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GIS Approach for Assessing the Damage Caused by 2015 Floods in Myanmar

by

Wuit Yi Thaw

GIS-104159

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Advisor (s):

Dr. Shahnawaz

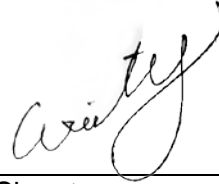
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Yangon, 05.11.2017

Science Pledge

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Yangon, 05.Nov. 2017

A handwritten signature in black ink, appearing to be 'A. Aung Mye Thazan', written in a cursive style.

Place and Date

Signature

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Abstract:

Komen was unusual tropical cyclone that originated near the southern coast of Bangladesh and later struck the same country while drifting over the northern 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 kilometers along the coast line. Cyclone Komen brought several days of heavy rainfall to Myanmar, Bangladesh and India. Myanmar divided 14 geographical regions based on ethnic group or geographical. There are 7 States for Shan, Kachin, Kayin, Kayah, Chin, Mon and Rakhine Ethnic groups. Ayawaddy, Bago, Yangon, Mandalay, Sagaing, Magway, Taninthayi Regions are based on geographically. 12 States and Regions. Among these 14 States and Regions, 12 States and Regions were flooded between July and August 2015. The Myanmar government requested assistance from the international community to cope with the disaster, considered the worst in the country since Cyclone Nargis in 2008.

This study is GIS approach for assessing the damage caused by 2015 floods in Myanmar. The elevation, water flow system and rainfall data are crucial for flood analysis. Country level elevation map and Dams on drainage network map by processing hydrology analysis were created from the ASTER DEM 30 m. The potential flood risk area of the downstream of Tha Phan Seik Dam was also calculated from ASTER DEM and the flood risk villages are identified in order to check with ground location as part of AOI. The Myanmar total rainfall of July and August 2015 map was generated by using data from the rainfall gauges. Moreover, the population density by township calculation was done and created

the map showing the relation between flood and people in the affected region geographically. The flood affected population map and the maps of township level loss and damages of transportation, houses, education centers, health facilities, and paddy fields caused by 2015 floods were created for spatial visualization. Then, the most affected region map will be proceeding based on these damages data.

Myanmar experiences flooding every monsoon season but has been particularly badly hit this 2015. The government had admitted giving a weak response to the disaster, according to state media. Based on cyclones Nargis 2008 and Komen 2015, Myanmar has suffered high risks. There was no actual disaster preparedness and information management. This assessment intended to find out the status of loss and damages of 2015 floods and it can be supported for future disaster preparedness, emergency respond and recovery activities of Government, NGOs and relevant organizations.

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Acronyms and Abbreviations

| | | |
|--------|---|---|
| ADPC | : | Asian Disaster Preparedness Center |
| AHP | : | Analytical Hierarchical Process |
| AOI | : | Area of Interest |
| ASTER | : | Advanced Space borne Thermal Emission and Reflection Radiometer |
| DEM | : | Digital Elevation Model |
| GDP | : | Gross Domestic Product |
| GIS | : | Geographic Information System |
| GLIDE | : | A Global IDentifier number |
| ICRC | : | International Committee of the Red Cross |
| MDLD | : | Myanmar Disaster Loss and Damage |
| MES | : | Myanmar Engineering Society |
| MIMU | : | Myanmar Information Management Unit |
| MMK | : | Myanmar Kyats (Currency) |
| MOAI | : | Ministry of Agriculture and Irrigation |
| MOH | : | Ministry of Health |
| NGO | : | Non-Government Organization |
| PDC | : | Pacific Disaster Center |
| RRD | : | Relief and Resettlement Department |
| RS | : | Remote Sensing |
| UNFPA | : | United Nations Population Fund |
| UNOSAT | : | United Nations Operational Satellite Applications Programme |
| UNTAR | : | United Nations Institute for Training and Research |
| USD | : | United State Dollar (Currency) |
| USGS | : | United States Geological Survey |

Chapter-1: Introduction

1.1. Background

El Niño affects the global climate and disrupts normal weather patterns, which as a result can lead to intense storms in some places and droughts in others. El Niño reduces overall rainfall, prolongs warming and causes unusually heavy downpours, happening at irregular intervals of two to seven years. Myanmar has started suffering from El Niño as it encounters abnormal climate change (Eleven, 2015).

Myanmar is situated in the South-East Asia, latitude between 9° 32' N and 28° 31' N and longitude between 92° 10' E and 101° 11' E. The neighbouring countries are China, Lao and Thailand in the East, India and Bangladesh in the West, bordering the Bay of Bengal and the Andaman Sea. Myanmar covers an area of 676,578 square kilometres in which 653,508 square kilometres of land and 23,070 square kilometres of water (MOH, 2014, p. 2). The country is divided administratively, into Nay Pyi Taw Council Territory and 14 States and Regions, see Map 1. It consists of 74 Districts, 330 Townships, 422 Towns, 3183 Wards, 13602 Village Tracts and 70838 Villages (MIMU, 2015d). The administrative structure is shown in Figure 1. The main features of the country are the delta region and the central plain surrounded by mountains.

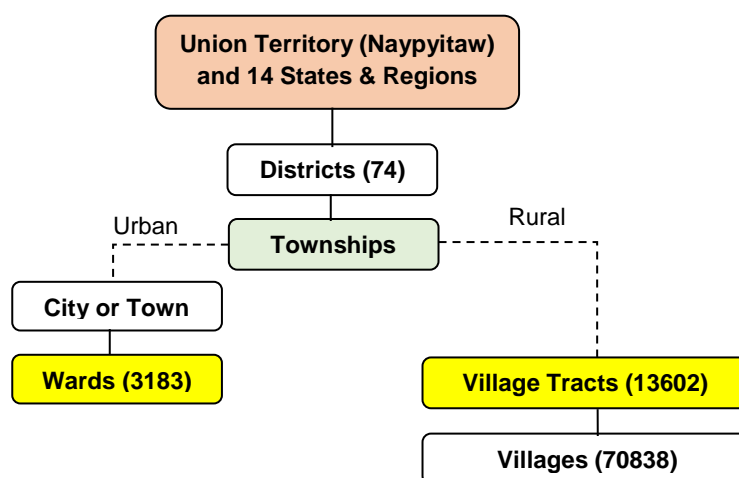
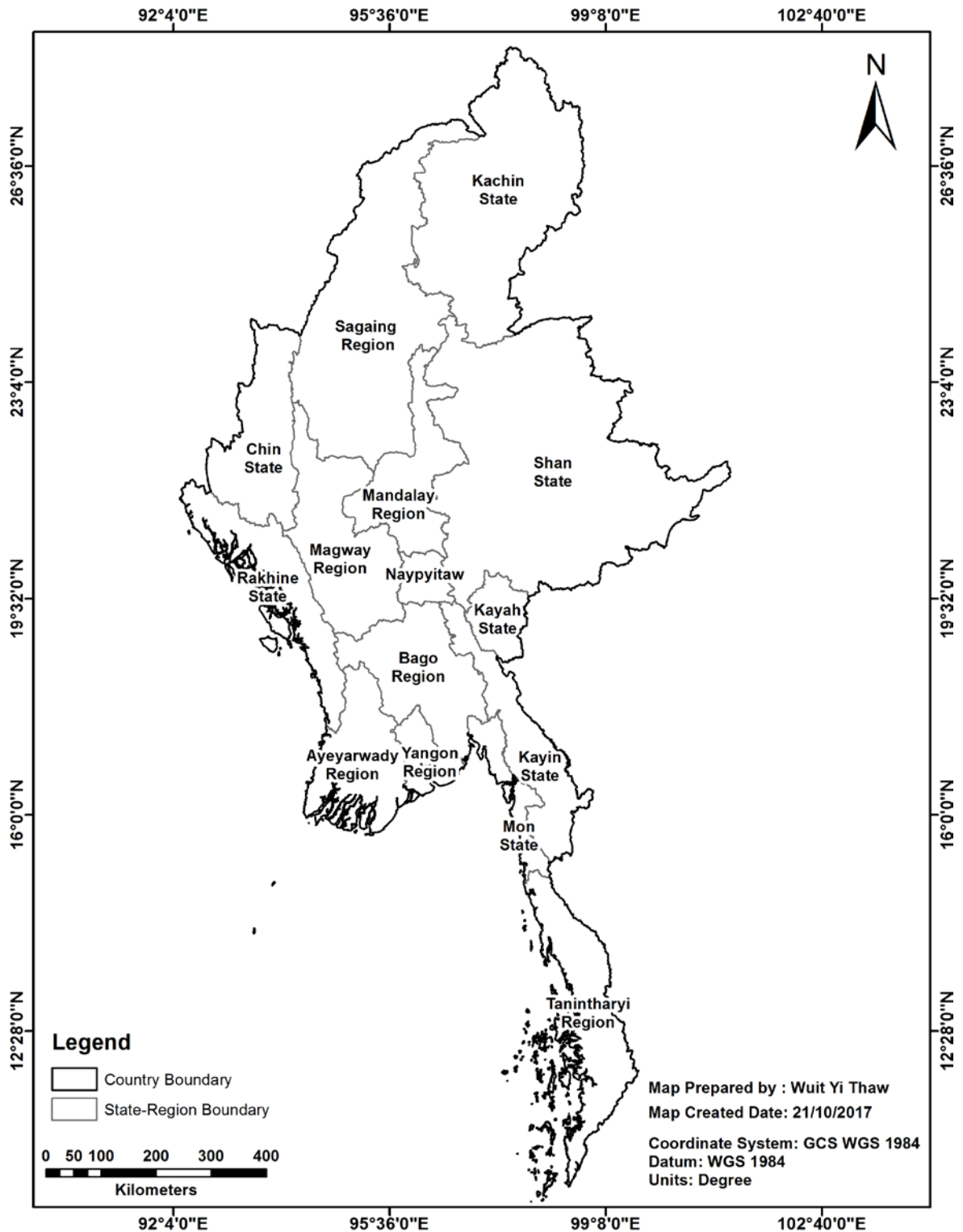


