfall over strategic areas of the river catchments.

- In ***Ayeyarwady*** and ***Chindwin*** rivers, the flooding occurs when intense rain persists for at least 3 days over northern Myanmar, the headwaters of the rivers. Most of the flooding in the lower Ayeyarwady and the delta is by Chindwin, when its flood coincides with upper Ayeyarwady floods.
- In ***Sittaung*** and ***Thanlwin*** rivers, floods are duly caused by rainfall associated with low-pressure waves (the remnants of typhoons and tropical storms of South China Sea) moving from east to west across the country.

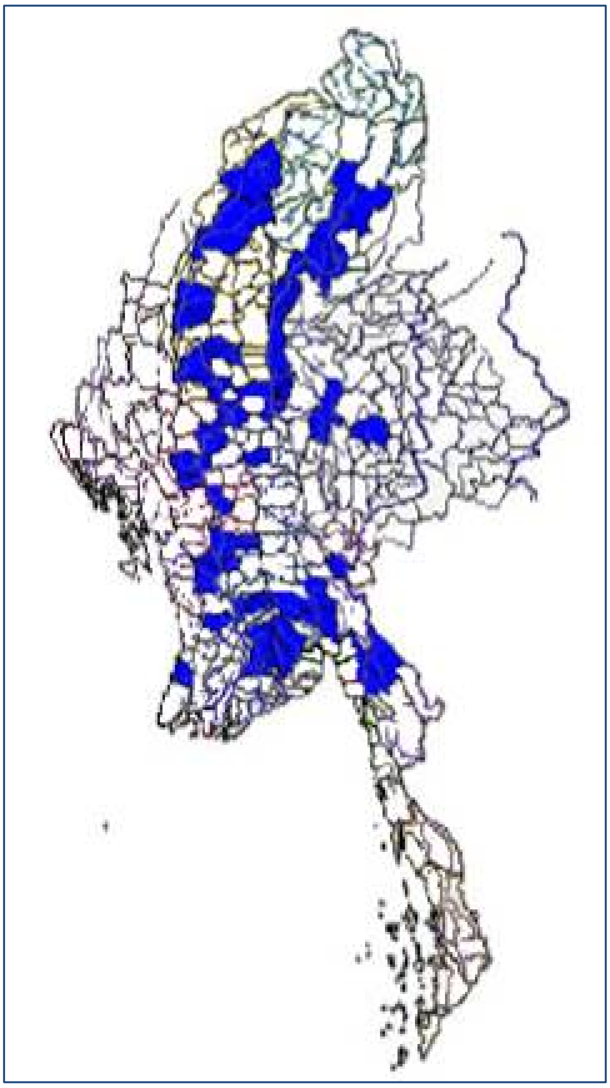
[27] "Figure 2: Source: Power-point presentation by the Department of Meteorology & Hydrology at "National workshop on Communicating Risks", Yangon, Myanmar, 30-31 May 2006

In addition to above mentioned four, other rivers as Bago and Dokethawady (tributary of Ayeyarwady) rivers also set off major floods.
However, annual riverine floods are considered natural phenomenon in the river basins that help clean the farm lands and replenish the ground with nutrients carried from upriver. For those working in fishing industry, the overflowing rivers are welcoming events as they facilitate the fish spawning process.

6.3 Flood Vulnerable Locations[28]

In general, the catchment areas of major rivers in the north and central zone are prone to riverine floods. The Southern Delta faces riverine floods when there is flood tide and high river water flow at the same period. In these areas, the lands are protected from floods by earthen dykes, but there were times when flood overpower the dykes and cause losses of lives and properties.

Figure 18: Flood prone areas in Myanmar



The mountainous and hilly in Kayin, Kachin, Shan, Mon and Chin States areas are threatened by flash floods. In Kachin State, at the confluences of the Ayeyarwady River, the snow in the higher altitude melt and flash floods occur quite frequently at the beginning of summer. Along the coastal region in Rakhine State, floods are secondary hazard generated by cyclones.

Furthermore, the Ayeyarwady River basin and the catchment occupy 60% of the country area traversing Chin, Kachin, Shan States and Mandalay, Magwe, Bago, Yangon and Ayeyarwady Divisions. Floods, in consequence, can occur over a wide range of region.

[28] Figure 25, Source: Power-point presentation by the Health Care Service Committee at "National workshop on Communicating Risks", Yangon, Myanmar, 30-31 May 2006

6.4 Major Floods in the Past (1997-2007)

The Table 20 indicates the past major flood events from 1997 to 2007.

Table 20 **Major Floods in Past (1997-2007)**

S/N	Location	Date	No. of Affected Village Tracts and Villages	No. of Affected Households	No. of Affected Families	Affected Population	Deaths	Loss (x100,000 kyat)
1.	Homalin, Sagaing Division	8/7/97	5 villages in 2 wards	9,916	9,950	59,594	-	99 *(9,000 USD)*
2.	Homalin, Sagaing Division	25/9/97	63 villages	3,867	3,867	28,399	-	238 *(21,636 USD)*
3.	Paungpyin, Sagaing Division	11/7/97	5 villages	6,652	6,652	44,143	2	-
4.	No. 2 Myoma Ward, Mawlaik, Sagaing Division	13/7/97	16 villages	3,622	3,622	21,897	-	-
5.	No. 10 Myopaw Ward, Myikyina Township, Kachin State	9/7/97	10 villages	4,254	4,471	30,615	4	33 *(3,000 USD)*
6.	Kayan Township, Yangon Division	7/6/97	-	1,189	1,189	5,878	-	-
7.	Bago Division	7/7/97	All villages in 6 townships	6,629	6,629	33,768	50	-
8.	Kayin State	1/8/97	All villages in 5 townships	18,804	18,855	109,840	-	-
9.	Hpa-an, Kayin State	13/8/91	6 villages	2,669	2,669	14,488	-	-
10.	Kyauktaw, Rakhine State	10/7/97	-	1,030	1,030	5,983	-	50 *(4,545 USD)*
11.	Wundwin , Mandalay Division	2/6/01	Thètaw village	463	1,164	2,172	42	-
12.	Monywa, Sagaing Division	18/8/02	-	9,178	9,460	48,746	-	2,535 *(213,909 USD)*

S/N	Location	Date	No. of Affected Village Tracts and Villages	No. of Affected Households	No. of Affected Families	Affected Population	Deaths	Loss (x100,000 kyat)
13.	Salingyi Township, Sagaing Division	18/8/02	-	1,647	1,702	10,216	-	-
14.	Kani Township, Sagaing Division	19/8/02	-	2,042	2,207	12,048	-	2,447 *(222,454 USD)*
15.	Kyaikmaraw Towship, Mon Division	19/8/02	-	829	829	4,686	-	414 *(37,636 USD)*
16.	Hta/16 Ward, Shwepyithar Township, Yangon Division	8/9/02	-	886	886	4,541	-	-
17.	Hkamti Township, Sagaing Division	3/7/03	-	1,230	1,536	8,131	-	-
18.	Kyaukse District, Mandalay Division	9/10/06	All villages in 4 wards	1,443	1,763	7,045	-	351 *(31,909 USD)*
19.	Sagaing Division	11/9/06	6 villages near Yaymyetgyi Lake	770	791	5,372	-	-
20.	Kyaukpadaung Township, Mandalay Division	9/10/06	2 villages	14	18	97	16	-
21.	Bhamo, Shwegu, Myitkyina Townships, Kachin State	24/7/07	-	600	600	3,167	-	-

Note: Exchange rate – 1,100 kyat = 1 USD

6.5 Flood Risk Reduction Initiatives in Myanmar

6.5.1 Forecasting and Warning

At the national level, the main responsibility of flood monitoring, weather forecasting and issuance of early warning falls on the Department of Meteorology and Hydrology (DMH). Under the guidance of the Director General of DMH, a committee headed by the Deputy Director General has been formed to take responsibilities for issuing flood warnings. If the water level of any station along the rivers is expected to reach or exceed its danger level, it is necessary to inform the Flood Committee immediately.

Upon receiving the flood information together with the computed flood forecasts, the Flood Committee discusses the possibility of the flood inundation. The Flood Committee, then, has to decide whether to issue the flood warnings. Once the decision is made, the warnings are disseminated through different channels of communication such as radio, television, newspaper, telegraph and telephone to the administrative authorities of the flood prone areas. If the expected flood is a severe one, the warnings are broadcast frequently (every 3 hours) through Myanmar Broadcasting Services (TV and Radio).

6.5.2 Flood Risk Mitigation

The key agency for flood risk mitigation in the country is the Irrigation Department under the Ministry of Agriculture and Irrigation. Irrigation Department and Forest Department are cooperating to undertake the conservation and reforestation activities in the important watershed areas. Ministry of Health, in addition, has identified, in close association with Department of Meteorology and Hydrology, 48 flood prone townships in the country for their planning purpose. Every year, from the beginning of the rainy season, public awareness raising programs are in place such as radio talks, radio plays, newspaper articles and TV short programs.

In terms of community level initiatives, Myanmar Red Cross Society is the leading force in implementing Community Based Flood Management capacity building programs in selected flood vulnerable areas in the country.

6.6 Trends in Flooding

In the past two decades, the duration of Monsoon is found to be getting shorter but rainfall becomes much more intense and heavier. For instance, in 2008, the annual rainfall surpassed normal amount significantly in Kachin, Upper Sagaing, Mon, Yangon, Ayeyarwady, Kayah, Kayin, Tanintharyi, Bago and Rakhine. Floods occurred along all major rivers during peak monsoon and in Monywa and Bago, the second maximum water levels in more than 43 years were recorded and the third maximum water level in 44 years was recorded at Shwegyin in 2008.It has been indicated in the studies from the Department of Meteorology and

Hydrology that at the stations located in the higher latitudes (central and northern parts), a change from warming to cooling has been observed since 1977 and for stations located at somewhat lower latitudes (Deltaic and Southern parts), an alternate pattern has been recorded.

6.7 Looking Forward

In Myanmar, the need for irrigation is highest in the central dry zone while the delta is more concerned with drainage and flood protection problems. Heightening the flood problems is the considerable siltation of the major waterways. It is recorded that 299 tons of silt get deposited into Ayeyarwady River annually. As a result, the frequency and severity of the flooding at many locations along the rivers are increasing.

Furthermore, the impacts of climate change and global warming can make the water level reduce in the central Dry Zone, resulting in water shortages, while the water level in the Delta Region will rise due to the change of sea level. With the intensified concerns over the global climate change, there is an urgent need to address the relatively low level of technological capability and the lack of appropriate trainings on these issues.

Construction of dams and flood retaining structures can, to some extent, reduce the flood damage but there requires a balance between the development of such infrastructure and the maintenance of natural wetlands and river basins. Disaster impact assessments should be carried out before a development project can be approved, specifically if they are to take place in fragile river catchment areas where floods are natural phenomenon.

Equally vital are the adoption of land use management practices and the enforcement of land use regulations, to be the integral parts of the development process. Nowadays, the urban population is growing significantly and most cities being situated within the reach of the any major rivers, it is imperative to employ measures to mitigate and reduce flood risks.

