J. Myanmar Acad. Arts Sci. 2018 **Vol. XVI. No. 5**

GEOHAZARDS AND PRELIMINARY STUDIES ON ENVIRONMENTAL DEGRADATION IN BAGAN - NYAUNG OO AREA, MANDALAY REGION

Tun Naing Zaw[1] ,Swun Wunna Htet[2]& Min Thura Mon[3]

Abstract

Bagan-Nyaung Oo area is the most picturesqu earchitectural complex in Myanmar. Bagan–Nyaunng Oo area is situated between 94°45'00" E to 95°00' 00" E and 21°00' 00" to 21°15' 00" N. The research aims are to demonstrate the application of Remote Sensing (especially satellite image analysis) and to interpret the Engineering Geology approach to Environmental Geology and vice versa. The research area covers mostly the alluvial plain flanking the Ayeyarwady River and partly the debris and small fan materials derived from Tuywin Taung and Tantkyi Taung hills whichare exposed with rocks of Miocene to Oligocene. Bed rock in the area is mainly represented by rocks of Irrawaddy Formation (Late Miocene to Pliocene), Okhmintaung Formation (Upper Oligocene) and Padaung Formation and Shwezettaw Formation (Lower Oligocene). Mainly the alluvial soils of Quaternary-Recent are deposited on the plain and along the river banks by fluvial action.The areas susceptible to landslides, rock falls, mass movements, and debris flows hazards are demarcated in the Tuywin Taung and Tantkyi Taungthat have been encountered with a number of small tension cracks, active and old landslides. Side cutting in both sides of Ayeyarwady River banks is caused by river bank scouring and rain water resulting into steep slopes. In the rainy season, low lands adjacent to the Ayeyarwady River and the main streams in the area are affected by flood. Low to medium bearing capacity areas are concentrated in the areas where active alluvial fan and river bed deposits. Most of the plain area is covered by a firm soil with a stable bearing capacity and so appropriate for small to medium scale construction purposes. Several locations of construction materials quarry sites are seen in the study area. Improper quarrying of construction materials trigger the landslides and river bank scouring. Existing land use patterns in the study area are agricultural, sparse forest and scrub, settlements, industries, recreation centres infrastructures, small land fill and waste disposal sites. The root causes of river water pollution in Nyaung Oo area are direct connection of sewage drainage, sewage pipe line, haphazard disposal of industrial, hospital and hotels waste in open space and stream and improper dumping of solid wastes into the riverside area.

1. Dr, Lecturer, Department of Geology, University of Yangon
2. 2nd year Honours, Department of Geology, University of Yangon
3. 2nd year Honours, Department of Geology, University of Yangon

Earthquakes on July 8th, 1975 and August 24th, 2016, severely damaged more than half of the important structures and irreparably destroyed many of them. Flood causes, destruction by earthquakes, landslides and erosion and LCLU (Land Cover/Land Use) evaluation are mentioned. The research would be a general help to planners and developers at local level particularly in hazard mitigation, environmental management and civil engineering developments within the research area.

Keywords –Environmental degradation, river bank scouring, bearing capacity, river water pollution, sewage, haphazard disposal, hazard mitigation

Introduction

Bagan-Nyaung Oo area, situated within the study are is the most picturesque architectural complex in Myanmar-Bagan, that reflects the day of the Buddhist religion, strengthening and aggrandizing the outlook of the whole of society. The World Heritage Site of Bagan is the Golden Land of wonders. Over 3,000 extant monuments are scattered across a vast arid plain that proclaims the piety and power of Myanmar's first empire. As a manifestation of a dynamic and original form of architecture, Bagan ranks among the other great Buddhist centres of South-East Asia, such as Angkorwat in Cambodia or Borobudur in Java, Indonesia.

Bagan is a global pilgrimage centre and contains ancient Buddhist shrines that have been restored and repaired to retain the original architecture. Earthquakes on July 8th, 1975 and 24th of August, 2016 severely damaged more than half of the significant structures and irreparably destroyed many of them. The study area is dominated by the ancient temples and pagodas. It also encompases both urban and rural environments.

Location

Bagan-Nyaung Oo area is situated between 94° 45' 00"E to 95° 00' 00"E and 21° 00' 00"N to 21° 15' 00"N. It is located on both sides of the Ayeyarwaddy River bank and approximately 145 km southwest of Mandalay and 187 km from Yangon. Bagan stands on the east bank of the Ayeyarwaddy, Figure (1).

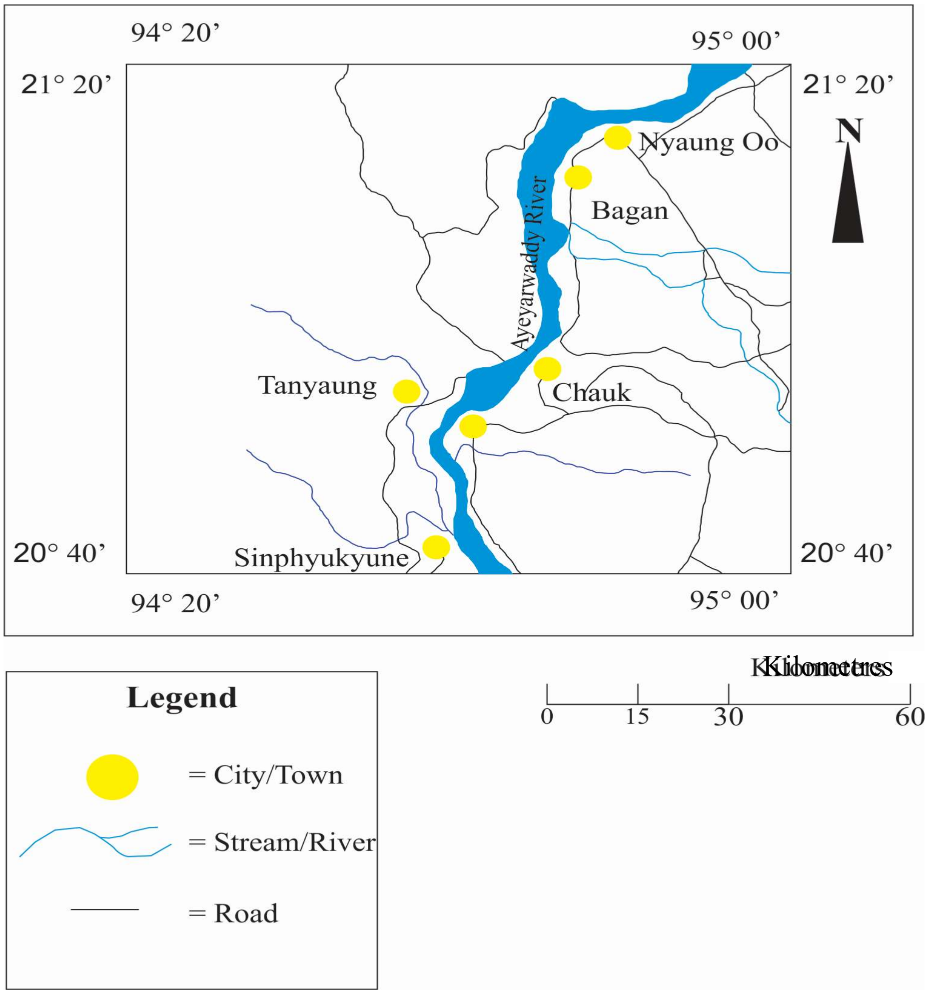


Figure 1. Location Map of the Research Area

Topography and Drainage

Generally, the study area is mainly within the low level plain flanking of the Ayeyarwaddy River. The elevation of the study area ranges from 5.2 m to 408m above mean sea level. Bagan-NyaungOo area lies on either side of Ayeyarwaddy River, as a vast plain on the eastern bank. There are hill ranges namely, TaywinTaung in the southeast and TantkyeeTaung in the west.

The drainage pattern in the study area is dominantly dendritic. Most of the drainage are very poorly but dense meaning the streams are all seasonal.

Ayeyarwaddy River tis the main perennial drainage channel of the studyarea fllowing in N-S direction. Its morphology is controlled by underlying structures and active tectonism.