Figure 1 Administrative Structure, Myanmar (MIMU, 2015d)

Myanmar States and Regions



Map 1. Myanmar States and Regions

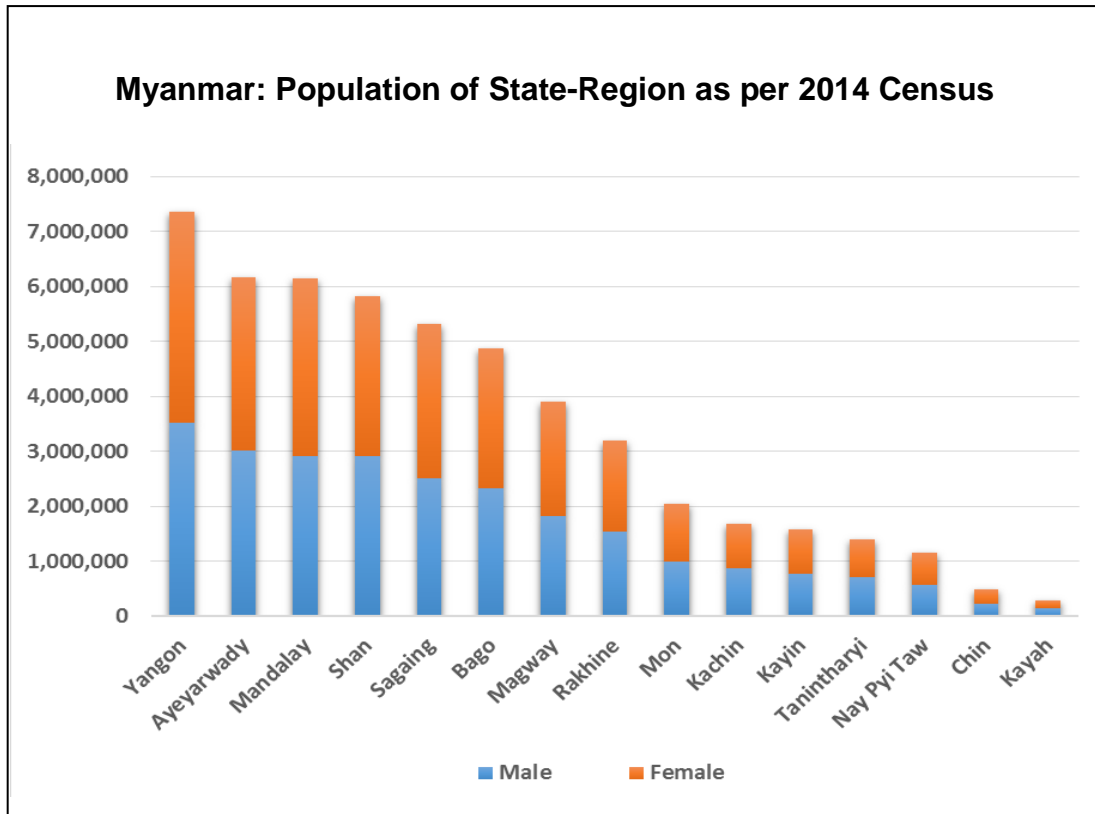


Figure 2. Myanmar: Population of State-Region as per 2014 Census

| State/Region | Male | Female | Total |
|--------------|-----------|-----------|-----------|
| Yangon | 3,517,486 | 3,837,589 | 7,355,075 |
| Ayeyarwady | 3,010,195 | 3,164,928 | 6,175,123 |
| Mandalay | 2,919,725 | 3,225,863 | 6,145,588 |
| Shan | 2,908,259 | 2,907,125 | 5,815,384 |
| Sagaing | 2,518,155 | 2,802,144 | 5,320,299 |
| Bago | 2,324,214 | 2,539,241 | 4,863,455 |
| Magway | 1,814,993 | 2,097,718 | 3,912,711 |
| Rakhine | 1,529,606 | 1,659,357 | 3,188,963 |
| Mon | 986,454 | 1,063,828 | 2,050,282 |
| Kachin | 877,664 | 811,990 | 1,689,654 |
| Kayin | 775,375 | 797,282 | 1,572,657 |
| Tanintharyi | 700,403 | 706,031 | 1,406,434 |
| Nay Pyi Taw | 565,181 | 593,186 | 1,158,367 |
| Chin | 230,005 | 248,685 | 478,690 |
| Kayah | 143,461 | 143,277 | 286,738 |

Table 1. Myanmar: Population of State-Region as per 2014 Census

Rural and Urban Population Ratio

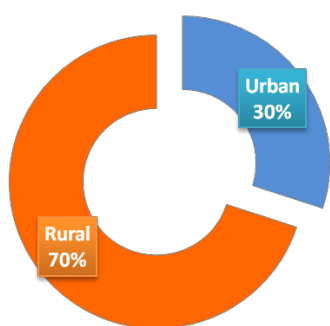


Figure 3. Rural and Urban Population Ratio

The total population of Myanmar is 51,486,253 that include both the enumerated population and the estimated population 1,206,353, the urban population is 14,877,943 and rural population is 35,401,957 that is 30% and 70% of Union population (MIP, 2015) and it is showed in Figure 3. There are 3 most populated Regions, Yangon, Ayeyarwady and Mandalay respectively (See Figure 2 and Table 1).

the Union of Myanmar is made up of 135 national races speaking over 100 languages and dialects. The major ethnic groups are Kachin; 12 races, Kayah; 9 races, Kayin; 11 races, Chin; 53 races, Bamar; 9 races, Mon; 1 race, Rakhine; 7 races, Shan; 33 races (Health, 2014, p. 4).

| 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 |
| <i>Average Magway</i> | | <i>658.22</i> |
| Mandalay | Nayung Oo | 624.84 |
| Mandalay | Mandalay | 830.58 |
| Mandalay | Meikhtila | 845.82 |
| Mandalay | Myingyan | 655.32 |
| Mandalay | Hlaingtet | 914.4 |
| <i>Average Mandalay</i> | | <i>774.19</i> |
| Sagaing | Monywa | 820.42 |
| Sagaing | Shwebo | 904.24 |
| <i>Average Sagaing</i> | | <i>862.33</i> |
| Average of precipitation of dry zone | | 740.56 |

Table 2. Myanmar: Average Annual Precipitation in Dry Zone (MES, MGS, MIMU, ADPC, & Government of the Union of Myanmar, 2009, p. 17)

Myanmar has a tropical climate with three seasons, the Rainy season from mid-May to mid-October, the Winter from mid-October to mid-February and the Summer from mid-February to mid-May. The annual precipitation in central Myanmar dry zone is less than 750 mm, while the national average precipitation is 2353.06 mm (MES et al., 2009, p. 17). The annual average precipitation over 10 years in dry zone at selected stations is at Table 2. 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 (MES et al., 2009, p. 44).

The Union of Myanmar is exposed to multiple natural hazards including destructive cyclones, floods, landslides, earthquakes, droughts and fire. Among them, flooding has always been one of the major hazards in Myanmar, accounting for 11% of all disasters, second only to fire. Over 2 million people are exposed to flood hazard in Myanmar every year (MES et al., 2009, p. 48).

As Myanmar is bordering Bay of Bengal and Andaman Sea with its 2400 km long coastal line, it is potentially rich with marine natural resources and also potentially threatened by the waves, cyclones and associated weather. Recent major cyclones are as follow;

- Cyclone Mala in 2006 April
- Cyclone Nargis in 2008 May
- Cyclone GIRI in 2010 October
- Cyclone Mahasen in 2013 May
- Cyclone Komen in 2015 July

Cyclonic Storm Komen 2015 was an unusual tropical cyclone that originated near the southern coast of Bangladesh and later struck the same country while drifting over the northern Bay of Bengal. The second named storm of the 2015 season, Komen brought several days of heavy rainfall to Myanmar, Bangladesh, and India. Its duration was from

26 July to 2 August 2015 (Wikipedia, no date). Because of Komen cyclone, unusual heavy monsoon rain poured around Myanmar, causing rivers and creeks to overflow with rainwater. This flooding is one of the consequences of El Niño affects (FAO, 2016, p. 1).