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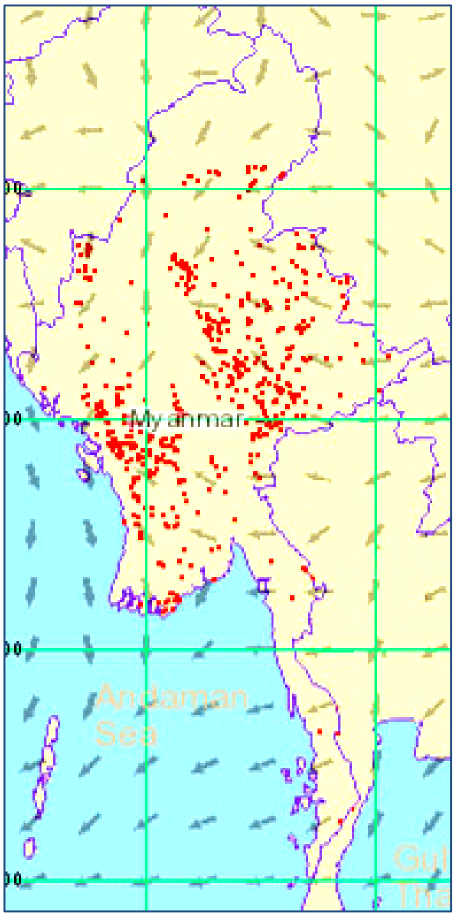
CHAPTER 7

7. Forest Fire

7.1 Forest Fire in Myanmar

Myanmar is endowed with one of the highest forest cover in the Asia-Pacific region with actual forested area of about 344,237 square meter or 50.87% of the total land area. Different types of forest can be found in different parts of Myanmar depending on the variation of rainfall, temperature, soil and topography. In the southern part of the country, tropical evergreen forests are abundant whereas in the eastern, northern and western regions, where elevation exceeds 900 m, moist temperate forests grow. In the central part of the country, as a result of the frequent dry spell and less rainfall, dry forest dominates the region[30].

Figure 19: Forest Fire Atlas of Myanmar



Forest fires and its associated recurring trans-boundary haze pollution have become the most prominent and pressing environmental problems in ASEAN. The resulting air pollution has negatively impacted the health, economy and environmental conditions of over 300 million people all over the southeast Asian region, with total loss amounting to 4.4 billion US dollars.
The underlying causes of the regional haze problems can be attributed to:

- Uncontrolled land and forest fires, mostly resulting from human activities such as the use of open burning techniques for conversion of forestland to other land uses and
- Prolong drought.

However, in Myanmar, forest fires, referred to as wild fire locally, are mainly surface fire that can spread over a large area but do not turn into intensified burning; therefore, they do not contribute to the regional haze problem. Nonetheless, surface fire can destroy up to 10 tons of forest fuel in one-hectare area. Consequently, every year 30 to 70 tons of top forest soil loss

[30] Figure 19: Source – National Environmental Agency, Singapore

occurs. Though Myanmar has high forest cover, in terms of the rate of siltation into rivers the country ranks at the 5th place globally.

7.2 Characteristics, Causes and Hot Spots[31]

The dominant type of forest in Myanmar is residual forest that sheds leaves during dry season. As a result, the associated forest fires, which are normally surface fire, are most frequent during the dry season, starting from around December until May, as shown at Table 21.

Table 21 10-day observation of forest fire cases (January to June 2008)

State & Division	1Jan-10Jan 2008	11Jan-20Jan 2008	21Jan-30Jan 2008	31Jan-9Feb 2008	10Feb-19Feb 2008	20Feb-29Feb 2008	1Mar-10Mar 2008	11Mar-20Mar 2008
Ayeyarwady	0.44	967	227	0	3178	3405	4994	4767
Bago	0.29	1064	1777	3698	7890	8629	10355	10355
Chin	0.43	68	0	0	1148	2755	8493	17675
Kachin	0.55	1137	0	02275	3981	5687	7962	10805
Kayah	0.15	224	150	75	524	1047	1272	2170
Kayin	2.67	1359	1359	388	3300	2330	4271	6600
Magway	0.29	856	1664	3708	15975	17116	22536	31093
Mandalay	0.14	1190	1666	2619	2619	3571	5952	7380
Mon	0.00	0	0	76	0	76	76	305
Rakhine	1.15	246	0	246	492	5162	3933	4671
Sagaing	0.15	2285	0	3014	1808	6631	10248	25318
Shan	0.00	43714	17158	35831	88583	124414	169203	353335
Tanintharyi	0.00	232	927	232	0	696	1391	2550
Yangon	0.00	65	131	261	261	522	261	326

Area (Acre)

State & Division	21Mar-30Mar2008	31 Mar-9Apr 2008	10Apr-19Apr 2008	20Apr-29 Apr2008	30 Apr-9May 2008	10May-19May2008	20May-29May2008	30May-8Jun2008
Ayeyarwady	1135	1362	4313	1816	227	0	0	0
Bago	10109	8876	11835	3205	0	0	0	0
Chin	16298	19053	16069	18135	459	0	0	0
Kachin	10805	79618	97247	75068	1137	2275	0	0
Kayah	1870	1421	1721	0	0	0	0	0
Kayin	7765	5047	7377	971	0	0	0	0
Magway	25103	22536	18542	15975	285	0	285	0
Mandalay	6428	5475	2857	714	0	0	0	0
Mon	152	76	76	0	0	0	0	0
Rakhine	3442	9342	9342	11308	0	0	246	0
Sagaing	47019	83188	74146	89246	1808	1206	1808	603
Shan	383195	333429	306556	129390	0	0	0	0
Tanintharyi	4405	4869	4869	464	0	0	0	0
Yangon	0	131	131	65	0	0	0	0

[31] "Figure 1: Forest Fire Atlas of Myanmar": Source – National Environmental Agency, Singapore.

Due to the excessive forest coverage of the country, the incidents are found in almost all states and divisions though sporadic. However, in particular, they are more common in upland regions of Divisions and States such as Bago, Chin, Kayah, Kachin, Mandalay, Rakhine and Shan.

Two main sources of forest fire cases in Myanmar can be categorized into natural and manmade. Yet, natural causes of lightning and friction of tightly packed trees are rarely the reason and the following man made causes are responsible for majority of the incidents:

- Shifting (slash and burn) cultivation;
- Deliberate burning of the forest for hunting purposes;
- Careless use of fire (smoking or cooking) in the forest;
- Blazing the tree trunk intentionally for collection of lacquer;
- Purposeful burning of fodder ground to make room for the growth of new grass.

7.3 Impact of Forest Fire

Notwithstanding the scarce cases of major forest fire in Myanmar, the outcomes are equally devastating and far reaching regardless of the strength of a fire. Significant impacts can be summarized as follows:

- *Loss of invaluable woodland*: Forest fires destroy saplings, valuable wood producing trees such as teak, bring about infestation of insects at burnt areas and soil degradation.
- *Threat to watershed areas*: When the forests in the headwater of rivers and streams are damaged, the surface soil loss can create increased siltation in the rivers and waterways leading to more severe flooding, decreased ground water level and dried up springs.
- *Threat to wildlife*: The death of wild animals and destruction of their habitats.
- *Threat to recreational facilities and resorts located within forest reserves*;
- *Loss of fodder ground*;
- *Threat to economy*: Loss of forest produce and precious forest resources.

At times, the effect of the forest gets magnified because of the delay in reporting of a fire event, weak coordination in the initial management of fire, difficulty in access to water, poor transportation facilities, inadequate fire extinguishing materials (traditional ones), difficulty in approaching the fire area, strong wind, dry and hot weather that creates low humidity conditions, lack of preparedness and mitigation plans or poor planning.

7.4 Forest Fire Risk Reduction Initiatives in Myanmar

The Department of Meteorology and Hydrology (DMH), in collaboration with the Forest Department and National Commission on Environmental Affairs (NCEA), is responsible for forest fire monitoring and reporting incidents, whereas fire fighting capacity is provided by Fire Services Department and Forest Department. The country's forest fire prevention procedures comply with the 1992 Forest Law and 1997 Fire Service Law.

Fire Services Department issues and deploys three basic fire prevention mechanisms in forest fire fighting:

- installation of 5-ft fire line around the fire prevention perimeter;
- installation of 15-ft wide fire trace by felling the trees and burning the debris to create a clear space;
- Installation of safety strip that spans from 300 to 500 ft in the area where forest fire might occur by felling the trees and burning the debris to create a clear space.

The real time data and information for monitoring are obtained from Singapore Weather Information Portal and National Environmental Agency of Singapore, that observes the southeast Asia regional haze situation, as well as from the international body such as National Oceanic and Atmospheric Association (NOAA).

Though not active currently, in 1998, the National Haze Committee[32] oversaw the development of the National Haze Action Plan. The plan captured the time, duration and major causes of forest fire incidents in Myanmar, aiming to mitigate the forest fire in the country and at the same time, contributing to the ASEAN Agreement on Trans-boundary Haze Pollution. Four key objectives of the plan are to develop policy and strategies to prevent forest fire, to strengthen collaboration among agencies, to mobilize resources for forest fire and haze and to develop monitoring centre for forest fire and haze.

To further the national commitment on addressing environment issues and sustainable development, the draft National Sustainable Development Strategy (NSDS) was developed in 2007, a participatory process mooted and initiated by NCEA and UNEP. The integrated goals of NSDS were sustainable management of natural resources, sustainable economic development and sustainable social development to establish sound environment policies in the utilization of water, land, forests, mineral, marine resources and other natural resources in order to conserve the environment and prevent its degradation.

[32] National Haze Committee is chaired by NCEA and made up of representatives from Ministry of Forest, Ministry of National Planning and Economic Development, Ministry of Science and Technology, Ministry of Progress of Border Areas, National Race and Development Affairs, Department of Meteorology and Hydrology and Fire Services Department

At the regional level, the Regional Haze Action Plan (RHAP) was adopted by the ASEAN Ministerial Meeting on Haze (AMMH) in December 1997. The ASEAN Haze Technical Task Force (HTTF) and the ASEAN Ministerial Meeting on Haze in 1999 endorsed the idea of an ASEAN Agreement on Trans-boundary Haze Pollution, which was signed by the ASEAN Environmental Ministers on 10 June 2002 and entered into force on 25 November 2003. The implementation of the Agreement is underway.

7.5 Looking Forward

Myanmar is often cited as the last frontier of global biodiversity in Asia. According to the Forest Department, recorded numbers of wildlife species in Myanmar are 1,000 species of birds, 300 species of mammals, 360 species of reptiles, and 1,200 species of butterflies. There are 30 wildlife sanctuaries and 6 national parks, constituting about 4.72% (31,938 sq. km) of the total land area of the country. The diverse flora and fauna and the exotic wild life mentioned above depends dominantly on the survival of the rich forestlands that provide sanctuary for them. In turn, food and other products as wood, rubber and medicinal produce are sought from the forest for national consumption as well as for foreign export. Moreover, the property of the forests in keeping the weather balanced and in mitigating episodes of extreme climate events, while preventing soil erosion and landslide problems are well known. Hence, the protection of pristine forest grounds and ensuring successful management of natural resources become necessity for the dual purpose of economic development of the country and the continued existence of animals and human.