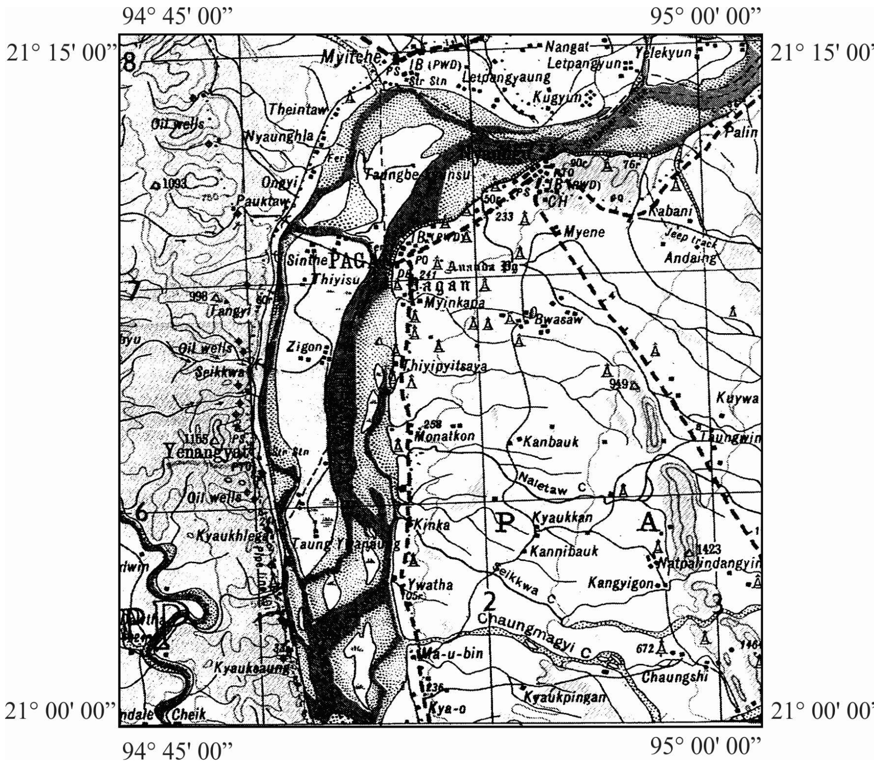


Figure 2. Topographic Map of the Research Area

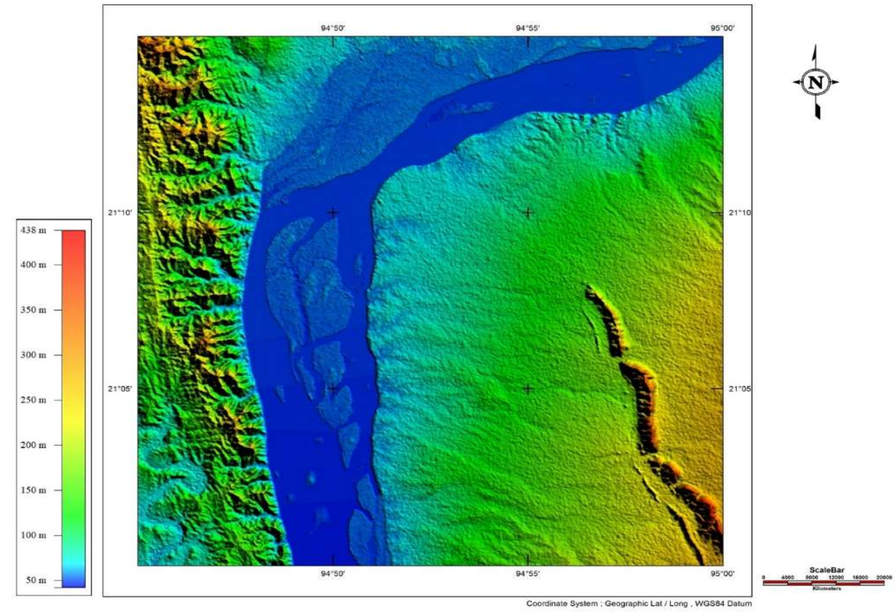


Figure 3. Physiographic Map of the Research Area

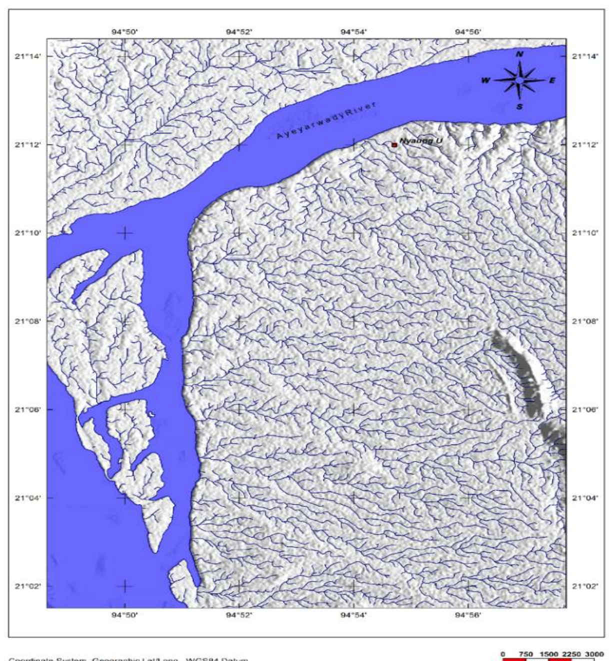


Figure 4. Drainage Map of the Research Area

Climate

The climate of the research area is tropical but the seasons can vary drastically. In summer (from March to May), the temperature rises to 43°C during the day and falls to 24°C in the night, with no rainfall. In the winter (from November to February), the temperature is about 30°C in the day and night temperature is about 30°C. Monsoon starts in June and ends in October. The rainy season lasts from May until October (see figure 5). Based on rain fall data, the highest peak of rainfall was recorded in 2000 during which high flooding along Ayeyarwaddy river occurraed, Figure 13a.

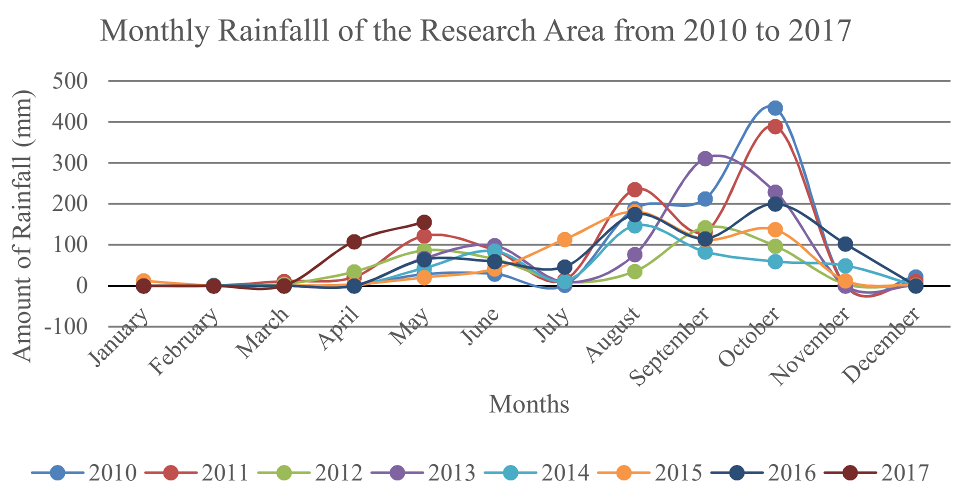


Figure 5. Monthly Rainfall of the Research Area from 2010 to 2017

Methods and Materials

The study aims at demonstrating the application of remotely sensed digital image processing and visual interpretation for engineering geology approach to environmental studies in a specific area. To carry out the ground survey for land interpretation it is necessary to check and link the information received from satellite images. The methodology of the study can be divided into interpretation of image, spatial analysis and field survey. Materials used in the study are maps, informations, software facilities and others.

(1) Satellite Images

The following satellite images were used:

Landsat 7,TM year of acquisition. (2010, 2015), path and row 133/045, 7 bands,

(2) Spatial Data

Topographic map, the scale of one-inch map sheet no. 84K/16 is used as the base map for geographic database of the research area. UTM (quarter-inch) and topographic map (quarter-inch) scale are used to identify the significant topographic features.

(3) Non-Spatial Data

Statistics data (monthly rainfall, monthly mean water level, and earthquake data from the Department of Meteorology and Hydrology (DMH).

(4) Softwares

Microsoft Excel 2013 for plotting the graph

Global Mapper 17

Geo Media Professional

CorelDRAW X8

ENVI 4.7.

Google Earth

(5) Technical Methods

Basically, technical methodology consists of three parts, the first one is visual analysis, the second is digital image analysis and the third is integration of field data and remote sensing analysis.

Satellite Image Analysis

Satellite data of Landsat 7 Thematic Mapper TM were selected for the research. These data are recorded on seven bands with Landsat 7 satellite wherein the study area falls within path/row 133/045 with 30 metre ground resolution. Visual image interpretation and digital image processing were applied for classifying images in a base of land cover/landuse and to enhance image quality. In this research, ground control points were selected by following permanent features evenly distributed throughout the area and identified easily both in image and topographic maps. The Universal Transverse Mercator (UTM) projection method is employed in the research area. The scale of Topographic maps used this research area was quarter-inch.

Image enhancement and band combination in the manipulation of image density were carried out to see more easily certain features of the image. In this research, the false colour composite (R: G: B=4:5:3) was made for land use/land cover interpretation. TM images are analyzed to identify the major structural patterns and lithology and LCLU by using ENVI 4.7.