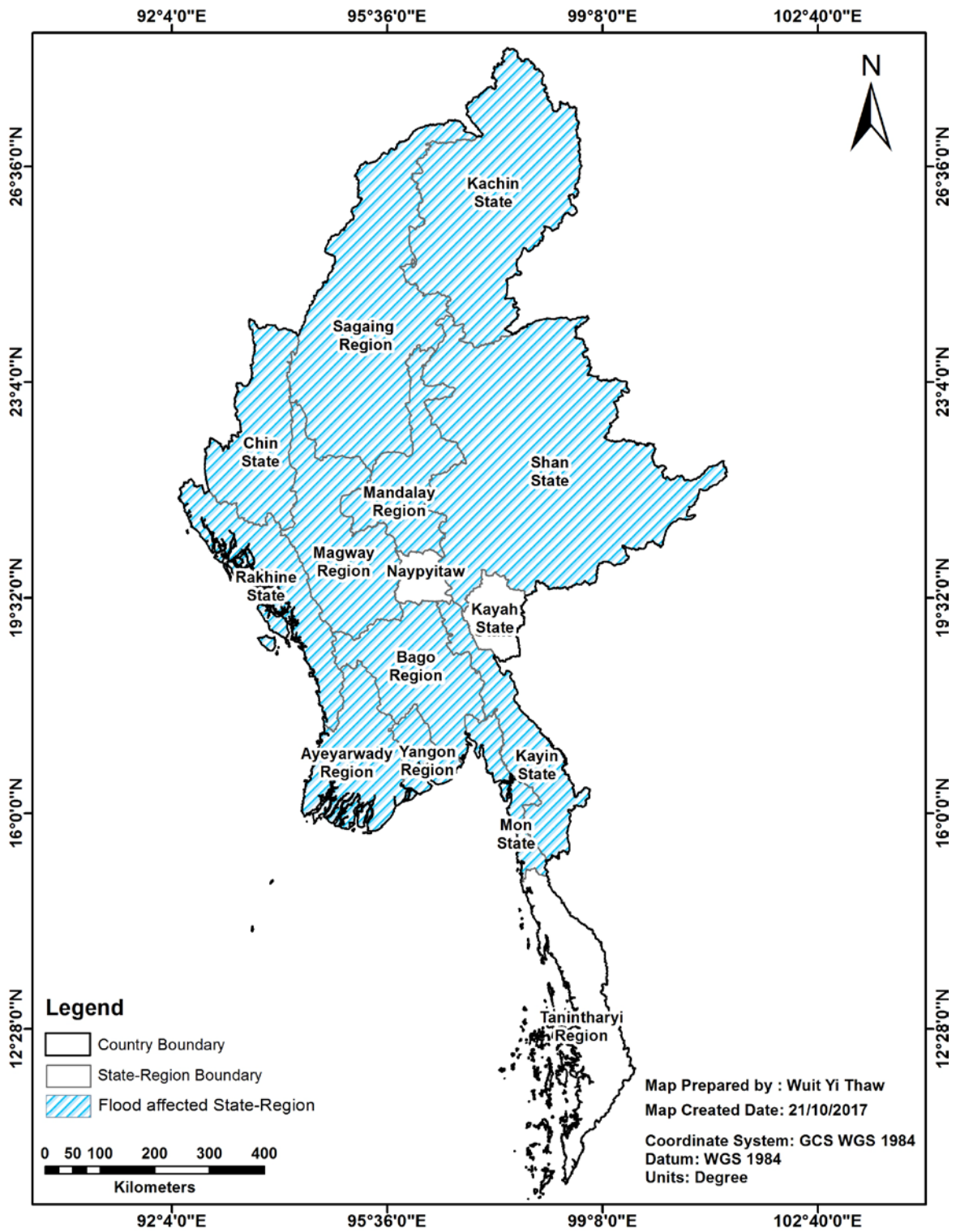
Torrential rains and the onset of Cyclone Komen triggered severe and widespread floods and landslides in July and August 2015 across 12 out of 14 States and Regions in Myanmar. The total economic value of the effects of the floods and landslides was estimated to be approximately MMK 1.942 trillion or USD 1.51 billion. The Exchange rate of as 11 November 2015; 1 USD is 1, 287. 40 MMK. Of this, MMK 792,493 million or USD 615.58 million was attributed to damages and MMK 1,149,522 million or USD 892.90 million to losses. The total effects would be the equivalent of 3.1 percent of Myanmar's gross domestic product (GDP) in 2014/2015 (Government of the Union of Myanmar, 2015).

Map 2 shows the flood affected States and Regions. This flood killed 132 people and affected about 1.7 million people and damaged 1.15 million acres of farmland during flooding (ICRC, 2015). The government has admitted giving a weak response to the disaster, according to the state media (BBC, 2015) and requested assistance from the international community to cope with the disaster, considered the worst in the country since Cyclone Nargis in 2008 (Wikipedia, no date).

Cyclone Nargis made landfall on 2 May 2008 near Haigyigyun in Ayeyarwaddy Region of Myanmar with wind speed up to 200 km/h accompanied by heavy rain and storm surge of 12 m in certain areas. 37 townships were affected in Ayeyarwady and Yangon Regions and total economic loss of Nargis was calculated at USD 4 billion, approximately 2.7% of Myanmar's projected GDP in 2008 (Government of the Union of Myanmar, 2008). The Exchange rate of 1 USD is 1,100 MMK used in the Post Nargis Joint Assessment Report 2009. Based on cyclones Nargis 2008 and Komen 2015, Myanmar has suffered high risks. There was no actual disaster preparedness and information management. Apply

high technology also not wide enough and few technicians can support only at severely affected areas.

Myanmar State-Region Affected by 2015 Floods



Map 2. Myanmar: State-Region Affected by 2015 floods

1.2. Objectives

The aim of the study is to identify the areas affected by 2015 floods, assess the nature and extent of damage and demarcate flood risk zone in the selected region. The outcome of current study can support for future disaster preparedness, emergency respond and recovery activities of Government, NGOs and relevant organizations.

The main aim of the study has been achieved through fulfilling the smaller objectives, which are following:

- to understand general topography of Myanmar,
- to analyse the rainfall distribution of peak rainfall month i.e. July and August 2015,
- to identify the spatial extent of 2015 floods in Myanmar,
- to estimate the flood vulnerable population,
- to assess the economic impact of 2015 floods,
- to demonstrate the utility of DEM in hydrological modelling for decision support and to prepare a potential flood risk zone map of selected area.

1.3. Area of Focus

GIS is a powerful and versatile computer-driven mapping technology with broad applications in disaster preparedness and management (PDC, 2005). Applying GIS in disaster management;

- Accurate data availability
- Location of site accurately within least permissible time
- Accessibility information between source and destination
- Real time visualization of area of interest
- Reduce the time element involved in activities (T.Sudheer, 2014).

GIS is a powerful tool to analyse spatial data and they play a crucial role in flood risk evaluation processes. The development of computational models to evaluate the future

flood damage is an important step to harmonise methods. Flood risk maps are essential in flood management processes (ELEUTÉRIO, 2012, p. 55).

GIS platform was able to produce series of thematic maps which was used to generate a geospatial database for flood risk analysis and assessment. The result of the analysis effectively demonstrated the contribution of geospatial methods in mitigating and monitoring the effect of flooding (Nkeki, Henah, & Ojeh, 2013, p. 123).

The area of focus in this paper is assessing loss and damage caused by 2015 floods in Myanmar. We study disaster loss and damage and potential flood risk assessment with the GIS point of view. We select this as part of disaster risk reduction. The study area is 12 States-Regions of the Country which were affected by 2015 floods and the area of interest; downstream of Tha Phan Seik Dam which suffered flash flood during 2015 floods.

1.4. Literature Review

Dutta, D., & Herath, S. 1999 proposed flood damage assessment methodology which is a combination of hydrologic model and damage assessment model. Authors described the detailed GIS database and some preliminary results of flood model and discussed about the dimension of economic damage due to any flood disasters in three major factors;

- i. Land use pattern of the flood affected area
- ii. Depth and Duration of flooding
- iii. Spatial distribution of flood

So, the author forecasted on the post disaster assessment by GIS point of view and it best to reference and available to process damage assessment caused by 2015 floods in Myanmar.

Crowe, P. 2003 Author has studied the uses and potential of Geographic Information Systems (GIS) in improving the management of flood response operations. GIS is using to represent flood intelligence geographically as well as to identify additional flood effects. Rather than completely relying on information about past floods, or waiting for the next

one to occur, flood intelligence can be generated synthetically in the GIS by overlaying information about the floodplain environment with flood boundaries based on different flood scenarios. Author also discussed about flood mapping, spatial data application to flood emergency management, using GIS in flood planning, using GIS for community education and in flood emergency response operations. Thus, author had used GIS to improve efficient response before and during flood for future floods. So it is also useful guide to be a full angle to view 2015 Myanmar floods.

Kourgialas, N. N., & Karatzas, G. P. 2011 has described that a reliable flood management plan has two components: (a) a proper flood management strategy, and (b) the determination of the flood-hazard areas. The flood management strategy includes:

- i. Pre-flood measures
- ii. Flood forecasting
- iii. Post-flood measures.

Authors introduced natural hazard loss estimation software, the Hazards US Multi-Hazard (HAZUS-MH) flood model to quantify the human, property, financial and social impacts of flooding under existing conditions and given possible mitigation measures. Then, six factors were considered to estimate the spatial distribution of the hazardous areas: flow accumulation, slope, land use, rainfall intensity, geology and elevation. As **Dutta, D., & Herath, S. 1999**, the author forecasts on post disaster assessment by GIS point of view and author fulfill Predisaster, during and after flood to be managed is also supported to my assessment.

Azaz, L. K. 2010 studied emphasize the importance of using remote sensing and GIS in damage assessment phase as part of effective Disaster Management Plan. Author has described Remote Sensing can assist in damage assessment monitoring and providing a quantitative base for relief operation and GIS can use to organize the damage information and the post-disaster census information and in the evaluation of sites for reconstruction.

Carlin, N. 2011 Author has developed a model to evaluate the infrastructure damages to determine if any spatial similarities exist which may be an indicator of predicting areas in

the future. The model used soil types, land use, slope and stream data. Each criterion was ranked as best (least likely to experience flash flooding), moderate, or worst (most likely to experience flash flooding), respectively. The objective was to define areas with the highest risk factors (most likely to flood) and assess how closely these locations are to the actual damage sites reported during the flood events.