One way of achieving this is through awareness raising and capacity building at all layers from national, sub-national to community level. Additionally, technology transfer of appropriate technology from the technologically more advanced nations, particularly GIS and remote sensing tools, can grant precise, frequent and timely data and information in monitoring and managing one's environment. With the cooperation of inter-governmental and non-government agencies including the private sectors, appropriate guidelines can be developed to realize the National Haze Action Plan and National Sustainable Development Strategies that can pave way for environmentally sound development practices in the country.

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CHAPTER 8

8. Landslide

Myanmar has experienced many types of geologic hazards including earthquakes, landslides and subsidence in karst area. Among these, earthquakes and landslides are major hazards affecting the country. Geomorphologically, Myanmar has two mountainous provinces: namely the Western Ranges and the Eastern Highland. These provinces are inherently unstable regions of the country. The steep slopes, unstable geologic conditions, and heavy monsoon rains combine to make the mountainous areas one of the most hazard-prone areas in Myanmar. More recently there has been an increase in human settlement in hazard-prone areas as a result of rapid population growth, as well as improvement in accessibility by road and the onset of other infrastructure developments. Consequently, natural and man-made disasters are on the increase and each event affects people more than before.

Earth materials on slopes may fail and move or deform in several ways, including flowage, sliding, falling and subsidence. The important variables in classifying down-slope movements are type of movement, slope material type, amount of water present and rate of movement. The causes of many landsides and related types of down-slope movement can be examined by studying the safety factor (the ratio of resisting forces to the driving forces). The controlling factors for the effect of landslides are the role of earth material type, slope, topography, climate, vegetation, water, and time. Nowadays, several new techniques related to landslide investigations such as aerial-photographic investigation, field investigation, geophysical investigation etc., are widely applied.

The principal methods in use for landslides mitigation systems are drainage system, construction of retaining wall, and well-designed civil engineering infrastructures. At present, Bio-engineering measures are the most popular and very interesting methods among them. Although the landslides are natural hazards, preventing systems and controlling techniques can be used to mitigate the loss of life and cause of damages. Technical and scientific supports on the basis of area-wise research projects are needed for effective planning and implementation of hazard mitigation scheme.

8.1 Introduction

Landslides are the most common geologic hazards in the world. The term “Landslides” is commonly used to denote the downward and outward movement of slope-forming materials along surfaces of separation by falling, sliding and flowing at a faster rate. Many different types of movement, materials, and triggering events may be involved in down-slope mass-movement of earth material. As human population increases and cities and roads expand across the landscape, mass-wasting processes become increasing likely to affect people. The geological history and activities often cause unstable conditions that lead to slope failures. Although landslides are primarily associated with mountainous regions, they can also occur in areas of low relief, especially in surface excavations for highways, buildings and open-pit mines. Moreover, erosion of river causes a large portion of landslide along the main river.

Tectonically and geomorphologically, Myanmar can be subdivided into three provinces: namely, the Western Fold Belt (WFB) in the west (southern continuation of Himalayan Fold Belt), the Central Lowland (CL) in the middle, and the Shan-Tanintharyi Block in the east. Therefore, geologically, Myanmar has two mountainous provinces: namely, the Western Ranges and the Eastern Highland. These provinces are inherently unstable areas of the country. They have steep slopes, unstable geology, and intense monsoon rains. These features make the mountainous areas the most hazard-prone regions in Myanmar. The major river of Myanmar, Ayeyarwady River flows from north to south in the central lowland. Because of flooding and erosion, landslides occur along the banks of this river and its distributaries. More recently there has been an increase in human settlement of hazard-prone areas as a result of population growth, as well as improvement in accessibility by road and the onset of other infrastructures. Thus, natural and man-made disasters increase and these events affect people more than before.

8.2 Causes of Landslide

Cause of many landslides and related types of down-slope movement can be examined by studying relations between driving forces, which tend to move earth materials down a slope and resisting forces, which tend to oppose such movement. The main cause of landslides is the event that is decreasing the resisting forces or decreasing in slope stability.

The main factors that influence slope stability are:

1. Gravity and slope gradient
2. Hydrogeologic characteristic of the slope
3. Presence of troublesome earth materials
4. Processes of erosion
5. Man-made causes
6. Geological conditions
7. Occurrence of a triggering event

8.2.1 Gravity and Slope Gradient

Shear stress and shear strength determine whether a body of rock or debris located on a slope will move or remain stationary. Shear stress may cause movement of the body parallel to the slope. As a slope become steeper, the shear stress becomes larger. Shear strength is the internal resistance of the body to remove. If shear strength exceeds shear stress, the rock or debris will not move.

$F = \frac{shear\ strength}{shear\ stress}$, If F (safety factor) <1, slope failure is imminent

8.2.2 Hydrogeologic Characteristics

Groundwater table rises up in the monsoon. It leaches out the cementing material from soil and rock masses. Perched water table builds up very fast in the season on impervious surfaces, e.g. clay seams, clay layers, bedrocks, etc. Seepage from choked catch drains may raise pore-water pressure along the slip surfaces. Due to the rising of groundwater table, it causes the saturation of the soil, which destroys the capillary tension in soil and reduces its cohesion because of increasing moisture content. Pressure of aquifers, such as sand layers or sandstone layers can cause very high pore-water pressure in slopes in sedimentary deposits.

8.2.3 Presence of troublesome earth materials

If the troublesome materials are present in an area, liquefaction, expansive nature, subsidence and sensitive phenomena occur. When water is added gradually to a granular dry soil, the materials first become plastic. If enough water is added, the particles lose contact with one another and the materials turn into loose slurry, losing their shear strength in this process. Some soils expand greatly when they are saturated with water and shrink when they dry out. They are called expansive or shrink-swell soils. They can cause extensive damage to the structures built on that material. Some compressible soils cause shrinkage and collapse resulting from water loss and that is referred to as compaction. These compaction soils result in subsidence. Liquefaction or compaction or subsidence that results from a disturbance of the internal structure of a soil is referred to as remolding.

8.2.4 The process of erosion

During the rainy season, high flow velocity of running water in steep gullies move very large boulders that will destroy roads, culverts and ecosystem. Uncontrolled flow of rainwater on slope surface washes out soil and boulders, which threaten the people who are living along the base of the hilly regions.

8.2.5 Man-made causes

Man-made landslides are due to large-scale indiscriminate deforestation, blasting and quarrying. Mass-scale construction of houses and heavy structures on the entire hill may also cause landslides. Construction of reservoirs and canals in the landslide prone area can lead to landslides. Side-casting or throwing excavated material on the downhill side also cause mass movement

8.2.6 Geological conditions

Dip of bedding planes, clay seams, joint set or weak rock layers are nearly the same as these of the slope causing planar sliding. Weathering of rock mass and weathering processes creates the permeable materials and these permeable materials can cause the increasing of pore-water pressure. Soluble rocks with solutions cavities in ***karst*** areas also cause subsidence. Huge boulders sitting on the hill surface are likely to topple or slide down.

8.2.7 Triggering events

Earthquakes have acted as triggers to many landslides and ground failures in many parts of the world. In Myanmar, serious landslides were occurred along the Kyaukkyan Fault due to Maymyo earthquakes (23 May 1912). Landslides, ground cracks, and sand blows were observed near Tagaung and its environs due to the Tagaung earthquake (5 Jan 1991). Earthquake induced landslides and liquefaction were also noted in Taungdwingyi area due to the September 22, 2003 earthquake. Since volcanoes in Myanmar are not active, there were no evidences of landslides induced as triggers volcanic eruption. The vibration of uncontrolled blasting also occurs as triggering event at the landslide prone areas.

8.3 Frequency and Impact

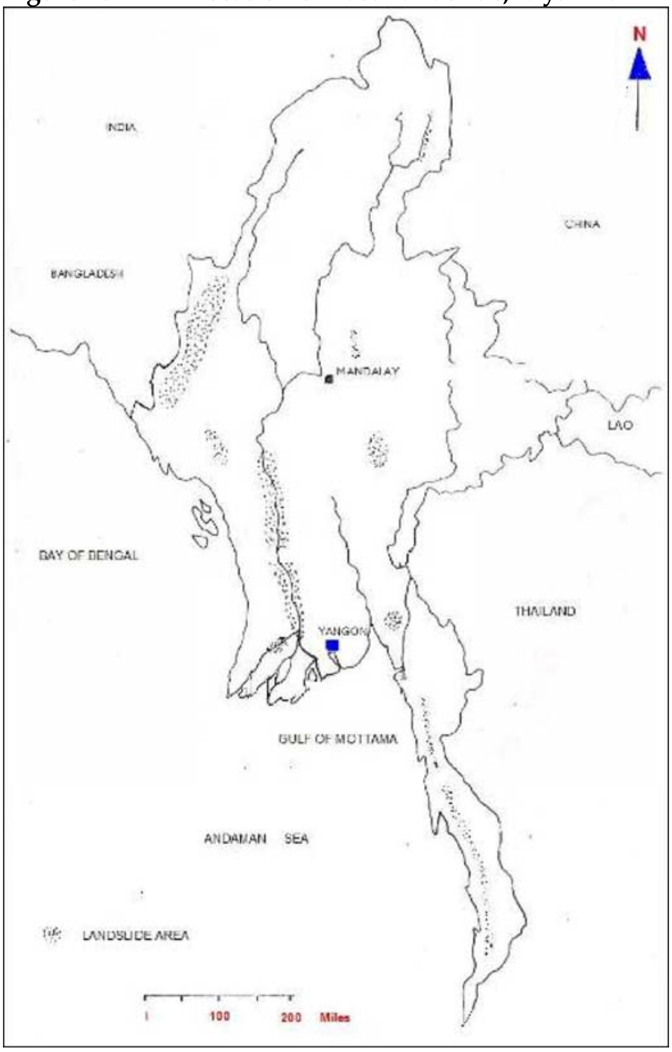
Various sizes of landslides had frequently occurred in mountainous regions of Myanmar especially in the Western Ranges and some localities in the Eastern Highland, especially along the western flank of the Tanintharyi Ranges. The collapses of river bank are found along the Ayeyarwady River and its distributaries. The western Ranges has experienced many types of landslides and earth, movement, i.e. rock falls, rock slides, soil avalanche and mud flows of various scales due to the wedge failure, plane failure, toppling, and circular failure. The direct impact of landslide in this region is the damage of the infrastructure rather than human settlement because these areas are sparsely populated.

In Eastern High Ranges, landslides of all types were occurred along the western flank of the Kachin, Shan and Tanintharyi Ranges. In Tanintharyi area, some rural houses and primary school were buried in the debris materials during the rainy season in 1999. The landslide hazards, which frequently occur in Shan State is along the railroad in hilly terrain, lying between the Yinmabin Plain and the Kywedatson Plain. Both plains are in metamorphic and igneous terrain, which were weathered deeply. They are more exposed in the East of Kyauk Pan Oo Stream. In 2001, subsidence events were occurred in Nansang area due to the ***karst*** formation. There were no any impacts due to those events. However, landslides in Mogok have observed as some types of mass movements and caused the loss of lives and properties in June, 2008.