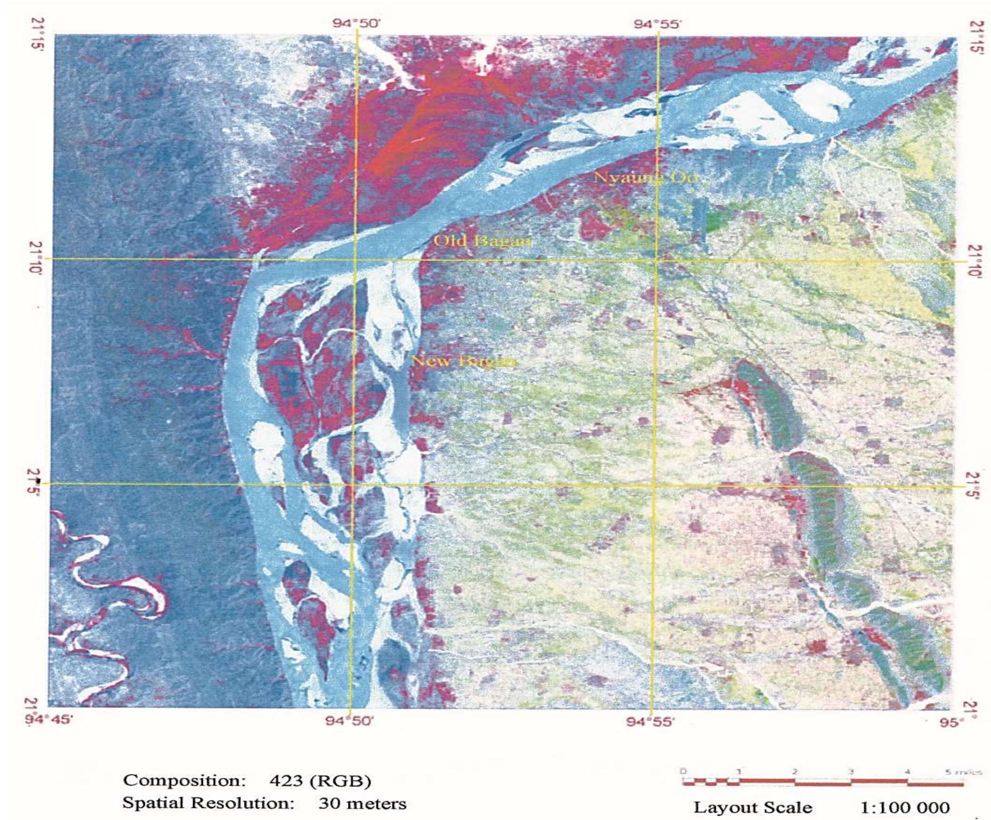


Figure 6. Satellite Image of the Research Area (Image Rectification)

Regional Geologic Setting of the Research Area

Coalesced Chindwin and Ayeyarwaddy Rivers formed elbeco occurs near Nyaung Oo and Bagan (the ninth century ancient city). High range Tuyin Taung (1423 ft) high gradually plunge to the northernmost tip as 948 ft. Tuyin Taung NE high is forming into broad high intrusive dome. The dome shapes are recognized as flower petal represented by 1000 ft contour interval. The height is compared to the west side of Tantkyi Taung, known as geologically as Yenangyat structure.

Recent alluvial is confined along the Ayeyarwaddy river banks. Topographic map all shows diverting straight ridges from the doming high towards the main Ayeyarwaddy cliff banks. Seasonal torrential rivers on Yenangyat fold (beside Myitche) and Sindewa, Pyaungpya (south of Myingyan) supply fertile soil distributing along the eastern Ayeyarwaddy river banks. This fertile soil strip fed and supported the cultural Bagan society beginning from the early 9^{th} century.

A large syncline to the west of Yenangyat fold and the broad intrusion dome align towards Pliocene extinct Popa volcano in the south and Shinmataung to the north. Which particular rifting trend is responsible for the latest catastrophic earthquake still remains as the hot challenging riddle in the mind of every geologist.

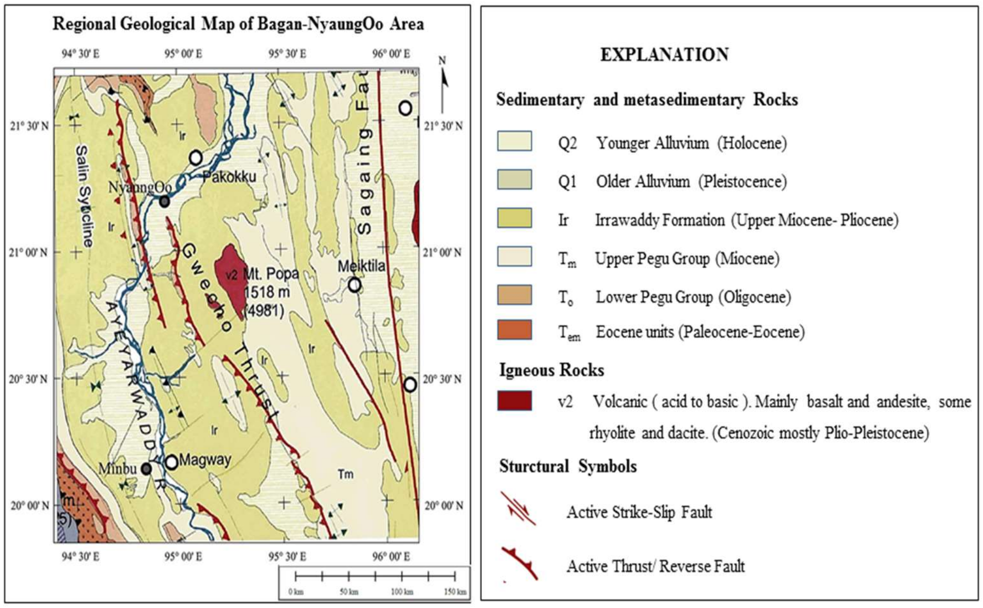


Figure 7. Regional Geological Map of the Research Area

The research area lies within the Central Myanmar Belt which is underlain by Eocene to Plio-Quaternary sediments and locally injected by Quaternary volcanoes (Pivnik et al., 1998). Central Myanmar Belt is structurally complex due to the multiple phases of deformation like folding, faulting oblique and dextral faulting and normal faulting (Pivnik, 1998). The regional structural trend of the research area ranges from NNW-SSE to NW-SE orientation. High relief of topography like Tantkgyi Taung, Tuyin Taung and thrust belt that represent the significant structural features of the research area.

Geology of the Research Area

The research area covers mostly alluvial plain, the debris and small fan materials derived from TuywinTaung and Tankyee Taung hills which are exposed with rocks of Miocene to Oligocene age.

In the research area, exposed rock units are Irrawaddy Formation (Late Miocene to Pliocene), Okhmintaung Formation (Late Oligocene), Padaung Formation and Shwezettaw Formation (Early Oligocene). The Shwezettaw

Formation is well-exposed along the Tuywin Taung Range. The Pyawbwe Formation well-exposed along the Tantkyi Taung Range.

The vast plain in the area consists of flood sediments derived by the Irrawaddy River. The alluvial soils (Quaternary-Recent) are deposited on the plain and along the Irrawaddy river bands. There are five types of soils classified as: (1) active alluvial fan, (2) river bed deposits, (3) gravel deposits, (4) colluvial soil and (5) residual soil.

Landslides and Erosion

Active and old landslides are marked in the research area along hill slopes of Tantkyi Taung and Tuywinn Taung Ranges. Small open cracks are denoted on the top parts of the landslides. In these ranges, slope angle of 40°-60° is unstable and can create further sliding in the rainy season. In addition to these, ranges with gully erosion and tension cracks are also recognized. Soil erosion and debris fall are also common on hill slopes of Tantkyi Taung and Tuywinn Taung Ranges because of soft sediments and fast weathering nature, deforestation as well as haphazard exploitation of construction materials. On the eastern flank of Tantkyi Taung Range, debris fall and soil erosion as well as landslides due to steep slopes are observed. High density of joints and differential erosion between soft mudstones and hard sandstones of Tantkyi Taung Ranges are developing to rock blocks which are liable to be detached creating landslide and debris fall hazards.