Haq, M., Akhtar, M., Muhammad, S., Paras, S., & Rahmatullah, J. 2012 Authors has developed the techniques for mapping flood extent and assessing flood damages which can be served as a guideline for Remote Sensing (RS) and Geographical Information System (GIS) operations to improve the efficiency of flood disaster monitoring and management. They used methodology as standard supervised maximum likelihood classification, editing of the images was carried out by visual interpretation, and intersecting topographic maps with accumulated shape file of inundated area to extract different types of info-layers for damage assessment.

Ojinnaka, O. C., Baywood, C. N., & Gift, U. A. 2015 exploited GIS and Remote Sensing Approach with the aim of identifying and mapping areas vulnerable to flood hazard and identify the extent of damage resulting from the 2012 flood disaster in Anambra state. They identified spatial variations in flood hazard levels, spatial and economic impact of the 2012 flood disaster and the population exposed to different levels of risk in Anambra with a view of fostering the best approach for flood management. They considered six factors as indexes of flood hazard identification and these included elevation, proximity to drainage, Land use, population density, flow accumulation and slope.

The above authors, **Azaz, L. K. 2010, Carlin, N. 2011, Haq, M., Akhtar, M., Muhammad, S., Paras, S., & Rahmatullah, J. 2012** and **Ojinnaka, O. C., Baywood, C. N., & Gift, U. A. 2015** gave better idea to manage damage assessment using GIS/RS and pushed me to create AOI to compare satellite photos during flood with calculated result. That we should get a way for disaster preparedness and management.

Chapter-2: Methodology

2.1. Data

This study is based on the three main types of dataset.

2.1.1. Digital Elevation Model (DEM)

ASTER DEM 30 meters resolution Digital Elevation Model from ASTER in-track stereo is available for free from Global Data Explorer platform of United States Geological Survey (USGS). For the nation, ASTER DEM was available to download by selecting for each State / Region except Shan State and Kachin State because of big data size. For those areas were selected manually with 'Define Rectangular area tool' and downloaded in 4 rectangular datasets. There are 2 rectangular parts for Kachin State; latitude from 25° 41' 27.6" N to 28° 33' 3.6" N, longitude from 95° 56' 9.6" E to 98° 47' 45.6" E and latitude from 23° 43' 22.8" N to 25° 46' 50.4" N, longitude from 95° 48' 32.4" E to 98° 56' 44.88" E. And also 2 rectangular parts for Shan State; latitude from 21° 43' 35.91" N to 23° 43' 36.435" N, longitude from 96° 7' 21.6" E to 100° 2' 22.6" E and latitude from 19° 16' 55.3" N to 21° 43' 35.91" N, longitude from 96° 7' 21.6" E to 101° 9' 52.93" E. So, 16 DEM datasets were combined to make a single raster dataset using 'Raster Mosaic' tool in ArcGIS 10.3.

2.1.2. Rainfall Data

The July and August 2015 rainfall data was acquired for 139 rainfall recording stations from Myanmar Climate Data Portal of Department of Meteorology and Hydrology, Myanmar. The collected data was saved to excel format and uploaded on ArcMap 10.3 using 'Display x,y' tool and exported to shape file.

2.1.3. Flood vulnerable population and loss and damage data by 2015 flood

The flood vulnerable population and loss and damage data by 2015 floods were collected at township level data. They are;

- Affected Population
- Damaged Houses
- Damaged Education Centers
- Damaged Health Facilities
- Damaged Paddy Area

There are two data sources; Myanmar Information Management Unit (MIMU) and Myanmar Disaster Loss and Damage Database (MDLD). MIMU is the unit under umbrella of UN and MDLD database is UNDP supported source to Relief and Resettlement Department (RRD) of Myanmar Government.

For collecting the affected population by township data, the most of the data was from MIMU but some from MDLD for the townships which absence in MIMU dataset but they were under the list of flood affected State/Region. The other loss and damage data except damaged health facilities were collected from MDLD database.

The other datasets using in this study are;

- 2014 Census data of Union of Myanmar
- Place Codes (P-codes) version-VIII_ Aug, 2015
- Administrative, Land use / Land cover and Transportation network shape files
- 2015 flooded area raster files and Dam list

2.1.4. Census data of the Union of Myanmar

UNFPA (United Nations Population Fund) had distributed 2014 census data of Myanmar and township level population data will be used for population density calculation and village tract level population data will be used to show the population distribution in the downstream of the Tha Phan Seik Dam.

2.1.5. Place Codes (P-codes)

Pcodes: an abbreviated term for 'Place Code'. P-codes are unique reference codes, represented by a combination of numbers and a Standard English transliteration, covering thousands of locations across Myanmar. P-codes cover Union Territory, States/Regions, Districts, Townships, Towns, Wards, Village Tracts and Villages in Myanmar. P-codes are currently maintained by the Myanmar Information Management Unit (MIMU). P-codes will be used in data joining process such as, township shape file with township level Census data table. In this study used P-Code version VIII, August 2015.

2.1.6. Data of Administrative Units, Land use/ Land cover and Transportation Network

The most administrative used in this study are;

- Union level, State-Region level and Township level,
- Villages to calculate and identify the potential flood risk villages.

Land use/ Land cover to present how much of country is covered by forests, wetlands, agriculture and other land. The last updated year for Land use / Land cover data is 2000.

Railway network (2010 data) and Main road network (2010 data) to show the main transportation structure in the flood affected State/Region.

These Administrative, Land use / Land cover and Transportation data are secondary data and collected from MIMU.

2.1.7. Data of 2015 Flooded Areas and Dams

Flooded area database was downloaded from United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme (UNOSAT). The dam information was collected from Myanmar River Network web site.

2.2. Methods

Heavy rain causes the dams over flood. The dams on the drainage network map was created to know the spatial distribution of dams and the structure of main drainage network in country level. If the drainage network is dense at any area, it will be a good indicator to high flow accumulation path and more likely to get flooded. Hydrology analysis was done to create drainage network from ASTER DEM 30m. DEM was processed by using with **Fill, Flow Direction, Flow Accumulation, CON** and **Stream order** spatial analysis in ArcGIS 10.3 software.

Rainfall is the crucial reason in flooding. Total rainfall of July and August 2015 map was created based on rainfall data from 139 rainfall stations by using **Kriging Interpolation** to present rainfall situation over the country. So **Histogram, Trend** analysis and **Average Nearest Neighbor** spatial statistics was performed before Kriging Interpolation to define the situation of rainfall data spatial distribution.

The map showing population density by township was created to define the populated area. The area of township generate from the township shape file by using **Calculate geometry**. Population density by township was calculated by using **field calculator**.

After flood events, the assessment of loss and damage is one of the most important issues. It is essential for many purposes such as flood relief work. The damages caused by a flood event can be divided as being either tangible that is quantifiable in economic terms or intangible that is difficult to assess in economic terms, such as psychological

damage or the inconvenience caused by the interruption of daily social activities, etc., Damages can also be divided into direct damages that caused by contact with floodwater or indirect damages that caused by the subsequent interruption or destruction of economic or social activities (Fattorelli & Frank, 2005). This study will only consider tangible damages. Mapping the lost and damage data using joined method between excel data and feature class, to present the loss and damage status of flood affected area.

The potential flood risk area of selected region will be calculated by using **Raster Calculation** based on the three criteria as elevation, slope and the buffer zones from drainage network for proximity of the damage site. The result would be used to compare with actual flooded situation of that area. Potential flood risk villages list will be extracted by using **select by location** method.

The figure 4 shows the methodology flow chart. The following procedures have been adopted to execution of the project objective:

1. Visualization of country level elevation in meter.
2. Derivation of drainage network using Fill, Flow direction, Flow accumulation, CON Stream Order and Stream to Feature
3. Visualizing Dams on drainage network
4. Mapping to visualise the spatial distribution of rainfall stations
5. Define appropriate degree and lag size by Trend analysis and Average Nearest Neighbour spatial statistics, these will be assessable in Kriging interpolation
6. Processing total rainfall distribution of July and August 2015 by Kriging interpolation
7. The process of calculating the township area in square kilometre with Calculate Geometry
8. Generating township level population density
9. Visualizing the structure of railways and major road networks with flood affected States-Regions

10. Generating township level loss and damage maps for affected population, damaged houses, damaged education centres, damaged health facilities, damaged paddy area and loss and damage ranking in State-Region level map .
11. Extracting the selected area from DEM that is downstream area of Tha Phan Seik dam by using Extract by Mask and mapping the population of that area.
12. Calculating the potential flood risk area of downstream area of Tha Phan Seik dam by using raster calculator and using select by location to extract the potential flood risk villages.
13. Presenting the real flooded area as the date of 18 July 2015 from UNOSAT that is to make comparison with outcome from potential flood risk calculation.