8.4 Landslide Prone Areas in Myanmar

Tectonically and geomorphologically, the physiographic unit of Myanmar can be divided into three provinces: the Western Fold Belt (WFB), the Central Lowland (CL), and the Eastern Highland (EH). Structurally and lithologically, potential landslide hazards can be found in parts of Eastern Highland and Western Fold Belt. One of the major rivers of Myanmar, River Ayeyarwady flows from north to south in the Central Lowland. Because of erosion and flooding of this river, landslide hazards occur along the bank of this river and its distributaries. These hazard areas are shown at Figure 20.

Figure 20 Location of Past Landslide, Myanmar



8.4.1 Landslide hazard in Shan-Tanintharyi Block

This province is composed of the oldest rock units in Myanmar, such as gneiss, schist, phyllite, greywacke, metasedimentary rocks, limestone and dolomite. Due to the long-term erosion and weathering, differential, erosional and weathered features such as scarps, steep slope and ***karst*** topography are occurred. Moreover, some igneous rocks which intruded among these units are also observed and these phenomena made the area more complicated. Because of the steep slope, highly weathered nature and heavy rain along the eastern part of this province has experienced many types of landslides. Landslide and karst photographs are at Figure 21.

Figure 21 **Landslide and Karst, Myanmar**

Landslide hazard in Western Fold Belt (Southern Continuation of Himalayan Fold Belt)

In this province, the landslide hazards are commonly occurred along the eastern flank of the ranges, Kale-Ti Dim-Falam road and Kale-Ta Mu road. The most common types occurred in this province are (i) circular failure (ii) plane failure (iii) wedge failure and (iv) toppling. As this region consists of Rakhine Yoma, Chin and Naga Ranges, most of the rock types occurred in these ranges are thick layers flysch rocks, metamorphic rocks metasedimentary rocks and ultrabasic rocks. The layers of the rocks are tightly folded and dipping east direction. Large over thrusts with inclined fault plane are exposed as north to south direction. The main causes of landslides in this province are abnormally high pore-water pressure, which rises during the rain storms, cutting down of natural vegetation, under cutting erosion, and digging of slope toe. Photograph of landslide from this belt is at Figure 22.

Figure 22 **Circular Failure, Kale Myo**

Landslide hazards along the banks of Ayeyarwady River

Landslide features are usually found along the banks of lower Ayeyarwady River and its distributaries. The landslide hazard is related with the seasonal rise and fall of river water-level. In rainy season, the water level of the Ayeyarwady River is high, and large amount of water may enter the banks, producing bank storage phenomena. When the water level suddenly drops in the hot season, the stored water in the bank is left unsupported. This process can produce an abnormal pore-water pressure and that reduces the resisting forces. Simultaneously, the weight of the stored water increases the driving forces due to this reason, and therefore under cutting of the banks can be formed. Finally, bank failure tends to occur along the river after the flooded water has receded. Thus, the landslide hazard has been occurred along the banks.

8.4.2 Landslide hazard in Yangon Area

Yangon area is situated at the southern extremity of a long narrow spur of the Bago Yoma. The most notable feature of the topography is the central ridge known as Shwedagon-Mingladon anticlinal ridge. Therefore, the central part of the area is higher than its limbs. Most types of the landslides occurred in this area are creeps, earth flow and slumps or block slides. Soil creeps are occurred at Shwe-Taung-Kyar, Botahtaung and Hninsigon Bobwa Yeiktha. Earth flow types of landslides are observed at Dhamazedi Road. Slumps or block slides are noted at Inya Myaing, University Avenue Road, and Cantonment, west of Yangon Zoological Garden.

8.5 Past Landslides in Myanmar

On 23rd May 1912, serious landslides happened due to Maymyo Earthquake. There were no casualties and loss of properties because the epicenter of this earthquake was in the forest, which is far from the human settlement. Landslides, ground cracks, and sand blows were found at Tagaung, Htigyaint, Kawlin and Thabeikkyin due to Tagaung Earthquakes on 12th September 1946 and on 5th January 1991. Many houses subsided and damaged due to the ground cracks and landslides.

On 22th September 2003, landslides, ground cracks and liquefaction were occurred in Taungdwingyi area because of the earthquake, which caused some casualties and damages. There was a large scale landslide (and earth movement) happened near KaleMyo, Sagaing Division of Myanmar in September 2004 during the rainy season. About 30 Kilometres of the main road including bridges were destroyed. Even a minor rock falls and soil slides block the main road and it takes several days to remove. Figure 22 shows recorded photograph of the Kale-landslide in 2004.

Landslide in Mogok, which was not related with earthquake happened on 12th June 2008. About eleven casualties occurred in this hazard. Some past landslides events are at Table 22.

Table 22 **List of Past Landslides in Myanmar**

Year	Location	Name and Type	Triggering Process	Impact
1912	North of Taunggyi	Maymyo landslide	Earthquake	serious landslides and ground cracks
1946	Tagaung	Landslides	Earthquake	380 acres of crop damaged
1991	Tagaung	Landslides	Earthquake	some buildings destroyed
1999	Along the western slope of the Tanintharyi Ranges	Landslides	Torrential rain	Buried some villages
2001	Nansang	Subsidence	Heavy rain	about 50 feet diameter circular graven appeared
2003	Taungdwingyi	Landslides	Earthquake	some slopes and rail roads along the western embankment of Bago Yoma failure
2004	Kale Myo	Kale Landslides	Heavy rain	bridges and about 30 km of the main road destroyed
2008	Mogok	Mogok Landslides	Heavy rain and Excavation	about 11 people killed

8.6 Landslide Hazard Map

There are three geologically and tectonically active landslide prone areas in Myanmar; the western region (part of the WFB) along the lower Ayeyarwady River and its distributaries and western flank of the Eastern High Land. The gradient of the slope, hydrologic characteristics of the slope, presence of troublesome earth materials, process of erosion, geological condition and triggering event cause many small and large landslides in Myanmar.

Taking consideration upon these facts, the proposed landslide hazard map is at at Figure 23. This proposed map is not detailed landslide zonation map. As a further work, landslide zonation map will be accomplished in the future.

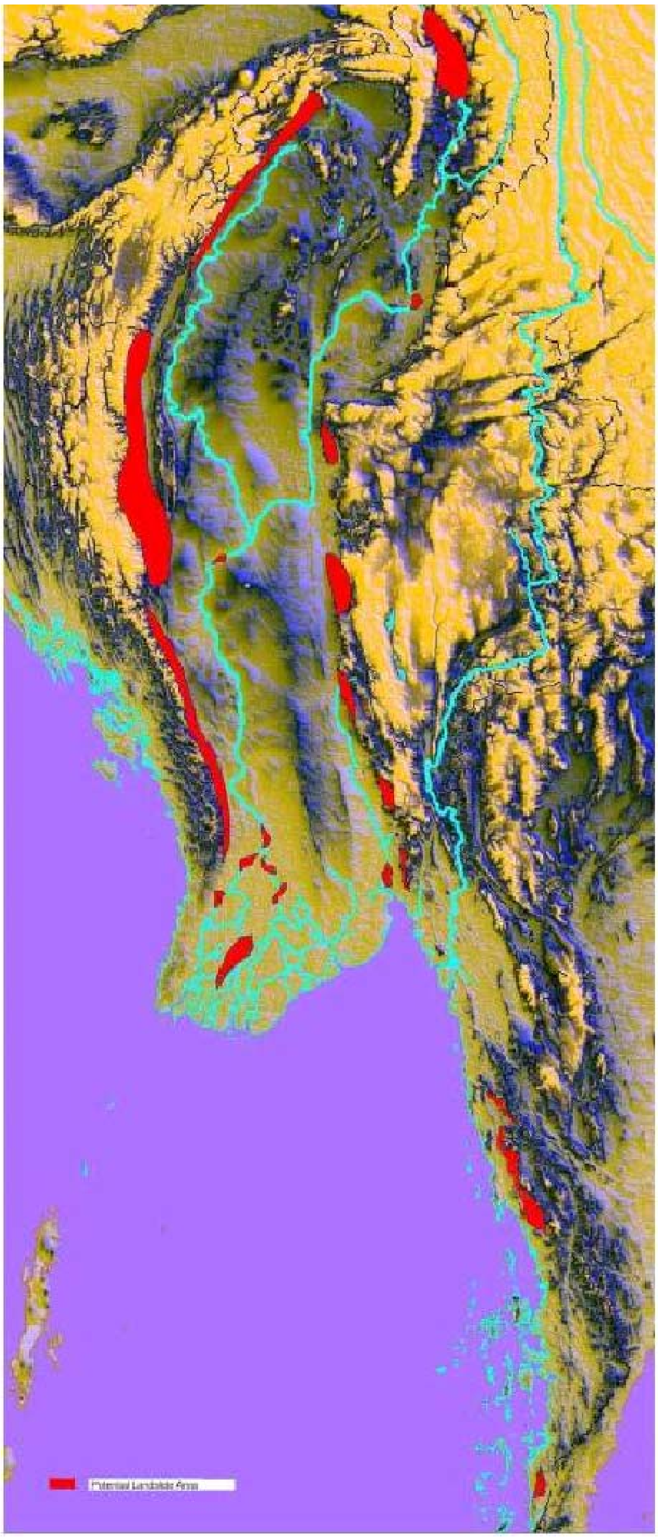
8.7 Landslide Hazard Mitigation

Much work has been done in different countries to develop adequate methods by which slides could be predicted and prevented but not much success has yet been achieved in these activities. The methods for controlling and mitigating the potential slides depends on factors like nature of the potential slide, the nature and amount of material involved in it and the economic considerations. Of many such methods, the most important are: (i) Avoidance methods, (ii) Excavation methods, (iii) Water management and drainage measure (surface drainage, sub-surface drainage), (iv) Structural support measure (rockbolts, earth or rock anchor), (v) Structural support measures (retaining wall, buttresses), (vi) Anchored structure (rockbolts, earth or rock anchor), (vii) Bioengineering, (viii) Geotextiles, (ix) River training measures (x) Landslide warning system.

8.7.1 Avoidance methods

In the construction of railway, motor roads and other engineering structures, the avoidance method is suitable for landslide prevention. If there is no way to avoid a potential slide and if prevention treatment will not assure stability, it is sometimes necessary to construct a bridge across the unstable area. Probably bridging method is used in order to prevent the landslide in the construction of the railroad.

Figure 23 Landslide Hazard Map (Proposed)



8.7.2 Excavation methods

These methods are designed to increase the stability of landslide mass by reducing the forces that cause movement. The chief methods are (a) Removal of head; (b) Flattening of slopes; (c) Benching of slopes, and (d) Complete removal of all unstable materials. Most of the problems involving the stability of slopes are associated with the design and construction of untraced cuts or highways, railways and canals. Cuts with greater depth and length are limited to prevent the landslide. The slope ratio of the road-cuts should be 1.5:1. In flooded area, the 2:1 and 3:1 slope ratios are recommended for side slopes of canals.