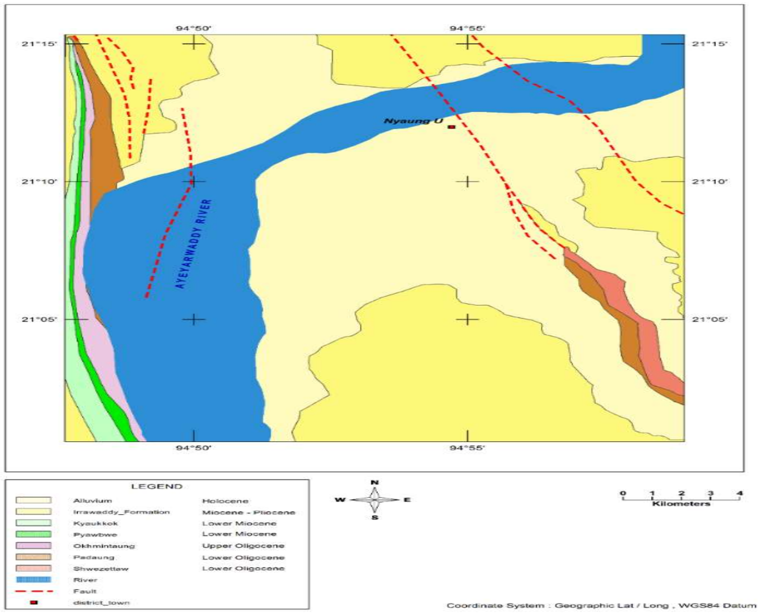


Figure 8. Geological Map of the Research Area (Tun Naing Zaw, Min Thura Mon, Swun Wunna Htet, 2017)

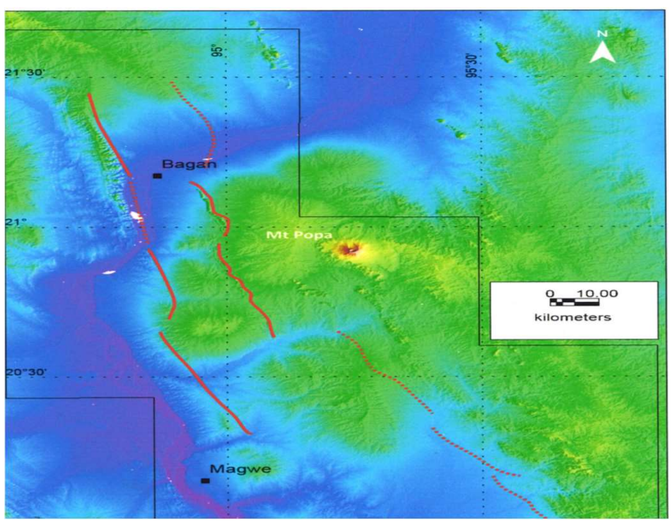


Figure 9. The Digital Elevation Model of the Bagan and Surrounding Areas showing the Surface Fault Trace of the Thrust Systems of the Research Area

Tantkyi Taung Thrust

It is clearly observed on the eastern limb of Tankgyi Taung anticline. Fault trend is running about 346° with steep slope and v-shaped gullies. Along the fault line, scarpsare characterized by erosional surface.Figure (9 and 10).

TuyinTaung Thrust

It is clearly observed in TuyinTaung near Bagan. Fault trend is running N330° and fault dips about 46° to the west. Figure (9 and11).

Left = Landslide (Facing-20°), Right = Old Landslide (Facing-80°)

Left = Cliff with debris at the bottom (Facing-70°),
Right = Old Landslide (Facing-50°),

Figure 10. Landslides in Tantkgyi Taung

Tuyin Taung (Facing=170°) (N 21 10’ 42.4”, E 94 52’ 31.6”)

Figure 11. Landslides in Tuyin Taung

Flood and Erosion

Both sides of Ayeyarwaddy River bank is eroded by both riverbank scouring and rain water resulting steep slopes. Slope failures causing landslides are common along the east bank of the river in the central portion of the research area. There is a number of river bank failures within 5 to 10 metres.

A buffer zone of 30m is desirable not to have any settlements and construction works to allow natural stabilization.

River bank cutting between Nyaung Oo and New Bagan is another threat to cutting failure that needs to be taken care of soil failure. Low land area gets flooded and covered with sediment deposited during the rainy season by flood.

Ayeyarwaddy River is generally bed load channel type. River flowing between the banks on the beds composed of sediments being transported by the river are sensitive to changes of sediments load, water discharge and variation of valley floor slope.

In the research area, west bank of Ayeyarwaddy River, three steps of river terraces are observed in Bagan-Nyaung Oo area (Chhibber, 1934) and alluvial terraces and colluvial deposits are widely distributed in the research area.

In the rainy season, lowlands adjacent to the river and the main streams in the area are likely to be affected by flood as they are prone to flood hazards. Hence, these areas are not suitable for human settlements but can be utilized for agriculture. A risk of flash flood can always be a threat in these areas in future in the rainy season .Figure (12 & 13).

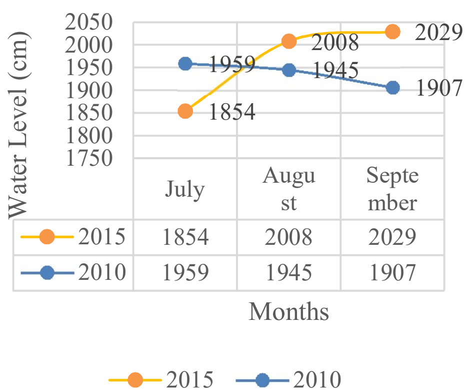


Figure 12. Monthly Mean Water Level of Research Area in 2010 and 2015

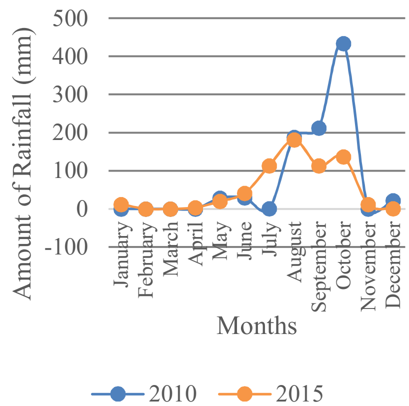


Figure 13. Monthly Rainfall of Research Area in 2010 and 2015

Location –N 21°09'33.6", E 94° 51' 34.5" Flooding in Mingaba village (25th August 2017)

Location: N 21°11'49.1'', E 94°54'9.5' Flooding in Streets in Nyaung-Oo Township (25th August 2017)

Location: N 21 11'13.4", E 94 53'21.6" Flooding in Wetkyee Lake (25th August 2017)

Figure 14. (a, b, c & d) Flooding in Nyaung Oo Area

Figure 15. Increase in water level causes river flooding near the eastern bank of Ayeyarwaddy River (25th August 2017)

Figure 16. Flooding in Tantkyi village near the west bank of Ayeyarwaddy River (Location: N 21 9'11.2", E 94 48' 8.9") (25th August 2017)

Figure 17. River flooding causes the villages in the central islands to evacuate the Theikkawa villagers to higher ground (25th August 2017)

According to the satellite image analysis, the rainfall in 2010 is significantly higher than that in 2015 (Figure 13) (2017 data not available during evaluation) resulting in the difference in volume of water body of Ayeyarwaddy River. In addition to the rainfall, the water level is higher 2015 than in 2010 due to the higher sedimentation of the river, thus sand bars and diluvium from river erosion and flood deposited. (Figure 18, a and b).

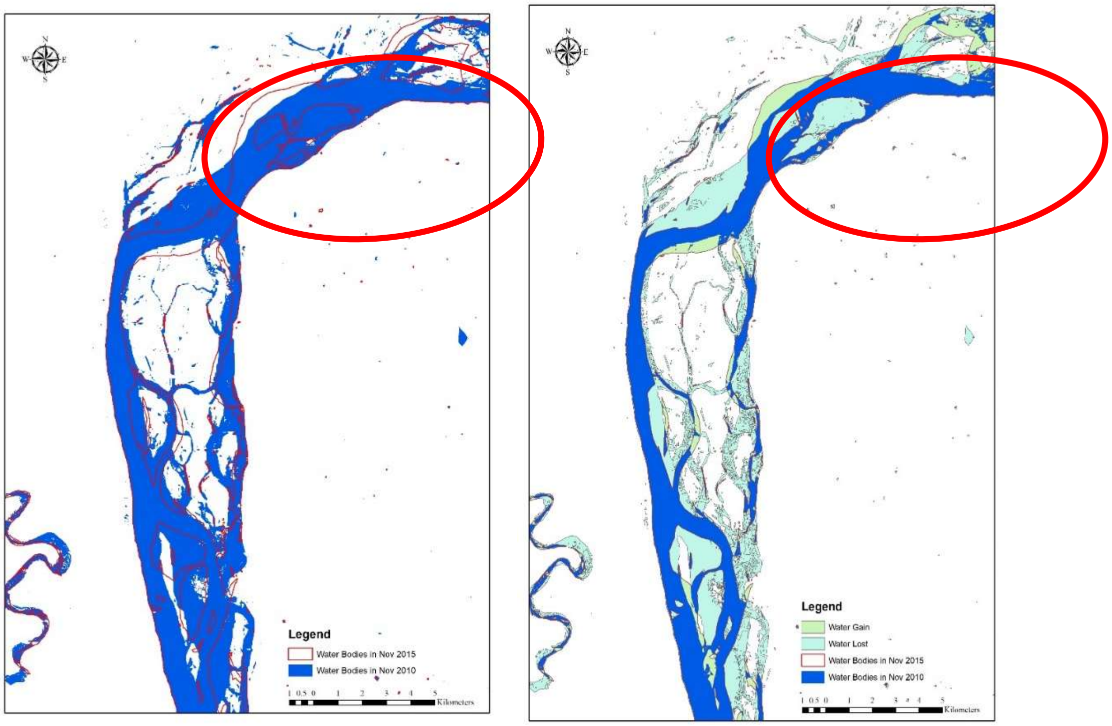


Figure 18. (a and b) Comparison of Water Bodies and Water Gain / Lost in 2010 and 2015 (Based on Satellite Images) as Shown with Red Circles

In 2010, the rate of western river bank erosion and deposition are obviously increased, therefore the west bank of Ayeyarwaddy River is more vulnerable to river bank erosion and flooding. See Figure (19, a and b). The same phenomenon happened in 2015. See Figure (20, a and b).