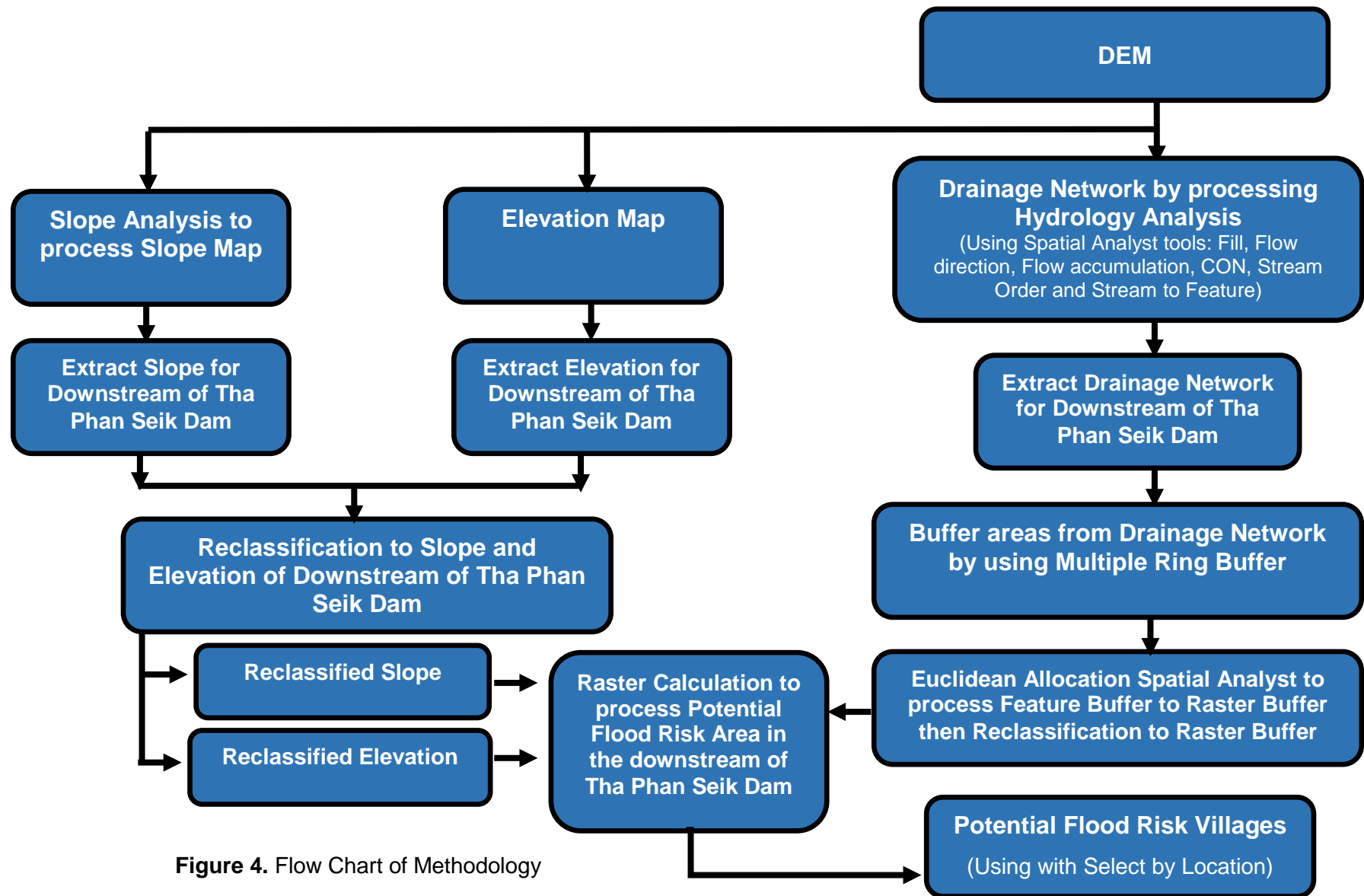


Figure 4. Flow Chart of Methodology

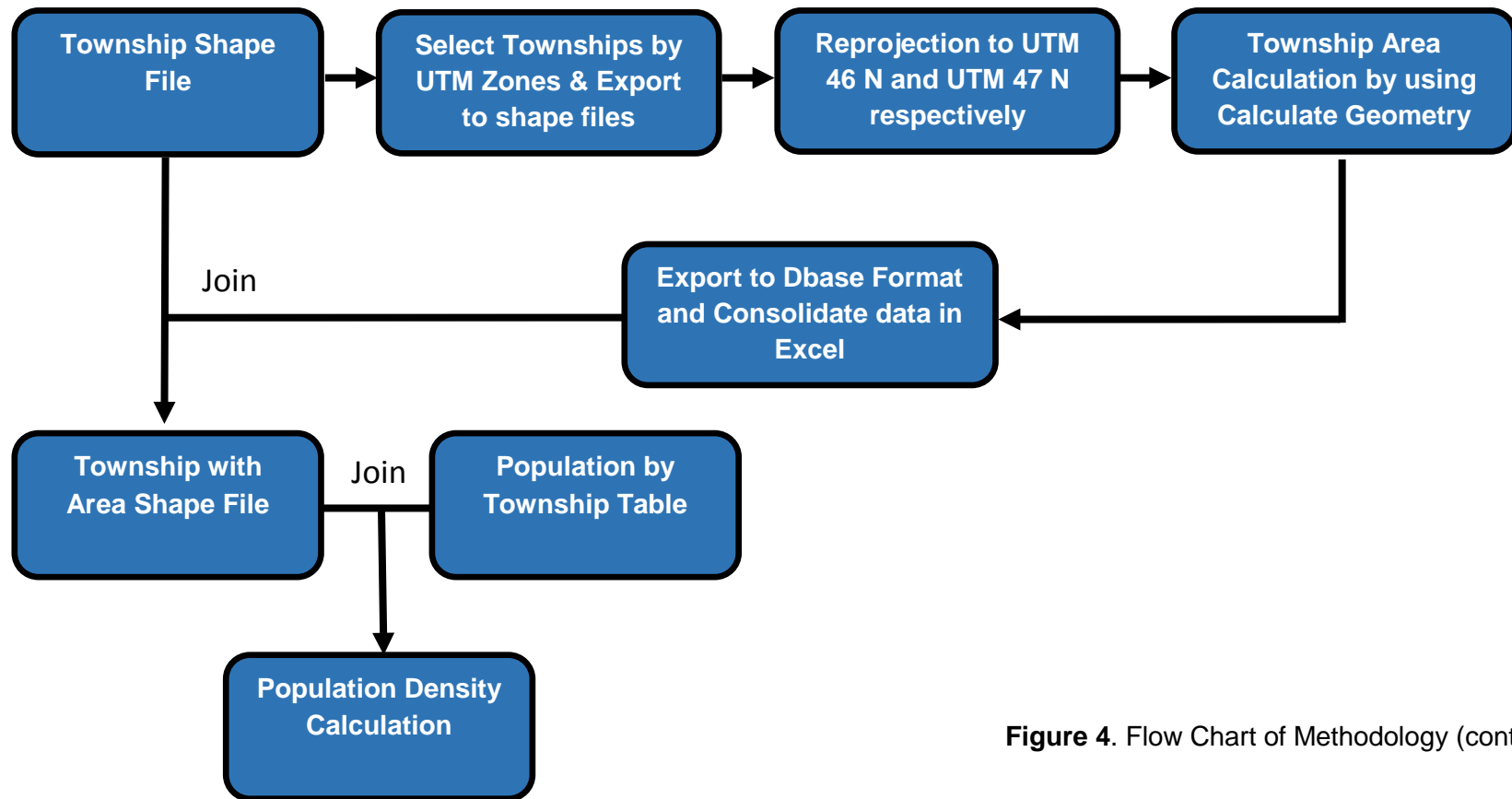


Figure 4. Flow Chart of Methodology (continue)

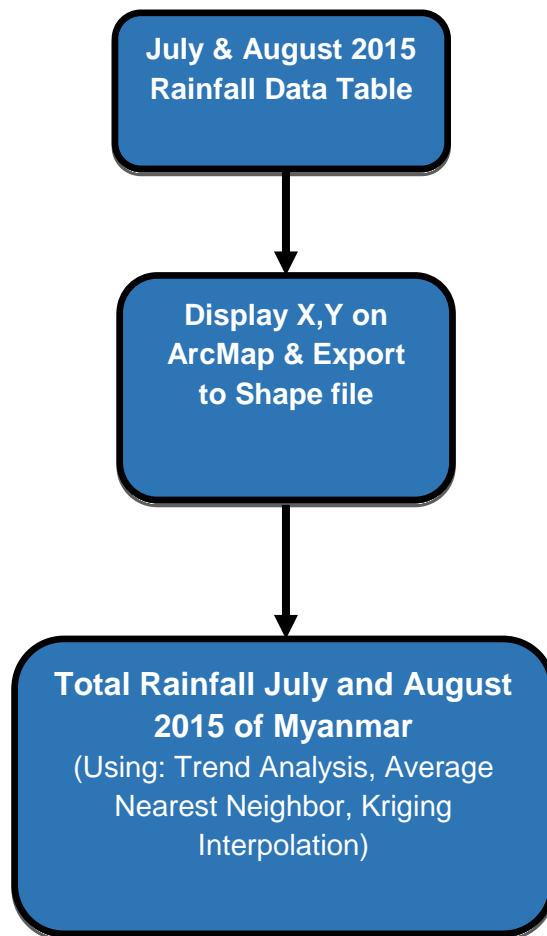


Figure 4. Flow Chart of Methodology (continue)

2.3. Software used

Software used to generate terrain features, drainage network, population density and loss and damage maps,

- Excel (Version 2010) to combine and clean to loss and damage data, rainfall gauge and the main Dams list.
- Google Earth Pro to check the Dams locations.
- ArcGIS (Version 10.3) to use for data integration, processing and analysis.

Chapter-3: Processes and Results

3.1. Terrain Analysis

Terrain analysis has been done in the form of elevation and slope. These two factors have been derived from digital elevation model ASTER DEM 30 m.