8. 7.3 Water management and drainage measures

Some of landslides were invariably associated with drainage problem. This indicates importance of drainage for the control of landslide. Drainage management has significantly improved the slope stability of medium and large landslides.

- **Surface drainage :** The rill and gully erosion were largely mitigated by surface drainage management. It consists of drainage channels or ditches, prevention of leakages, cleaning natural ditches.
- **Sub-surface drainage :** Sub-surface drainage of a soil-rock mass can be achieved either by pumping the water up to the surface or by opening an artificial outflow to a point which is situated at a lower level than the projected level of the lowered water table. This can be done in slopes where boreholes are drilled from the lowest point of the slope in slightly upward direction deep into the slope. These boreholes have the advantages that drainage is independent from a source of energy; the water flows out by itself. This drainage consists of drainage tunnels, counter fort trenches, deep-seated counter fort drains, vertical drill holes, horizontal borehole, slope seepage drainage wells of Ferro-concrete, and drainage of linear plates.

8. 7.4 Structural support measures

Structural support measures improve the stability of slope by increasing stabilising component of sliding mass. Structural support measures include retaining wall, anchored structures, rockbolts, earth anchors, rock anchors.

- **Retaining wall :** Retaining wall may be classified as (a) Gravity wall (b) Tie-back wall (c) Driven cantilever wall (d) Reinforced earth wall.

  Retaining wall constructed from concrete cribbing, gabions (stone filled wire baskets) or piles (long concrete, steel or wooden beams driven into the ground) are designed to provide support at the base of a slope. They should be keyed in well below the base of the slope, backfilled with permeable gravel or crushed rock and provided with drain holes to reduce the chances of water pressure building up in the slope.
- **Buttresses :** Buttresses are used in connection with embankment construction and seldom, if even, to restrain slopes in excavation. A modified application of the buttresses has been found effective in preventing sloughing or flowing of wet cut

slopes. This method, which is really a combination of drainage and buttress, consists of placing over an excavated slope a heavy blanket of clean coarse gravel or similar previous materials.

8.7.5 Anchored Structure

- **Rockbolts :** Rockbolts with bar tendons are particularly useful where plane failures and wedge failures are likely to occur. The principal of rockbolts is to integrate rock plates together so as to form monolithic mosaic. The measures are basically preventive in nature and minimises future failures of rock.
- **Earth /rock anchor :** The mechanism of load transfer from anchor relies on band at the soil-grout interface and tendon grout interface, rather than soil-soil frictional resistance. The length of earth/rock anchors in the fixed anchor zone varies depending on the degree of consolidation of soil material on nature and degree of weathering bed rock.

8.7.6. Bioengineering

Bio-engineering is the use of living vegetation, either alone or in conjunction with civil engineering structures and non-living plant material, to reduce shallow-seated instability and erosion on slopes. Bio-engineering measures can contribute the followings: (i) Prevention of scour erosion; (ii) Reduction of shallow planar land-sliding; (iii) Channelling of runoff to alter slope hydrology; (iv) Providing support to the base of the slope and trapping material moving downward.

8.7.7. Geotextiles

Geotextiles and related materials are permeable sheets or strips of materials, which are used in association with soils. They are usually made from petroleum products such as polyester, polyethylene and polypropylene. All geotextiles have the range of physical properties, mechanical properties, hydraulic properties and durability properties.

Geotextiles provide additional technology for low cost slope stabilization and reinforcement. Multiple layers of geotexiles placed in during construction or reconstruction. They will reinforce the soil and provide increase slope stability. Soil reinforcement allows for the safe construction of steep slopes, typically on the order of one horizontal to one vertical. Even vertical structures can be safely constructed. The most important benefits are: (i) reducing amount of fill material and the cost; (ii) it is easy to place gentle slope with reinforced steep slope; (iii) increasing the factor of safety of marginally stable slope; (iv) resisting construction damage imposed by compaction equipment.

8.7.8 River Training Measures

The main factor for the chosen landslide is the flood on river and the stabilization measures required river bank protection together with drainage, structural and bioengineering measures. The aim was to safeguard the road side bank rather than to train the road itself. The river bank protection work included either revetment or spur, or a combination of both.

8.7.9 Landslide Warning System

Landslide warning systems do not prevent landslides. But they can provide time to evacuate people and their possessions, and to stop trains or reroute traffic.

- Hazardous areas can be visually inspected for apparent changes and small rock falls on roads and other area can be noted for quick removal.
- Having people monitor the hazard tends to have advantages of reliability and flexibility but becomes disadvantages during adverse weather and in hazardous locations.
- Other warning methods include electrical systems, tiltmeters and geophones that pick up, vibrations from moving rocks. Shallow wells can be monitored to signal when slopes contain a dangerous amount of water and in some regions, monitoring rainfall is useful for detecting when a threshold precipitation has been exceeded and shallow soil slips become much more probable.

Landslides are threatening to the infrastructure in the hilly regions of Myanmar. The slope geometry, slope height and the material composing the hilly terrain are basic components for the instability of the slope. Mapping of terrain configuration and geology should be carried out. The landslide often associates with the ingress of both surface and subsurface water of nearby areas. Thus, hydrological and hydrogeological studies should also be conducted. The proper planning and implementation of Highway and road construction is required with the aid of engineering geologists and earth-scientists. Local community plays an important role in landslide hazard mitigation. Therefore, education on landslide hazard for rural areas should be undertaken.

8.8 Conclusion

Landslides are natural hazards of ground failure type. Many different types of movement, materials and triggering events may be involved in down-slope mass movement of earth material. The geological history and human activities often cause unstable conditions that lead to slope failures. The landslide investigations have undergone significant developments in the past few decades. Several new techniques related to landslide investigations have been evolved. The prevention and control works are carried out in the landslide areas based on the two concepts. The first concept is to save human lives and the second concept is to avoid buildings, public structure and road at landslide prone area without preventive measures. Although landslides are natural hazards, management and controlling techniques can be applied to mitigate the loss of lives and damage of properties. In Myanmar, technical and scientific supports on the research projects are needed for effective planning and implementation of mitigation programme for landslide hazards.

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CHAPTER 9

9. Storm Surge

9.1 Causes and Characteristics

Storm surge is an extraordinary flooding due to a storm. It generally occurs due to waves generated by the strong wind in tropical revolving storms. The slope of the coastline is considered as one of the important factors controlling the intensity of storm surge.

Myanmar, borders with the Bay of Bengal and the Andaman Sea, with its 2400 km long coast line are potentially threatened by the waves, cyclones and associated weather. As a tropical agricultural country, the majority of the people live in the fertile plain land which is often inundated by river floods and coastal areas exposed to stormy weather.

The Bay of Bengal of the North Indian Ocean stretches northwards from the equator to the river mouths of Bramaputra, Ganges and Magna and eastward from Madras coast of India to Myanmar coast, in the tropical region. The cyclone is accompanied by three destructive forces; such as strong winds, heavy rains and storm surges. Strong winds are as high as 120 mph, heavy rains of more than 5 inches may be collected in 24 hours, and waves higher than 10 feet may be experienced due to a landfall cyclone. Extent of damage is mainly due to the storm surge, which depends on the vulnerability of the place of landfall.

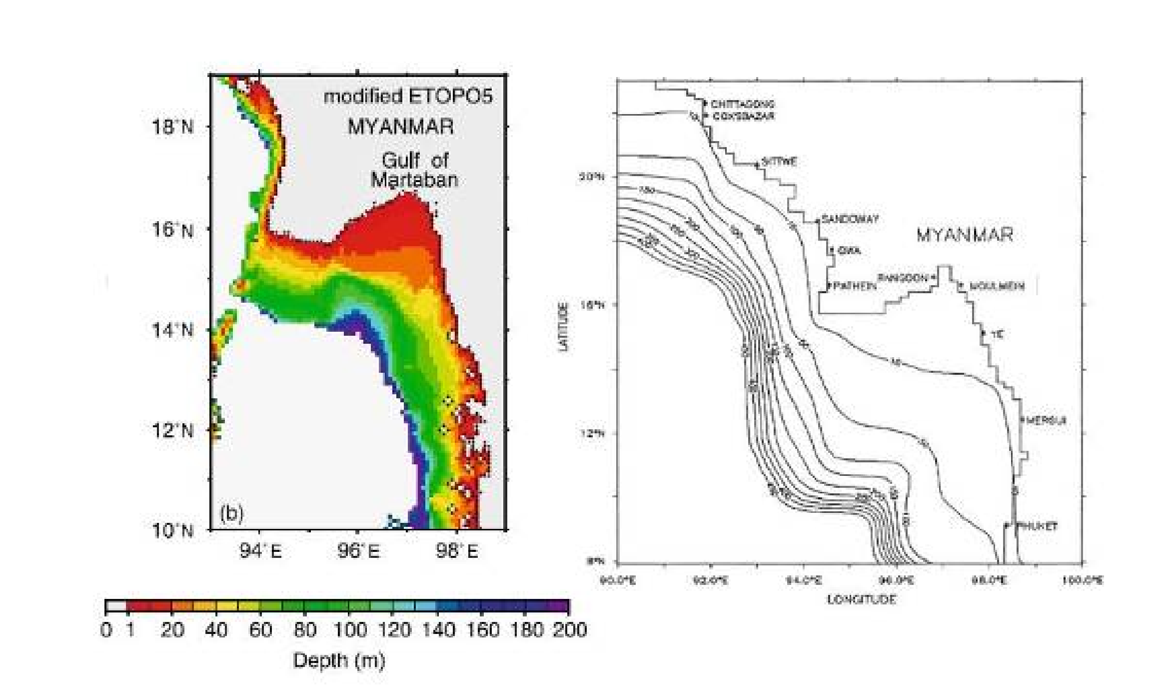
Annually, there are about ten tropical storms in the Bay of Bengal from April to December. Severe cyclones occurred during the pre-monsoon period of April – May and post-monsoon period of October- December. The tropical storm that forms during the monsoon period June – September is weak and short lived before landfall over Indian coast. Therefore, the Bay of Bengal has two cyclone seasons annually about a month before and three months after the southwest monsoon. Scientists estimated the possible heights of the storm surge based on origin and path of the storm, average velocity, water depth, time, density of seawater and other technical factors. For a generalized model for a certain area, water depth is the most important controlling factor while other information is conditional. At Figure 24, bathymetry information along the Myanmar coast are configured.

The storm surge or flooding accompanied with cyclone largely depends on the place of landfall and its path. From the experience of Nargis Cyclone in 2008, water bodies along the storm path are undeniably important in surge estimation. The following factors are some of those controlling potentiality of high storm surge in an area:

- Altitude above mean sea level,
- Distance from the sea,

- Water volume of nearby source of surge,
- Nature of the river mouth, and
- Route of the storm and interaction with tributaries.