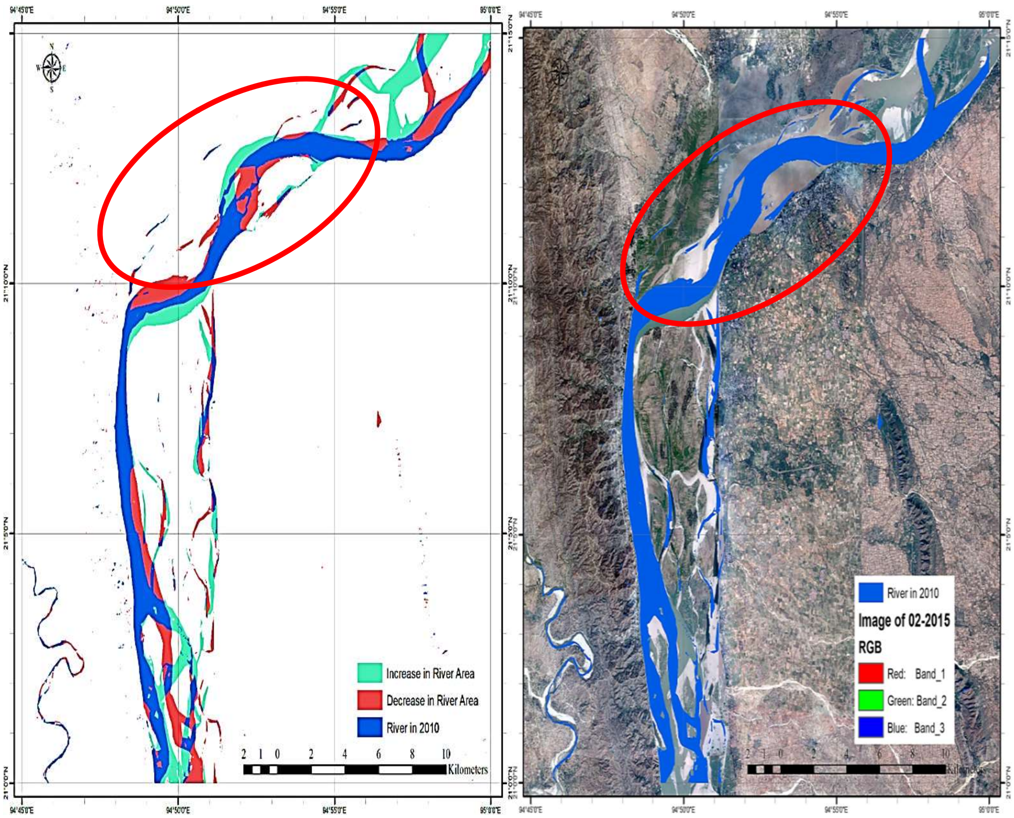


Figure 19. (a) **Figure 19. (b)**

Figure 19. (a and b) 2010 Ayeyarwaddy River Line with Increase and Decrease in Water Body

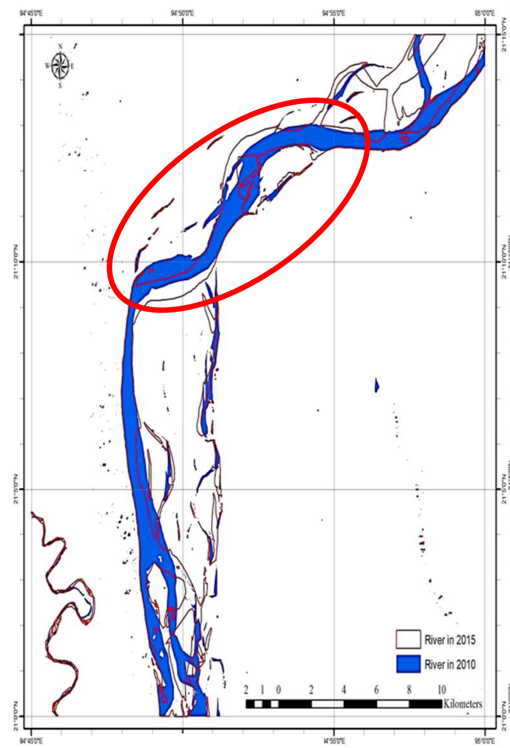


Figure (20, a)

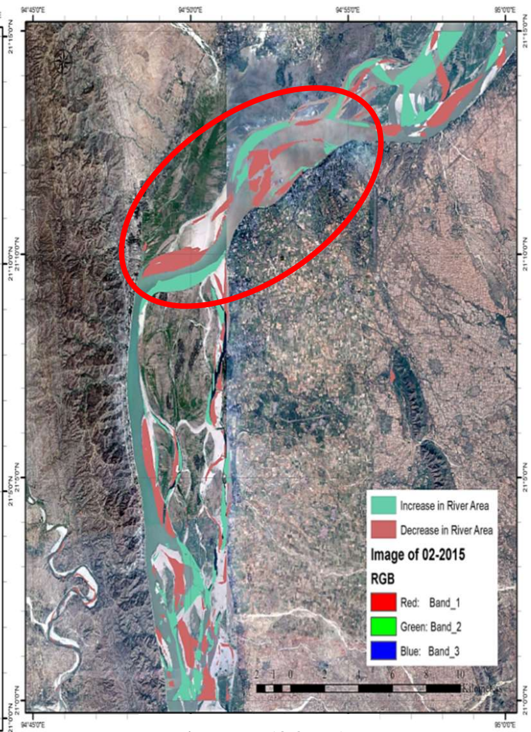


Figure (20, b)

Figure 20. (a and b) 2015 Ayeyarwaddy River Line with Increase and Decrease in Water Body

Sedimentation along Ayeyarwaddy River in March, 2017 as shown is Figure (21) implies that less volume of water body in the river at that time. This indicates that the intensity of flooding will increase during the rainy season.

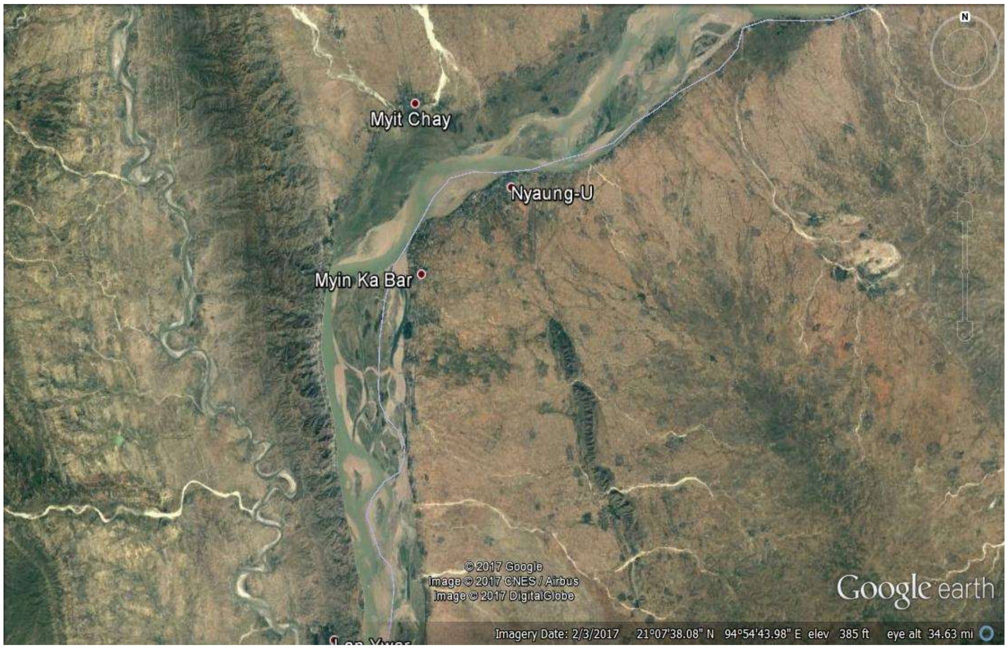


Figure 21. Recent Sedimentation along Ayeyarwaddy River Path Obtained from Google Earth (Imaged in 2nd March 2017)

Earthquakes

Earthquakes constitute a serious natural environmental hazard. There are many earthquakes every year in the research area, but most of these are relatively small events that do not release large amount of seismic energy. Historical accounts of two major earthquakes are shown in Table (1).