3.1.1. Elevation Analysis

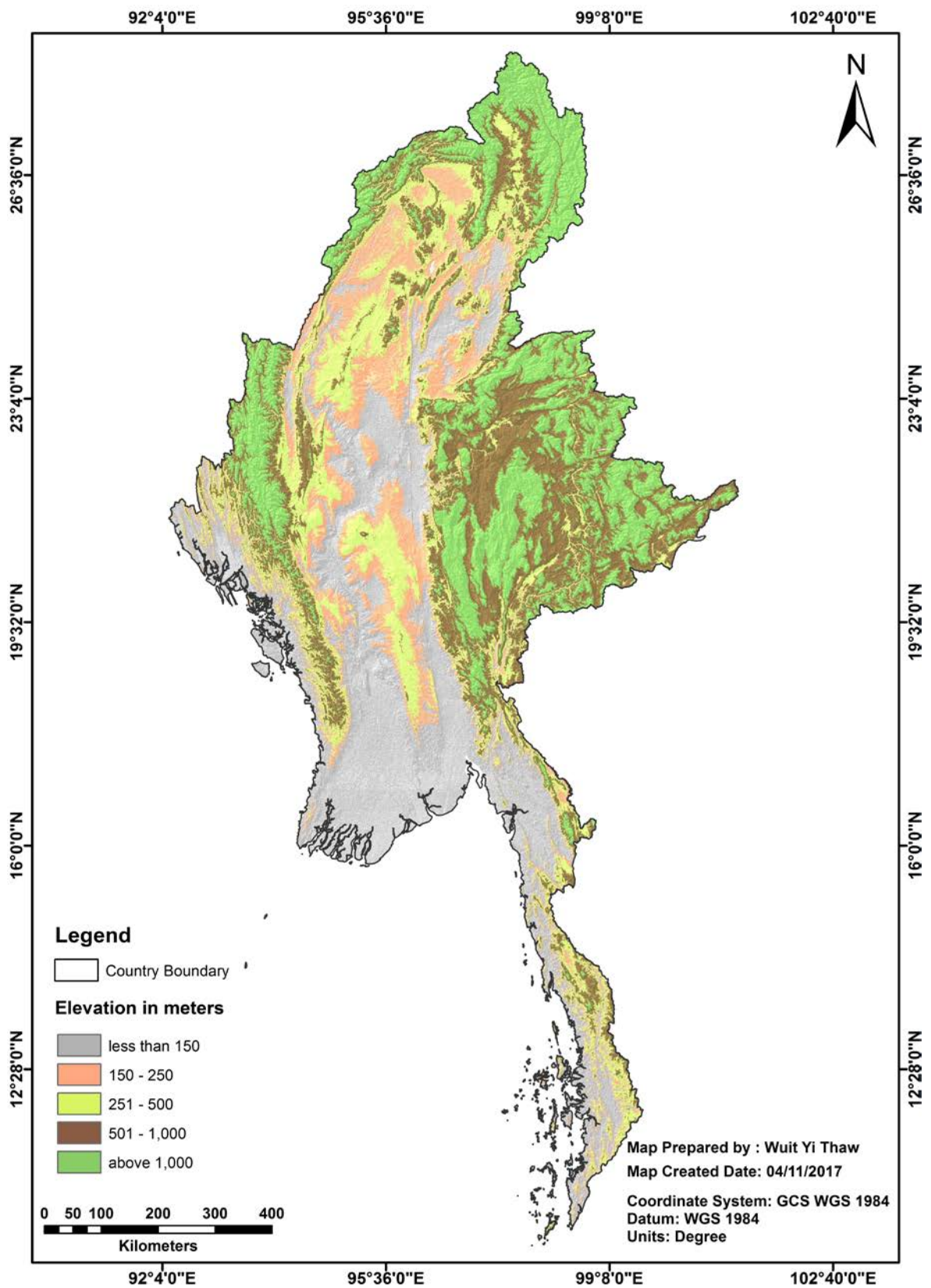
Map 3 shows the country level land elevation that was created from ASTER DEM 30 m. The lowest elevation is 0 meter; Andaman Sea and the highest elevation is 5,881 meters; Hkakabo Razi.

The lower and undulating plateau areas with elevation less than 150 meters presented in grey colour and land elevation from 150 to 250 meters presented in light salmon colour and these areas are about 41 percentage of the country and they fall in the costal line areas of Rakhine State, Mon State and Tanintharyi Region, Ayeyarwady delta region and the dry zone region in the central of Myanmar. So elevation less than 150 meters are the low areas have the high potential to flood.

The land elevation from 251 to 500 meters is shown in yellow-green colour that covers about 16 percentages of the country. The land elevation from 501 to 1000 meters presented in brown colour that is about 22 percentages and the land elevation above 1,000 meters that presented in green colour is also about 22 percentages of the country.

The land elevations above 1000 meters are mountainous areas. They are mostly situated in the Shan, Kachin, Chin and Rakhine States which are in the eastern part, northern part and western part of the country.