Figure 24 **Region and depth contours in meters based on ETOPO5***



*Sindhu et al., 2007 and Jain et al., 2006 left and right pictures respectively

9.2 Frequency and Impact

During 1975 Pathein cyclone, with a radius of 20 Km maximum wind and pressure drop of 22 hPa, highest surge near landfall point resulted 1.2 m, in Yangon 0.6 m and coastal stretch from Mawlamyaing to Ye was 0.4 to 0.7 m. In 1982 Gwa cyclone, radius of maximum wind at 30 Km, pressure drop of 55 hPa, the storm surge was as high as 4 m near the landfall point near Gwa. In 1992 Thandwe cyclone, radius of maximum wind at 20 Km, pressure drop of 25 hPa, resulted maximum surge 1.5 m near Thandwe, and in Sittway at 0.7 and in Pathein at 0.3 m. During 1994 Sittway cyclone, with a radius of maximum wind at 30 Km and pressure drop of 50 hPa, maximum surge occurred near Sittway was 4 m.

Among the above-mentioned four disastrous cyclone events that occurred during 1975 to 2000, maximum surge 4 meter in the landfall point experienced and found the 80 per cent decrease of surge level that was 0.2 m at the extent of 200 Km apart. In addition, there also occurred three more events viz. Kyaukphyu (2003), Gwa (Mala cyclone) (2006) and Laputta (Nargis cyclone) (2008) cyclones (Table 23).

9.3 Vulnerable Locations in the Country

Myanmar has a fairly long coastline which is about 2400 kilometers long. It consists of three main segments; namely, the Rakhine (formerly Arakan) Coast in the northwest, the Ayeyarwady (formerly Irrawaddy) Delta in the middle, and the Tanintharyi (formerly Tenasserim) Coast in the south.

The northern Rakhine Coast, adjacent to Bangladesh, consists of some large offshore islands, and the intervening areas between these and the coastline are marshy and partly covered with mangrove forests. This setting, therefore, provides partial protection from surge waves; however, its flat nature and very gentle slope with numerous streamlets reinforce the vulnerability of the region. The southern Rakhine Coast is generally rocky and sandy with three popular resort areas. Thus, this part is comparatively more vulnerable to the storm but surge hazard.

The Ayeyarwady Delta is a large delta with wetlands and mangrove forests, which provides partial protection from storm waves. The delta front is wide with shoals in some places, thus slowing down the speed of tsunami; however, most part is opened to the storm surge. Immediately to the east lies the mouth of Sittaung River, which is a wide estuary that widens southwards to form the Gulf of Mottama. According to the controlling factors described in Section 9.1, Ayeyarwady delta has the highest vulnerability to the storm surge as it occupies lowest altitude, and high water volume because of numerous tributaries: several open or bell shaped river mouths, and very shallow slope.

The Tanintharyi Coast consists of two geomorphic parts. The northern part is rocky and bare, but the southern part contains the Myeik (Mergui) Archipelago consisting of more than eight hundred islands, which are sparsely populated, with human settlement mainly on the east coasts. Compared to the Bay of Bengal, the Andaman close to the coast has rather less possibility for cyclones or tropical revolving storms. Therefore, the potential of storm surge can be minor.

9.4 Past Occurrences

The highest surge occurred along the Myanmar Coast during 1975 to 2000 have been already described in Chapter 9.3. At Figure 25, observed maximum surge during 1947 to 2008 are displayed. Recent events are tabulated at Table 23.

Figure 25 **Storm Surge observed along the Myanmar Coast (1947-2008)**

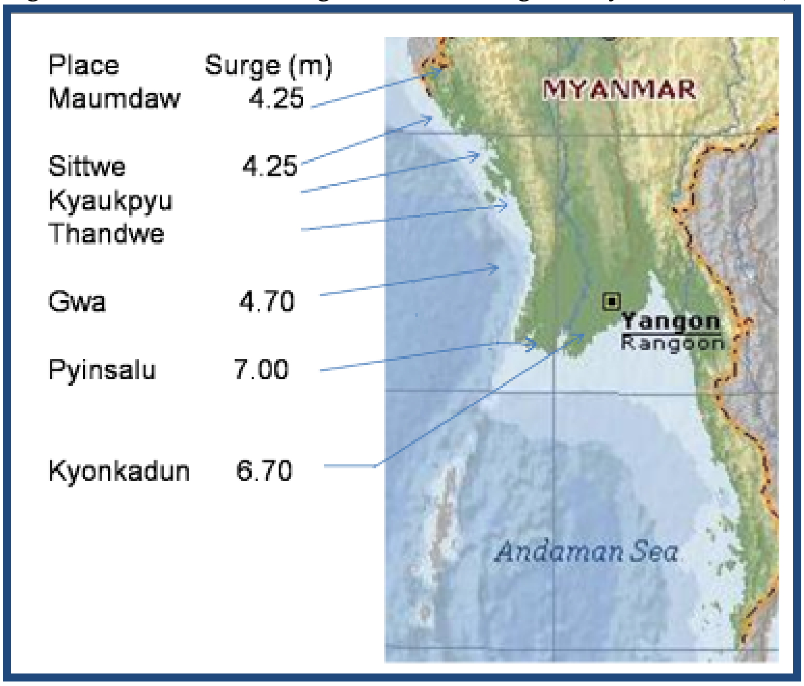
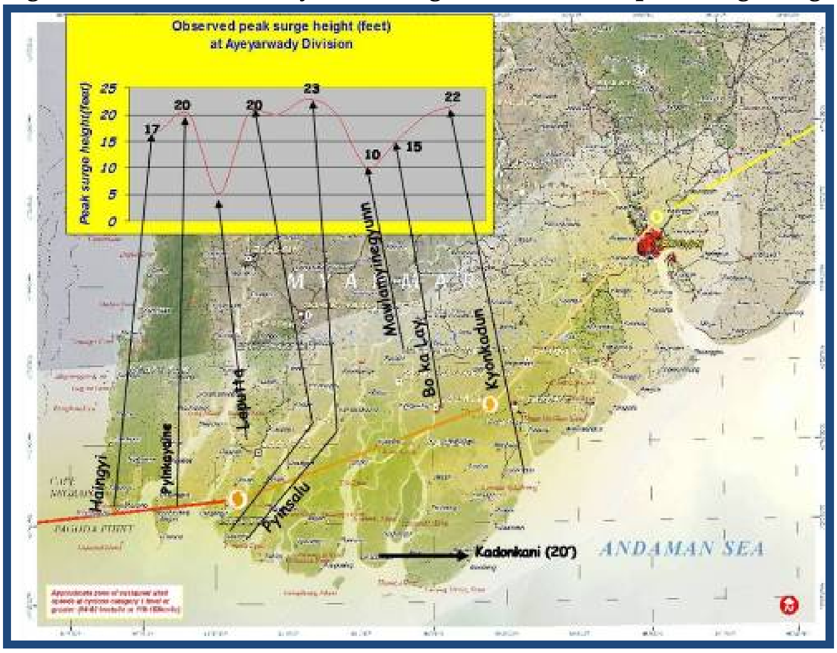


Table 23 **Some observed and model results (without correction) of surge**

S/N	Date	Landfall	Max wind (m/s)	Surge observed (m)	Surge computed (m)
1	4-5-1982	Gwa	70	3.70	8.35
2	10-5-2003	Kyaukpyu	35		3.70
3	29-4-2006	Gwa	60	4.57	7.18
4	3-5-2008	Pyinsalu	60	7.01	4.08

During the cyclone Nargis, the most notable event in which hundred thousands of people were killed in storm surge, the highest flood levels were recorded because of its path along or close to the 200 km long coast line with 50 per cent total occupation of river mouths. As the tropical revolving storm acts in anti clock-wise wind circulation and present one moved east of northeast or leaving the large water bodies including sea in the right side, a large amount of water have been blown upon the land. The highest surge in Pyinsalu (Laputta Township) of 7.6 m occupied 90 per cent of land for several hours (Figure 26).

**Figure 26	Path of Cyclone Nargis and observed peak surge heights by DMH**



## 9.5	Possibility of Storm Surge Hazards

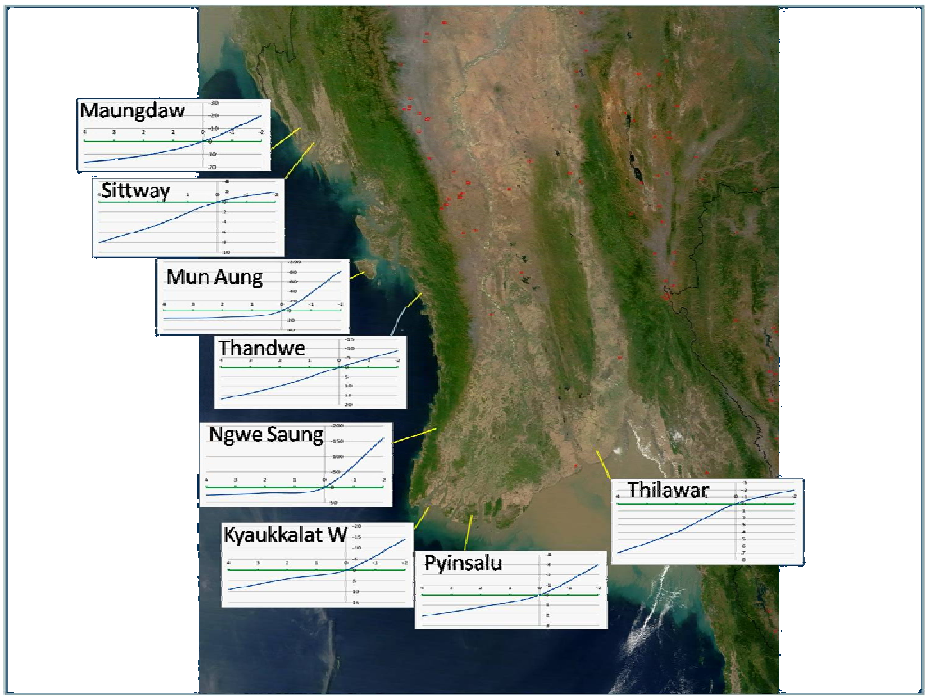
Studying possibility of storm surge for Myanmar Coast is on two major scopes:

(i)	Potential of cyclones and

(ii)	Potential flood hazard for a certain area.

In this text, the main potential flood hazard for Rakhine Coast, Ayeyarwady Delta, and Tanintharyi Coast has to be highlighted as potential of cyclones has already described in the another report. Several scholars pointed out that bathymetry or slope and depth information of the near shore region as one of the most important controlling factor for the storm related flood level (Indu et al., 2006; Sindhu et al., 2007; San Hla Thaw and Soe Thura Tun, 2008). At Figure 27, slope information along the Myanmar coast is shown.