Table 1. List of the Earthquakes with Magnitude (>5) in Bagan-Nyaung Oo Area

No	**Date**	**Epicentre**		**Richter Magnitude**	**Remarks**
		Latitude	Longitude		
1	8th July, 1975	21.485°N	94.7°E	6.8	Many historical pagodas destoryed, 2 killed, 15 injured.
2	24th August, 2016	20.919°N	94.579°E	6.8	Damaged temples and pagodas= 397

The strongest intensity of 1975 earthquake was felt in Nyaung Oo, Pakoku, Yesagyo, Myaing, Chauk and Natmauk townships. Generally, intermediate depth earthquakes are likely in this region. The epicentre was located at the northern tip of TankyiTaung Thrust. Table (1). It is suggested that 1975 Bagan earthquake is related to the growth of Tankyi Taung Thrust at the west bank of Ayeyarwaddy River.

However, some researchers believed that the source of Bagan earthquake (1975) is Gwegyo thrust or Chauk-Yenangyat thrust which are located close to Bagan (most yulnerable area). According to focal mechanism of the earthquake (La Dein et, al., 1984), Bagan earthquake (1975) represents the subduction zone earthquake. Therefore, the possible source of Bagan earthquake (1975) is still controversial.

Bagan Earthquake, 1975

The distribution of microseismic intensities of 1975 Bagan Earthquake is shown in Table (2).

Table 2. Microseismic Intensity of the Bagan Earthquake (1975)

Town	Location		Intensity (MMI)	Destruction
	Latitude	Longitude		
Bagan (Ancient)	21.17°	94.86°	9	Destruction and collapse the upper part of Arnanda Pagoda and other ancient building and pagodas
Bagan (New)	21.13°	94.85°	9	Destruction of the old buildings and pagodas
Nyaung Oo	21.2°	94.92°	8	Large fracture at Shwe Sigon and Gu Pyauk Kyi Pagodas
Tantkyi Taung	21.16°	94.77°	8	Damage of Tankyi Taung Pagodas
Tuyin Taung	21.12°	94.94°	8	Destruction and large open fracture of Tuyin Taung pagoda

Table 3. 1975 Bagan Earthquake Damage Records (Shwe Gaing Tha, 1975 and Min Htwe Naung, 1978)

Locality/ city	Long	Lat	Damage description: Shwe Gaig Tha (1976)	Damage description: Min Htwe Naung (1978)	MMI*
Myaing	94.854	21.61	15 pagodas collapsed to the bell. Duration 2 min		VIII
Bagan (Sandbars)	94.83	21.12	Liquefied.	Tsunami in the river. River flow towards upstream for a moment. Ground cracked about 200 yards. Sand shot up about 10 ft high	VIII
Nyaung-U	94.9	21.19	Pagodas and temples destroyed	2 people died. 15 Injured. Many Pagodas collapsed.	VIII
Yesagyo	95.24	21.63	57 Pagodas destroyed. Duration 2 min.		VII
Pakokku	95.08	21.33	80 buildings destroyed. Bridge cracked. People ran out of buildings. Couldn't stand on ground.		VII
Taungtha	95.445	21.28	Pagodas and temples destroyed		VI
Chauk	94.82	20.89	Parapet and stone wall along the river settled and destroyed. Some oil rigs toppled down.	1000 yard long stone wall fell into the river. One oil rig topple down into the river, 3 rigs tilted. One oil storage tank sunk into the ground.	VI
Kyaukpadaung (Indaw vil.)	95.12	20.84	Ground cracked about 2 miles.	One monument column toppled down.	VI
Natmauk	95.4	20.34	Railkway bridge settled 1ft and railway lines bent.		V
Minbu	94.87	20.16	One diapir sunk 2 ft and road uplifted 6 inches. Water pipe broken.		V
Phyu	96.43	18.48	4 min		IV
Latbadan	95.75	17.78	Local seich		IV
Thegon	95.41	18.65	30 second		III

Most of the earthquakes are shallow to moderate focus earthquakes with the moderate magnitude and the depth of hypocentre ranges from 10 km to 157 km under the earth's surface. Table (4).

Table 4. Instrumental Records of the Earthquakes (Moderate to Strong Earthquakes) in the Research Area (USGS, 1964 to 2013)

Date	Hypocentre		Richter Magnitude	Depth (km)
	Latitude (N)	Longitude (E)		
18/12/1972	21.23°	94.17°	5.3	72
8/7/1975	21.48°	94.70°	6.5	157
24/1/1982	21.45°	94.66°	5.4	113
27/7/1996	21.31°	94.8°	5.2	110
17/7/2005	21.02°	94.99°	5	120.3
3/3/2006	21.12°	94.47°	5.2	112.8

Bagan-Chauk Earthquake, 2016

The strongest intensity of 2016 Bagan earthquake was felt in Salin, Seikphyu and Chauk which are the most damaged towns and are situated near the intensity level 6. Seismic intensity 5.5 to 6 reached Pakokku, Nyaung Oo, Bagan, west of Kyaukpadaung and Yenanchaung. Due to its effect, many historical structures including monasteries, pagodas, stupas and temples were severely damaged or destroyed. Figure (14, 15, 16 and 17). Statistically, 270 Bagan monuments were destroyed and 3 people died. The buildings around Bagan other than the ancient monuments are also more or less damaged.

Figure (22, 23, 24, 25) The destruction of Ancient Bagan Temples and Pagodas Caused by (2016 Bagan Earthquake Source: Internet)

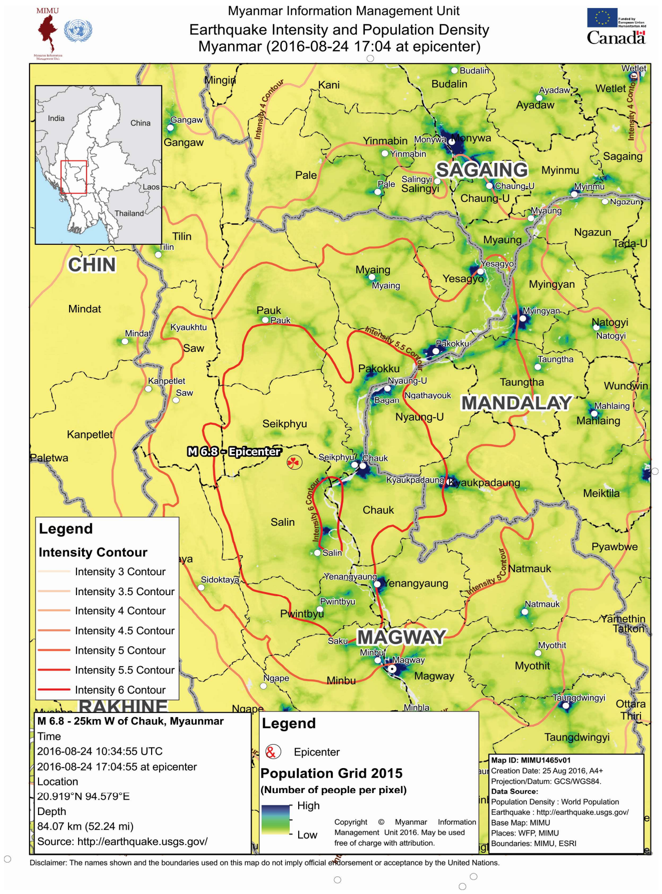


Figure 26. Earthquake Frequency and Population Density of the Research Area (Organized by Myanmar Information Management Unit, MIMU, European Union Humanitarian Aid, United Nations and Canada in 2016)

According to PGA and PGV data(USGS) from research area (Bagan, Nyaung Oo and surroundings), the instrumental intensity is VI to VII, so the area received strong to very strong quaking and potentially has light to moderate damage. Table (5).