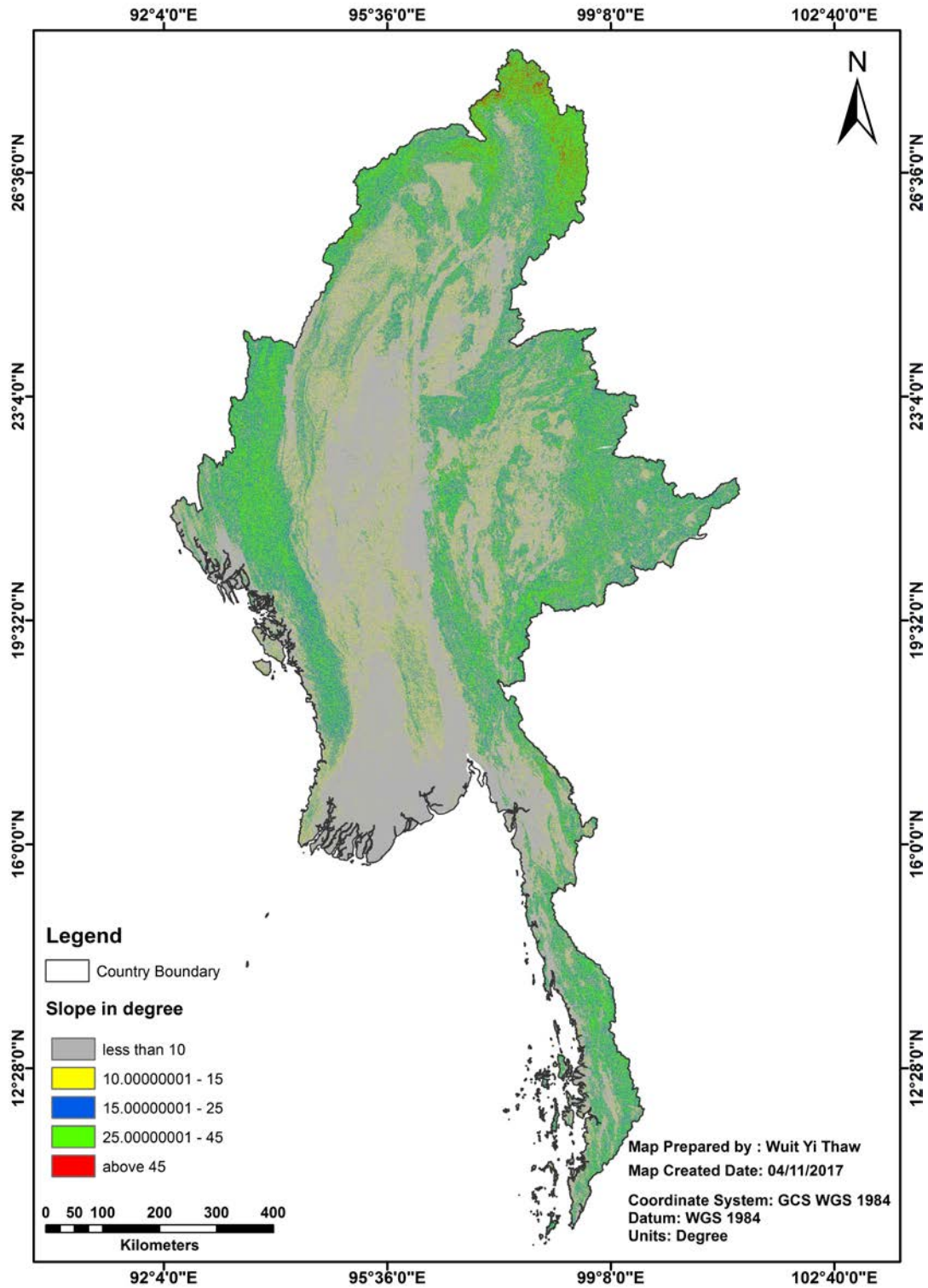
Myanmar Elevation Distribution



Map 3: Myanmar: Distribution of Elevation

3.1.2. Slope map

Myanmar Slope Distribution



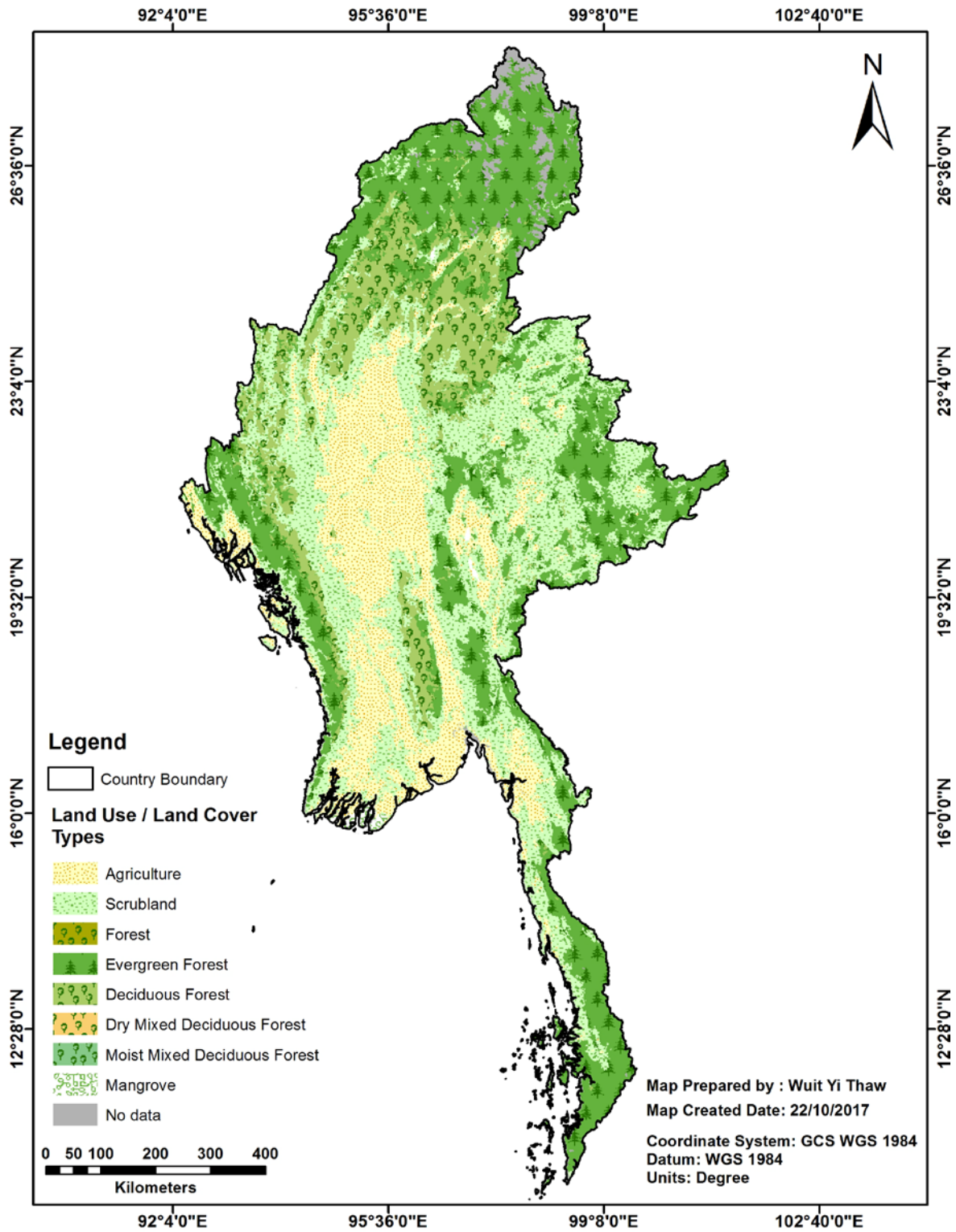
Map 4. Myanmar: Distribution of Slopes

The spatial analyst tool was used to create slope for the country level from Digital Elevation Model ASTER DEM 30m. The result shows in Map 4. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell. It is the lower the slope value, the flatter the terrain and also the higher the slope value, the steeper the terrain. The flatten area of slope degree 0 to 10 degrees presented in grey and above 10 to 15 degrees presented in yellow, these areas are situated along north to south which fall central part of the country and delta area. Slope degree above 15 to 25 showed in blue and above 25 to 45 showed in green can be seen in Kachin State in Northern Part, Rakhine State and Chin State in Western Part, Shan State in Eastern Part and Tanintharyi Region in Southern Part of Myanmar respectively. Steepest slope areas are situated at the most northern parts of Myanmar, above 45 degree of slopes are shown in red color in the map. The steeper slopes produce the more potential flash floods and landslides. Chin State located in the western part of Myanmar suffered extreme landslide while cyclone Komen in 2015, the area falls slope between 15 and 45 degrees. Due to the massive damage and persisting landslide risks, geologists and engineers were assessing the feasibility of relocating the Chin State capital, Hakha, to a safer location (Government of the Union of Myanmar, 2015).

3.2. Land Use / Land Cover Pattern

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 (MES et al., 2009, p. 71). 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 (MES et al., 2009, p. 19).

Myanmar Land Use / Land Cover



Map 5. Myanmar: Land Use/Land Cover (MIMU, 2000)

The type of land use/ land cover is important factor for flood damage in the flood affected areas. Depending on the type of land use/ land cover such as agriculture, residential area, commercial area, real estate, etc., flood damage characteristics vary to a great extent. A detailed land use/ land cover information is very much important for adequate flood damage assessment that should be categorized into several groups for analysis (Dutta & Herath, 1999, p. 110). Map 5 presents the land cover of Myanmar country level in general. So, more up to date detail of land use/ land cover country level information is needed to make effective analysis.

3.3. Rainfall Pattern

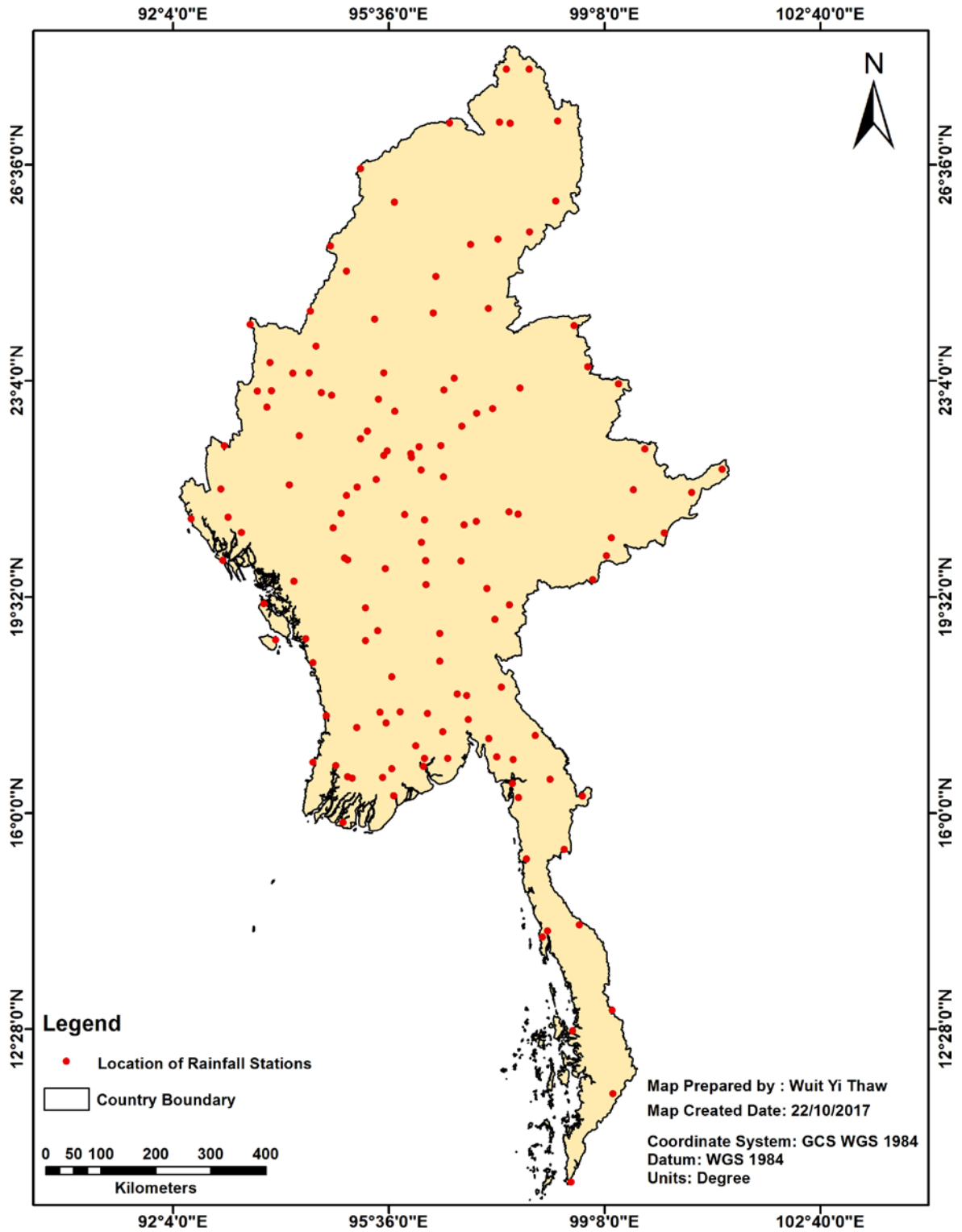
Heavy rainfall made overtopping dams, overflow streams and rivers, floods and landslides. The description of rainfall terminologies: 64.5 to 124.4 mm is Heavy, 124.5 to 244.4 mm is Very Heavy and greater than or equal to 244.5 mm is Extremely Heavy for during 24 hours (Government of India, Earth System Science Organisation, & India Methodological Department, 2015, p. 21).

Cyclone storm Komen caused very heavy rain in Myanmar from 26-30 July 2015 and Mindat rainfall station at Chin State got 125 mm on 30 July 2015 and it breaks previous maximum rainfall of 76 mm of 51 years ago (The Mirror, 2015). On 29 June around 132 mm of rain fell in 24 hours in Sittwe, Rakhine State. Later, Kyaukpyu, also in Rakhine State, saw 120.9 mm of rain fall in 24 hours between 02 and 03 July 2015 (Davies, 2015).