Figure 27 Slope information along the Rakhine and Ayeyarwady Delta coasts**



**Bathymetry information is based on Burma Survey (1953) maps and SRTM imagery

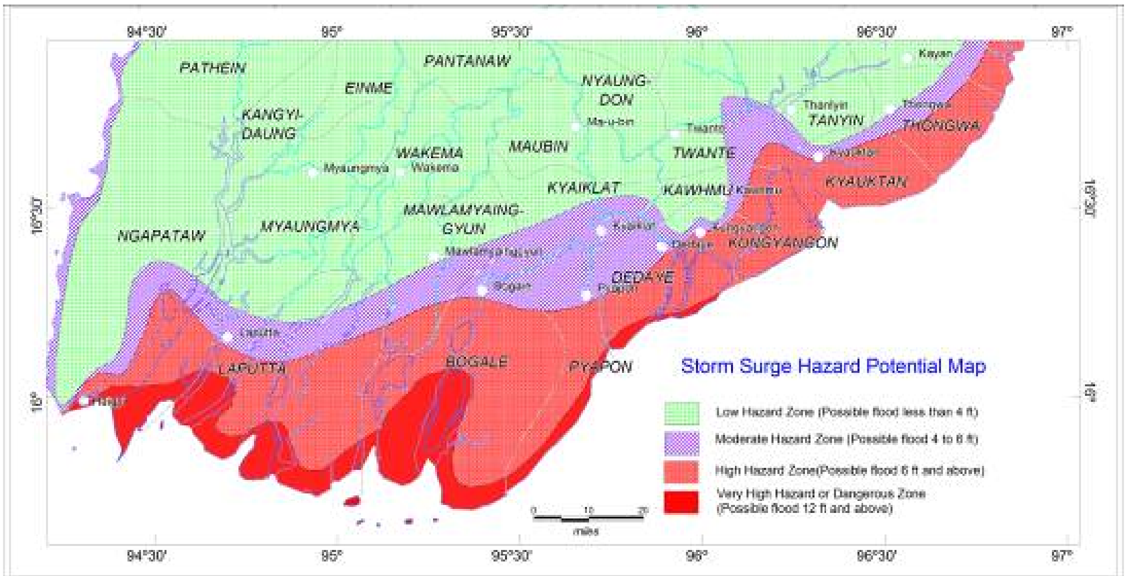
Table 24 River mouth (from West to East) along the Ayeyarwady and their width

S/N	River mouth	Width (km)
1	Pathein	15.20
2	Thetkethaung	12.00
3	Yway	3.60
4	Pyinsalu	6.00
5	Ayeyarwady	12.00
6	Bogale	13.40
7	Pyapon	2.00
8	Thandi	11.00
9	Toe	8.00
	Total	**83.2**

Apart from the computed storm surge models (e.g. Indu et al., 2006), we can take lesson from the past cyclones that its path leaving the sea in the right side and tributaries and their river mouths are serious factors controlling the peak surge. According to the factors described in

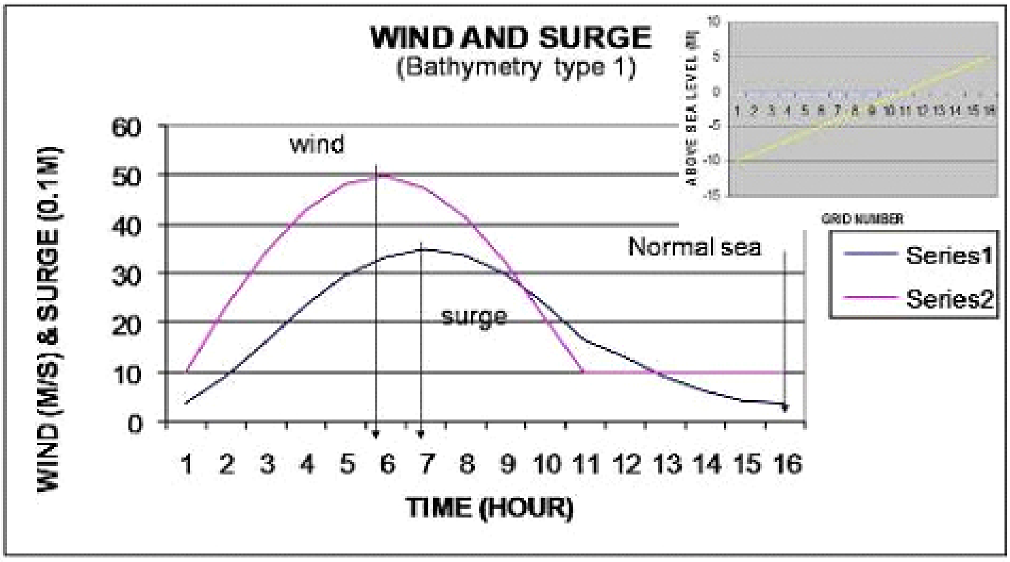
Section 9.1, the Myanmar Engineering Society recently published the Storm Surge Hazard Potential Map for the Ayeyarwady Delta shown at Figure 28.

Figure 28 Storm Surge Hazard Potential Map of the Ayeyarwady Delta Region***



*** Map (version 1.2; 2008) by Myanmar Engineering Society; township boundaries are displayed for disaster management purpose

Figure 29 Storm and Surge Model****



Maximum surge height occurs about one hour after maximum wind.

Seasonal wave is about 0.3 m with prevailing wind of 10m/s.

**** San Hla Thaw (2008)

Table 25 **Distribution of Storm surge hazard potential (in percent) of Townships in Ayeyarwady and Yangon Divisions**

Hazard Zones	Low	Moderate	High	Very High
Ayeyarwady Division				
Bogale	0	15	60	25
Einme	100			
Kangyidaung	100			
Kyaiklat	55	45		
Kyaunggon	100			
Laputta	15	20	40	25
Maubin	100			
Mawlamyinegyun	50	30	20	0
Myaungmya	95	5		
Ngaputaw	60	12	15	13
Pantanaw	100			
Pathein	90	10		
Pyapon	0	25	55	20
Yangon Division				
Dedaye	50	35	15	
Kawhmu	35	30	35	
Kayan	60	18	22	
Kungyangone	30	156	55	
Kyauktan	15	20	65	
Nyaungdon	100			
Tantabin	100			
Tanyin	80	20		
Thongwa	20	20	40	
Twante	45	35	15	
Yangon City	85	15		

9.6 Recommendation for Storm Surge Hazard Reduction

As shown at Figure 29, maximum flood normally arrives about an hour later than maximum wind during the storm. While people know the highest flood level of their area, they have sufficient time to find the place to be free from surge. It is recommended that following activities may be undertaken for the Storm surge hazard reduction:

Scientific and Technical

- Conduct research on Storm and Storm surge to understand more about Myanmar Coast and adjacent waters

- Prepare storm surge hazard potential maps for 3 coastal segments and modification throughout (only first version map for the Ayeyarwady Delta has been produced)

Authority

- Build emergency shelters in high risk zones
- Disseminate Do's and Don'ts related to Storm surge

Communities

- Share the knowledge on Storm and Storm surge
- Identify escape route, minimum time to reach shelter from each location, make known to all inhabitants by having stone landmarks for every 10 hectre (about 25 acres) for the high risk and danger zones
- Identify and train people who can take care of vulnerable groups during disaster
- Identify resources and keep in state of preparedness

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Chapter 10

10. Tsunami

10.1 Causes and Characteristics

Myanmar indeed is earthquake-prone as it lies in one of the two principal earthquake belts of the world-the Alpide Belt. The historical and seismic records show that in addition to some major historical earthquakes in the distant past, there had been at least 16 large earthquakes with M $\geq$ 7.0 RS within the territory of Myanmar in the past 170 years. There were also records of moderate Tsunami generated by two large magnitude earthquakes, which originated in the Andaman-Nicobar Islands. [These are 31 December 1881 Car Nicobar Earthquake (7.9 RS) and 26 June 1941 Andaman Island Earthquake (7.7 RS)]. Of course, the Tsunami generated by the giant 2004 Sumatra Earthquake also caused moderate damage in some parts of the Myanmar Coast (*see* also Satake et al, 2006). Thus, it is evident that Myanmar is vulnerable to hazards from moderate and large Tsunami along its long coastline. In view of these, it is necessary to assess the earthquake and tsunami hazard potential along the Myanmar coastal areas.

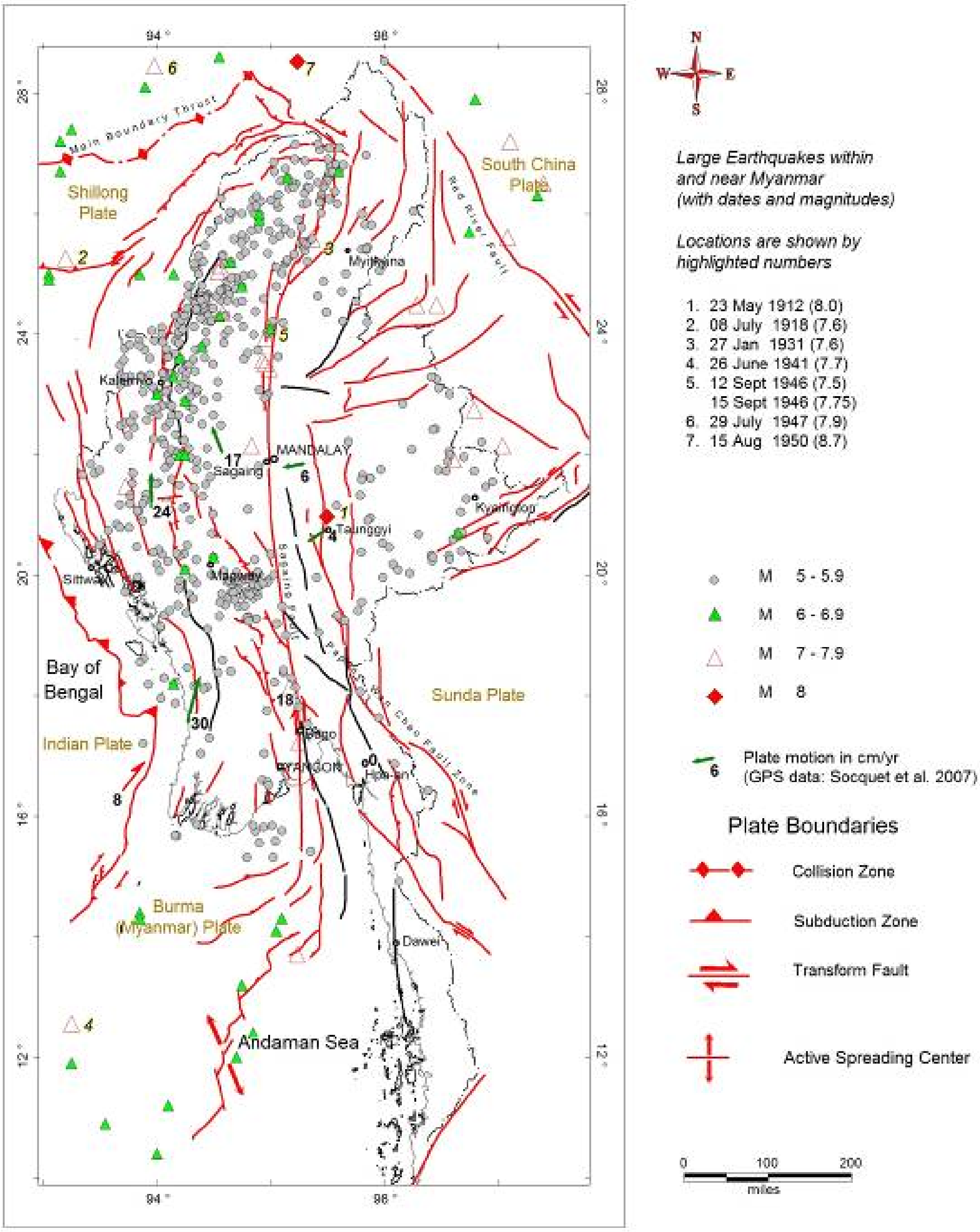
The seismotectonics of the Myanmar region is shown at Figure 31. Earthquakes in the Myanmar region have originated from two main causes: (1) the subduction (with collision only in the north) of the northward moving India Plate underneath the Burma Plate at an average rate of 4–6 cm/year along the Andaman Megathrust Zone; (2) the northward movement of the Burma Plate from a spreading centre in the Andaman Sea at an average rate of 2.5–3.0 cm/year. Very large over-thrusts along the Western Fold Belt have resulted from the former movement, and the Sagaing and related faults from the latter movement.