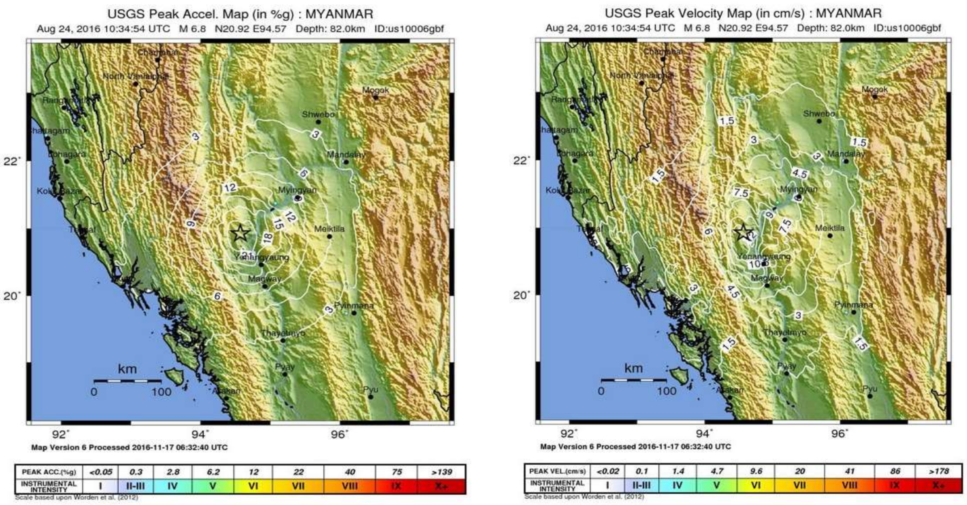


Figure (27, 28) USGS Peak Acceleration Map and Peak Velocity Map of the Bagan-Nyaung Oo Area

Table 5. SMI intensity scale (after Wald et al., 1999a)

Perceived Shaking	**Not-felt**	**Weak**	**Light**	**Moderate**	**Strong**	**Very Strong**	**Severe**	**Violent**	**Extreme**
Potential Damage	None	None	None	Very light	Light	Moderate	Moderate/ Heavy	Heavy	Very Heavy
PGA (%g)	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2	18-34	34-65	65-124	>124
PGV (cm/sec)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
Instrumental Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+

According to Department of Meteorology and Hydrology as shown in Table (6), the PGA value recorded the highest (0.12g Up and Down Shaking) from Nyaung-Oo station. Due to the intense up-and-down shaking, liquefaction and severe damage to the upper part of the ancient monuments happened.

Table 6. 2016 Chauk Earthquake PGA Data from DMH

Recorded Stations	PGA (g)		
	NS	EW	UD
Nyaung Oo	0.08	0.09	**0.12**

Possible earthquake source of 2016 Bagan earthquake is subduction-related but is still controversial because of its various hypocentre depth information (82 km measured by USGS while others got 84.1 km), mechanism is composite (generic) with a magnitude of 6.8 on Richter Scale at which its epicentre was 16 miles west of Chauk.

(http://earthquake.usgs.gov/earthquakes/eventpage/us10006gbf#shakemap).

Land Use

In the research area, existing land use patterns are agricultural land, sparse forests and scrub, settlements, industrial, recreation centres, infrastructures and small land fill/ waste disposal sites.

(1) Engineering Approach to Land Use for Construction

The research area has heterogeneous soil distribution character with different engineering properties. Low to medium-bearing capacity (1.8 to 4TS F) areas are concentrated in the area where active alluvial fan and river bed deposits have high permeability and loose density. Most of plain area is covered by a firm soil with a stable bearing capacity and so appropriate for small to medium scale construction purposes.

Gravel deposit in Nyaung-Oo area, being derived from landslide-induced active alluvial fans and river bed deposits by erosional forces, is locally developed on the both banks of the rivers and streams. It consists of sub-angular to pebbly and gravelly rounded quartzite, gneiss and phyllite with fine sand, silt and clay matrix. **Colluvial soil** occurred at the base of slopes and consists of clay, silt and sand with angular gravel to cobble size fragments of shale, phyllite and quartzite/ meta-sandstone). These colluvial deposits are derived from old landslides.

In Bagan area, **residual soil** is developed in place on flat to gentle hill slopes. It mainly consists of clay, silt, and gravel size rock fragments. Mostly, the residual soil in New Bagan is derived from Irrawaddy Formation. Four boreholes data measured by JICA Project and Ministry of Construction are used in engineering analysis for calculation of bearing capacities of each boreholes and test pits. Figure (29, 30, 31).

We would like to conclude that the bearing capacity of gravel bed in Nyaung-Oo is sufficient for shallow foundation, however, without the compaction of gravel soil under the footing of the specific foundation, It is likely that the differential settlement will occur causing the foundation unstable due to the poorly sorted gravels.

For Bagan area, since the residual soil comes from Irrawaddy Formation which has a bearing capacity of 2.9 – 4 TSF at the depth of 2m according to geotechnical analysis, shallow foundation with square footing for two to three-storey houses and hotels are suitable for construction. In spite of the availability, the Ministry of Construction stipulates only to build structures of 30ft high with two levels.

Depth	Bearing Capacity
2.1 Ft	1.7 TSf
3.2 Ft	2.5 TSf
4.3 Ft	2.3 TSf
5.3 Ft	2.4 TSf
6.5 Ft	2.7 TSf
7.5 Ft	2.8 TSf
8.6 Ft	2.9 TSf

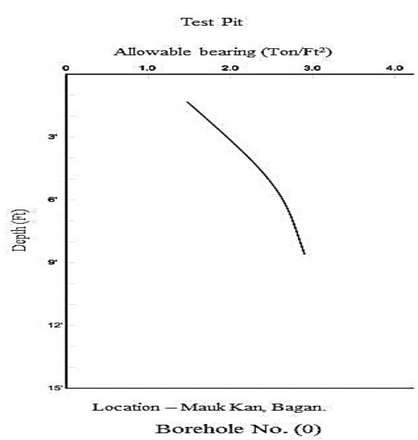


Figure 29. Test Pit Result of Borehole No.(0), Mauk Kan, Bagan

Depth	Bearing Capacity
2.1 Ft	2.9 TSf
3.2 Ft	3.3 TSf
4.3 Ft	3.7 TSf
5.4 Ft	3.8 TSf
6.5 Ft	4 TSf

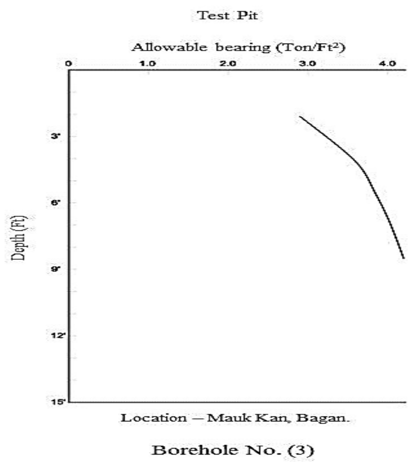


Figure 30. Test Pit Result of Borehole No.(3), MaukKan, Bagan

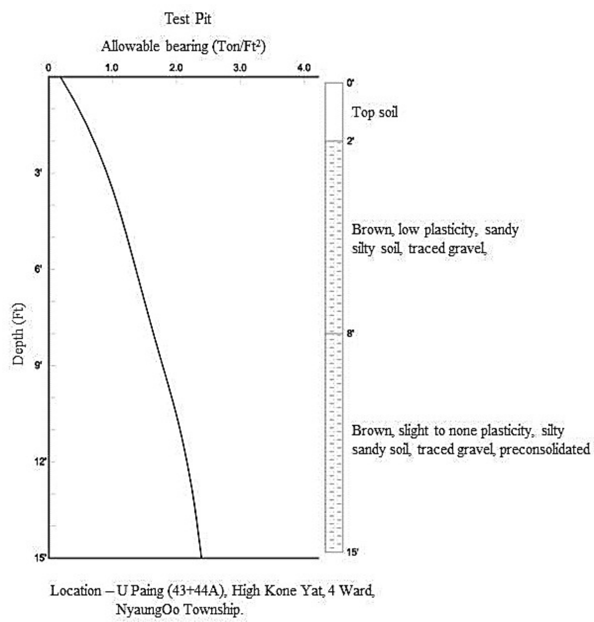


Figure 31. Test Pit Result of Nyaung-Oo Township

(2) Agricultural and Scrub Lands

Most of the flat, lowlands in the plain along the river bank and hill sides are covered by sparse forests and scrubs. Open forests, swamp forest, orchard, palm trees, scrub, bush and grass are categorized in the research area. Low angle sloping lands (hill sides) are good for dry cultivation (maize, millet, wheat and cereals).

(3) Urban Settlement and Industrial Areas

Urban settlements include existing area, planned area, proposed area, and expanded area. Proper drainage system in Nyaung Oo and Bagan is adequate now. Crucial area of man-made pollution is located in the east of NyaungOo. On the banks of the Ayeyarwaddy River, squatters' settlements are creating.

Figure (32, 33) (Left)Urban Settlement and Agricultural and Scrub Land (Right)

(4) Recreation Centres and Open Spaces

Lawkananda reserve forest near New Bagan is the only existing public and natural park in the area. The research area has religious and cultural values where most of pagodas are located form north to south. Bagan golf field and Recreation Park are located west of NyaungOo beside of the main highway road.

(5) Landfill and Waste Disposal Sites

NyaungOo municipality lacks sanitary landfill site to manage safe disposal of its solid wastes produced from the urban settlement and industries. It is temporarily dumping its daily wastes on the river bank.

(6) Cultural Heritage Site

Bagan, being regarded as the Golden Land of Wonders, is a tourist attraction filled with cultural monuments and the ancient Bagan's amusing architectures of First Myanmar Empire. The present government is now trying their best to make Bagan to be one of the World's Heritage Sites approved by UNESCO. In our field trip, we observed some places of Bagan's monuments suffering from environmental degradation. Thus, here we will mention some facts to remedy the deteoration based on our field data.

Bagan has over 3,000 ancient monuments scatterred across the vast arid plain. They can be categorized into four types: (1) temple, (2) stupa, (3) monastery and (4) unexcavated mounds. Figure (32) Most of the monuments in Bagan were destroyed by the earthquakes in the past. Table (2) and (3). The repaired parts and upper parts of the monuments (square tower, spire) after 1975 earthquakes were collapsed Figure (33). Vegetation and microorganisms encroaching on the monuments are damaging them. Figure (34). Further studies related with cultural heritage sites and maintenance of monuments are essential for Bagan.

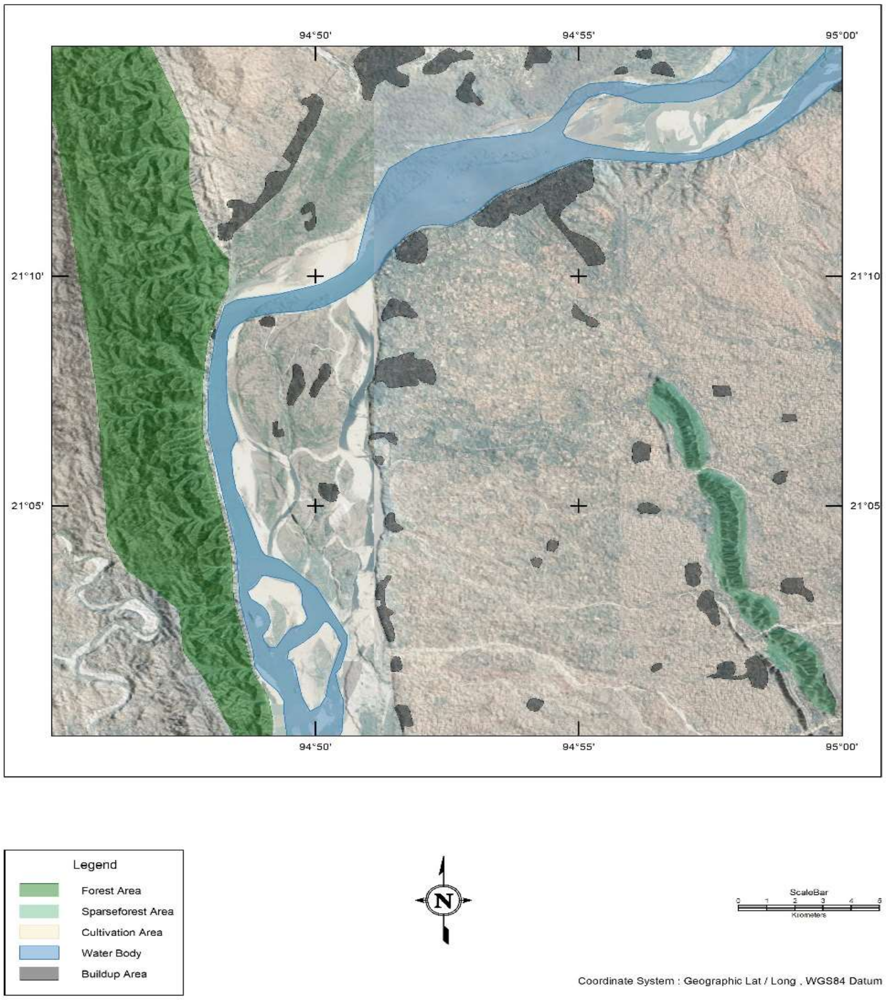

Temple


Monastery

Figure (32) Various Types of Monuments

Figure (33) Damages in Repaired Parts and Upper Part of Monuments

Figure (34) Damages Due to Vegetation and Microorganism



Figure(35) Land Use Map of the Research Area

Summary and Conclusions

(1) The study area is situated between E 94° 45’ and E 95°, N21° and 21° 15’. It is located on NyaungOo area, Mandalay Region.

(2) The study showed that remote sensing techniques are useful tools for assessing and analyzing the geological purposes.

(3) TM images are analyzed to identify the major structural patterns and lithology and LULC.

(4) Bagan stands on the east bank of the Ayeyarwaddy River.
(5) Bagan, an old capital of Myanmar, is famous global pilgrimage centre and contains ancient Buddhist shrines.
(6) An earthquake on July 8, 1975, severely damaged more than half of the significant structures are irreparably destroyed many of them.
(7) Statistically, 270 Bagan monuments were destroyed and 3 people were dead. The buildings around Bagan other than the ancient monuments are more or less damaged by 2016 Bagan Earthquake
(8) Shake-Map can be used to observe damage patterns and can also be generated for different anticipated scenarios to aid emergency planning and hazard mitigation.
(9) Old and new landslides are found on the flanks of Tantkyi Taung and Tuywin Taung.
(10) Floods are the most common and the most destructive geologic hazards. We need to control flooding by non-structural approach through sound flood plain management and engineering efforts such as artificial levees, flood-control dam and channelization.
(11) Essential protection of western Ayeyarwaddy River bank, Nyaung-Oo and Bagan banks are required to reduce erosion.
(12) Squatters' settlements on the banks of the Ayeyarwaddy River are creating an alarming threat of encroachment of the river bank and flood plain. It is advised that settlements in these areas must be prohibited.
(13) Sanitary condition of solid waste disposal sites are essential in Bagan-Nyaung Oo area.
(14) Learnt from the 2016 Bagan-Chauk earthquake destroying 270 monuments, we need to particularly establish earthquake awareness by the public, accelerated research on earthquake and earthquake engineering and new technology and methods of repairing the monuments without disfiguring ancient architecture and cultural treasures.
(15) Effects of disasters will be different, past and present, depending on the density of population and highrise structures. Thus we suggest that more preparedness for mitigation of natural hazards is necessary at all times.

Acknowledgements

The authors are deeply grateful to Professor and Head, Dr. Day Wa Aung, Department of Geology, University of Yangon, for allowing us to do this research.

Heartfelt thanks are extended to Professor Dr. U Thein (Retired Rector), for his suggestion and advice given to us during the preparation and compilation of our research.

We would like to express our sincere thanks to U Win Maw, Retired Chief Executive Officer, MOGE, for his encouraged discussions, suggestions and permission.

Our special thanks go to Dr. Ohn Thwin, Retired Professor, Department of Geology, University of Yangon for his participation of field trip and his helpful comments and advice.

With our deepest gratitude, we acknowledge U Than Htay, Deputy Director General (Retd.), DGSE, Ministry of Mines, for his kindness to immensely improve not only English but also the geologic sense of this paper.

We acknowledge JICA Projects in Nyaung-Oo Area and Administration Department with gratitude for their vital technical data support.

We also thanks the Department of Meteorology and Hydrology for their relevant data and information.

Finally, the authors would like to deeply thank U Than Htut Khine, (1984Geology),Deputy Director, Directorate of Hotels and Tourism (Bagan Branch), for his generous hospitability and informations concerning land use/ land cover.

References

Bender, F., (1983) *Geology of Burma*, 1st Edition, Gebruder Bortraeger Stuttgard, Germany, 293 pp.

Chhibber, H.L, (1934). *The Geology of Burma*, Macmillan, New York, 538 pp.

Kramer., S., and Upsall., S.B., (2006), *Instrumental Intensity Scales for Geohazards*, Engineering Conference International Paper.

Le Dain, A.Y., P. Tapponnier, and P. Molnar, (1984), Active Faulting 1854 Fore Arc/ Back-Arc Basin Deformation and Tectonics of Burma and Surrounding Areas: *Jour. Geophysics. Res*., 89 (1), p. 453-472

Lillesan, T.M and Kiefer R.W., (2000).*Remote Sensing and Image Interpretation*, 4th Edition, John Willey and Sons Inc, New York

Mg Thein and Khin Maung Latt (1975).*The Bagan Earthquake, 8th July 1975*. Unpublished field report, Dept. Geol, University of Yangon, 23pp.

Min Htwe Naung (1978) *Myanma Earthquakes,* Sapay Beikman*, Yangon, Myanmar* (in Burmese)

Min Htwe Naung (1984) *The Earthquakes of Myanmar*, Burma Tran. Soc.*,Yangon, Myanmar*.

Pivnik D.K (1998) *Poly face Deformation in a Fore-arc/ back-arc Basin, Salin Sub-basin, Myanmar (Burma)*, AAPG Bulletin, V-82, No. 10 (October 1998), p 1837-1856.

Shwe Gaing Tha (1976) *Historical Earthquakes and the Bagan Earthquake*, Sanay Literature Group, Yangon, Myanmar (in Burmese)

Thornbury, W.D.,(1969*) Principles of Geomorphology*, Second Edition, John Wiley & Sons. Inc, New York, p. 594