Intermittent jerks along the northern extension of the Sumatra-Andaman Megathrust Zone can cause tsunamigenic earthquakes, as the nature of plate convergence is thrust type mechanism. The earthquakes generated by sea-floor spreading in the Andaman Sea, however, are mostly small to moderate and shallow-focus, and are not capable of generating tsunamis.

10.2 Frequency and Impact

Tsunami record in Indian Ocean has not been well documented until now. After 2004 Tsunami, scientists from Geological Survey of Japan could find at least three large tsunami records in the Bay of Bengal and Andaman Sea region during 2800 years time span. The last one before 2004 was dated as of 550 to 700 years ago (Jankaew et al., 2008), after studying peaty soils in the sand sheets of Phra Thong Island, 125 km north of Phuket, Thailand. Therefore, it can be assumed that big tsunami might occur in about 500 to 700 years.

Figure 31 Seismotectonic map of Myanmar and surrounding regions*



* Active faults are shown in red lines (Earthquake data: ANSS Catalogue for the period 1950 2008; from other sources for 1912-1949; data are in Richter Scale)

10.3 Vulnerable locations in the country

Myanmar has a fairly long coastline, which is about 2400 kilometers long. It consists of three main segments; namely, the Rakhine (formerly Arakan) Coast in the northwest, the Ayeyarwady (formerly Irrawaddy) Delta in the middle, and the Taninthayi (formerly Tenasserim) Coast in the south.

The northern Rakhine Coast, adjacent to Bangladesh, consists of some large offshore islands, and the intervening areas between these and the coastline are marshy and partly covered with mangrove forests. This setting therefore provides partial protection from tsunami waves. However, the Southern Rakhine Coast generally is rocky and sandy with three popular resort areas. Thus, this part is comparatively more vulnerable to the tsunami hazard. The Ayeyarwady Delta is a large delta with wetlands and mangrove forests, thus providing partial protection from tsunami waves. The delta front is wide with shoals in some places, thus slowing down the tsunami speed. Immediately to the east lies the mouth of Sittaung River, which is a wide estuary that widens southwards to form the Gulf of Mottama.

The Taninthayi Coast consists of two geomorphic parts. The northern part is rocky and bare, but the southern part contains the Myeik (Mergui) Archipelago consisting of more than eight hundred islands, which are sparsely populated, with human settlement mainly on the east coast, i. e., in the shadow sides from tsunami waves. Moreover, the southern part is partially covered with mangrove forests, thus providing partial protection from tsunami waves. These factors indicate that the southern part is comparatively less vulnerable to the tsunami hazard.

10.4 Past occurrence inferred from historical earthquakes and flooding

In recent months, some geoscientists (Cummins, 2007; Sieh, 2007) speculated that there can be a possibility of a giant tsunamigenic earthquake in the northern Bay of Bengal (that includes the Rakhine Coast) in future. Their speculations were based partly on the Megathrust tectonic setting and stress and crustal strain observations, and partly on the historical account of a large earthquake that occurred on 2 April 1762 in northern Bay of Bengal. Both authors refer to the account given by Halstead (1843) that was recorded some eighty years after the said event. Halstead recorded raised marine terraces in six different localities along the northern Rakhine Coast with heights ranging from 3 m to 7 m. He also mentioned “the sea washed to and fro several times with great fury, and then retired from the grounds”. However, according to him, no lives were lost. This may perhaps suggest a local tsunami.

Chandra (1978) (in Satyabala, 2003) located the epicenter of 1762 earthquake at 22° N and 88° E, i. e., north of Kolkata. On the other hand, Ganse and Nelson (1982) located the epicenter at

22° N and 92° E, i. e., east of Chittagong where the damage was severe. In case the epicenter was on land, the possibility of tsunami is very less. Considering the two different views on the epicenter of 1762 Earthquake, it is difficult to ascertain whether the Earthquake generated tsunami or not.

Recent paleoseismological studies by the joint Myanmar-Japanese teams in the northern Rakhine Coast (Than Tin Aung et al., 2008) reveal the presence of at least three raised marine terraces with radiocarbon dates ranging from 1400 BC to 1860 AD, and indicate that there were at least three great earthquakes (including 1762 earthquake) in that general region in the past 3400 years. Based on an average recurrence interval of about 1000-1800 years, the authors suggest that in the near future the chance of next large earthquake may be low. So far, tsunamites have not been recognized yet.

Figure 32 Record of damage and casualties in 2004 Tsunami at the Ayeyarwady Delta Region

Table 26 Damage and death in Myanmar due to 2004 Tsunami

State/Division, Township	Villages	House-holds	Affected Population	Injured	Missing	Deaths	Properties damaged
Ayeyarwady Division							
1. Labutta	7	337	1,138	41		25	99 boats, 8 schools, 4 rice mills, 1 pagoda
2. Ngaputaw	9	108	1,007			5	19 boats, 1 bridge, 2 pagodas
3. Bogale (urban areas)						1	wall collapsed
Rakhine State						22	
Tanintharyi Division	7	92	447			8	44 boats, 3 warehouse, 1 bridge
Total	23	537	2,592	41	3	61	162 boats, eight schools, four rice mills, three pagodas, three warehouses, two bridges, one wall

During 2004 Indian Ocean Tsunami, some casualties and damage occurred along the Ayeyarwady Delta Region shown at Figure 32. At Table 26, a summary of reported damage record is captured.

10.5 Possibility of Tsunami Hazards

With reference to the seismic zone map of Myanmar prepared by Maung Thein and Tint Lwin Swe (2006) as shown at Figure 33 and certain characteristics of the three segments of the Myanmar coastline as mentioned in Section 10.3, the probable earthquake and tsunami hazards along the Myanmar coastal areas are summarized at Table 27.

Table 27 Probable earthquake and tsunami hazards along the Myanmar coastal areas

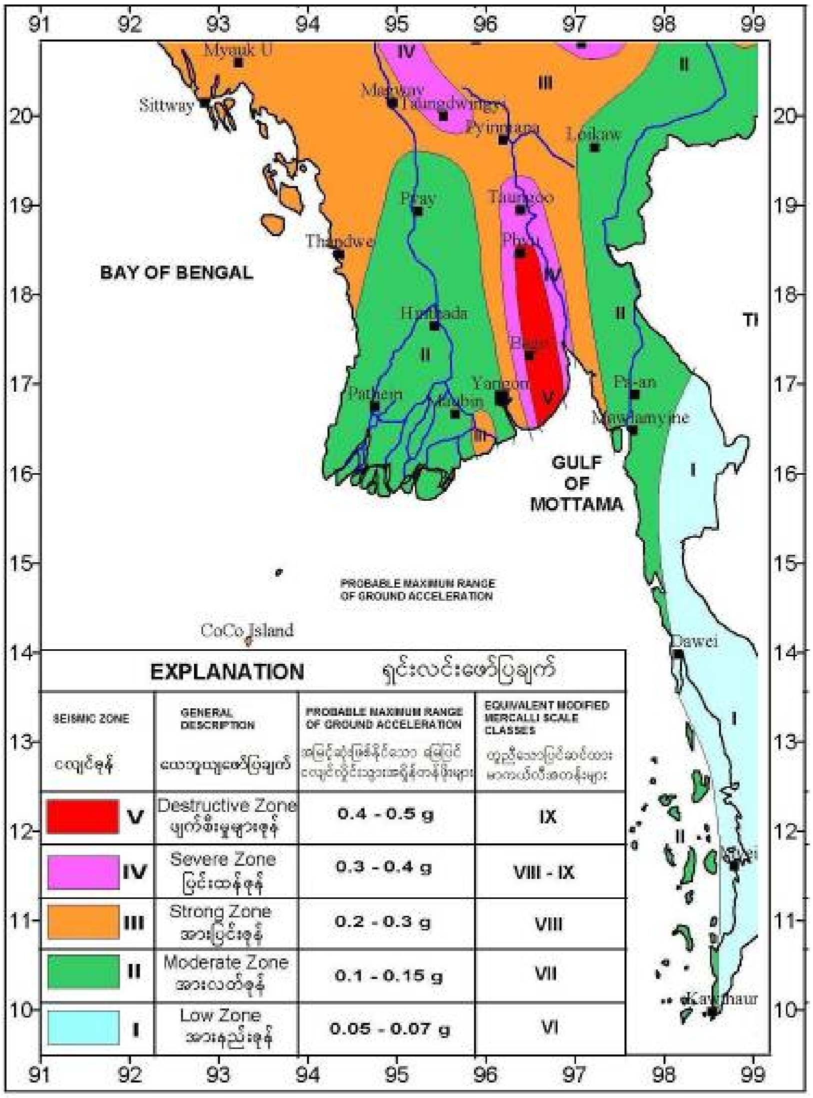
Coastal Region	Area	Earthquake Hazard	Tsunami Hazard
Rakhine Coast	Northern part	Strong Zone with MMI 8	Moderate*
	Southern part	Moderate Zone with MMI 7	Moderate
Delta Area	Ayeyarwady Delta	Moderate Zone with MMI 7	Moderate
	Sittaung Estuary	Severe Zone with MMI 8-9	Moderate
Tanintharyi Coast	Northern part	Moderate Zone with MMI 7	Moderate
	Southern part	Moderate Zone with MMI 7	Light**

* maximum run-up height 4 m, **maximum run-up height 2 m

10.6 Recommendation for Tsunami Risk Reduction

In the light of such hazard potential, concerted efforts by scientists and organizations are needed for the preparedness and mitigation of earthquake and tsunami hazards along the Myanmar coastal areas. Furthermore, as mentioned in Section 10.5, recent paleoseismological findings in northern Rakhine Coast suggest that the chance of future large earthquake may be low. However, Cummins' (2007) idea of the possible generation of tsunamis by submarine landslides in the very thick (about 20 km thick) Bengal Fan should also be taken into consideration. Thus, it is prudent to install an effective tsunami warning system in the northern Bay of Bengal with international cooperation. Myanmar Engineering Society is preparing a tsunami hazard potential map for mitigation and preparedness.

Figure 33 Seismic zone map of coastal areas**



** Extract from Maung Thein and Tint Lwin Swe, 2006

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