Map 6 shows the distribution of rainfall gauges by country level. These data were collected from Myanmar Climate Data Portal and it provided data in monthly based. The rainfall points are extracted from the Excel file that shows as table in Appendix 1 and it was converted to ArcGIS as point events, to become the feature class Rainfall_Jul_Aug. The precipitation measuring stations are sparse and available data are not sufficient enough to characterize the highly variable precipitation and its spatial distribution. The

collected rainfall data was limited and this study is trying to present rainfall distribution from these sample data by applying theory to practical estimation.

Myanmar Location of Rainfall Recording Stations



Map 6. Myanmar: Location of Rainfall Recording Stations

There are several methods of spatial interpolation can be used to estimate precipitation variables at other locations. For this study, Kriging interpolation of geostatistical analyst will be used to estimate the country level total rainfall distribution for July and August 2015 that is to identify the highest rainfall areas during 2015 flooding. Geostatistics is a class of statistics used to analyze and predict the values associated with spatial or spatiotemporal phenomena (ArcGIS 10.3 Desktop Help).

Figure 5 shows geostatistical work flow. Descriptive statistical analysis as Histogram tool for frequency distribution, trend analysis and average nearest neighbor analysis will process on rainfall point data to identify and confirm their spatial patterns.

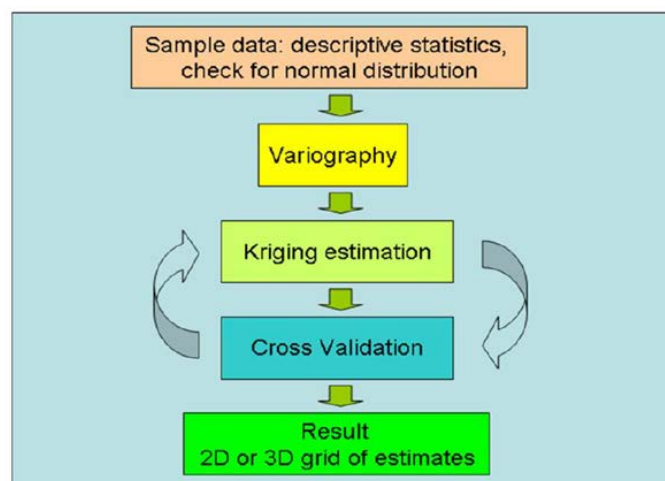


Figure 5. Geostatistical work flow (Marschallinger, 2013c, p. 5)

3.3.1. Histogram Analysis

Histogram tool is used to examine the distribution of total rainfall July and August 2015 point data. In figure 6, selected the frequency distribution in 10 classes for average rainfall dataset and keep transformation as **None**. The coefficient of skewness is a measure of the symmetry of a distribution and it is zero when symmetric distributions.

In below histogram, the skewness is 0.83065 and that means it has long right tail of large value. The mean is larger than the median for positively skewed distributions and vice versa for negatively skewed distributions. Mean is 859.1 and Median is 572 in figure 6. Thus, the data can be decided as positively skewed distribution. Kurtosis is based on the size of the tails of a distribution and provides a measure of how likely it is that the distribution will produce outliers. The kurtosis of a normal distribution is equal to three. Distributions with relatively thick tails are termed leptokurtic and have kurtosis greater than three. Kurtosis in below histogram is close to normal as it is 3.1348. Based on the histogram results, rainfall point data distribution is not perfectly normal distributed but positively skewness is not large. So, no transformation will make when Kriging interpolation analysis.

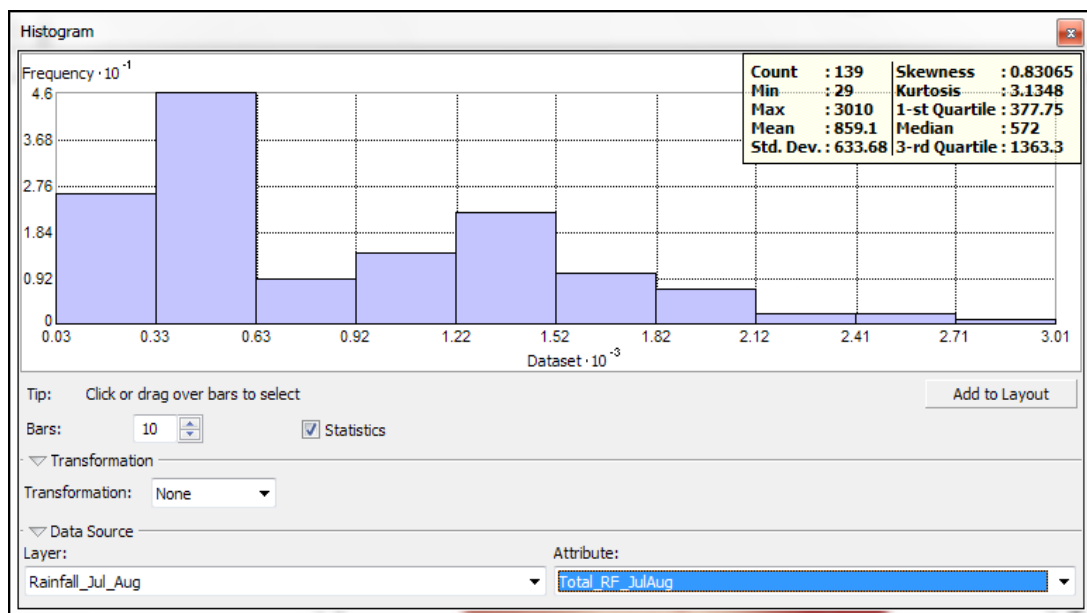


Figure 6. Histogram of total rainfall July and August 2015

3.3.2. Trend Analysis

Trend analysis will use to identify the presence or absence of trends in the input dataset. It provides a three-dimensional perspective of the data. The locations of sample points are

plotted on the x,y plane. Above each sample point, the value is given by the height of a stick in the z-dimension.

The purpose of the tool is to visualize the data and to observe any large-scale trends that the modeler might want to remove prior to estimation. It is best to keep the Kriging model as simple as possible and to only remove a trend if it significantly improves prediction errors.

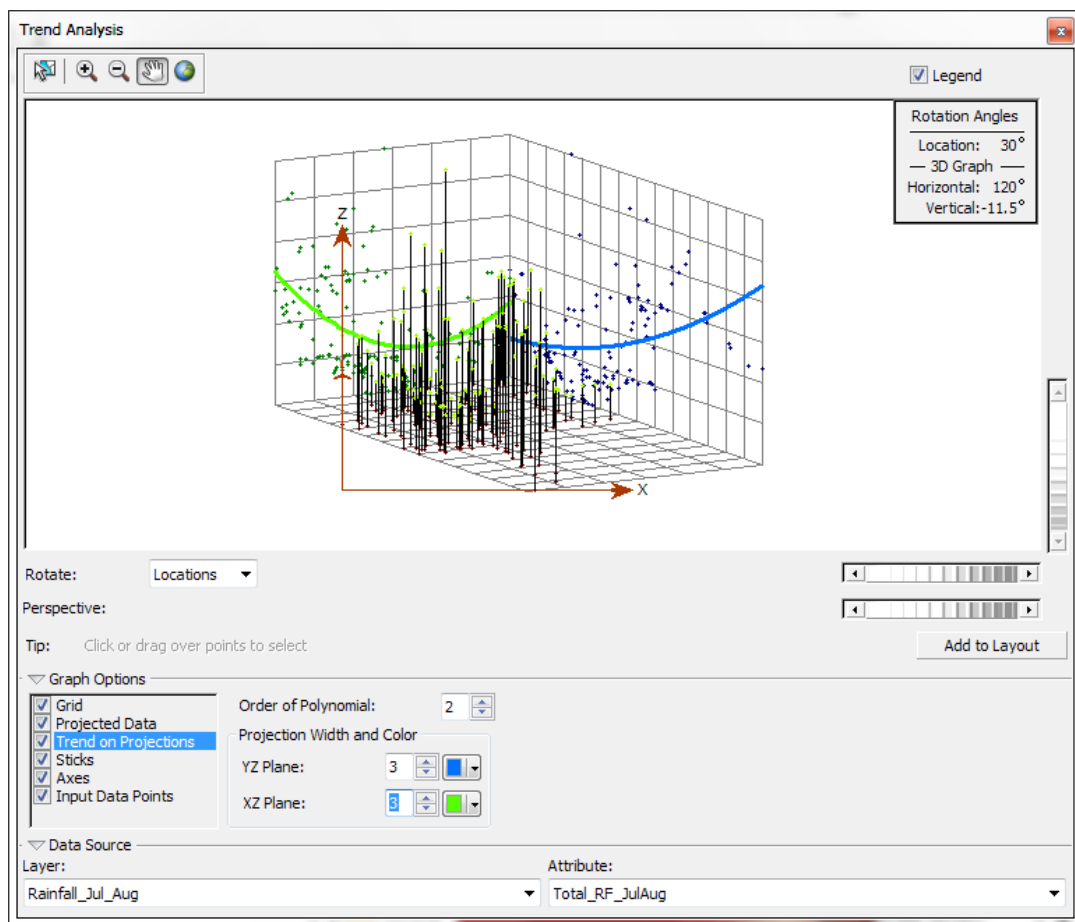


Figure 7. Trend analysis of total rainfall July and August 2015

In figure 7, green line is the East-West trend line and blue line is the North-South trend line. The significant upward curve as shown by the green line and the slightly upward curve as shown by blue line that means there is trend in the data. So this is a better trend pattern to the second order polynomial at 30 degree rotation. The light green line starts out with high rainfall values and decreases as it moves toward to the center of x-axis, then

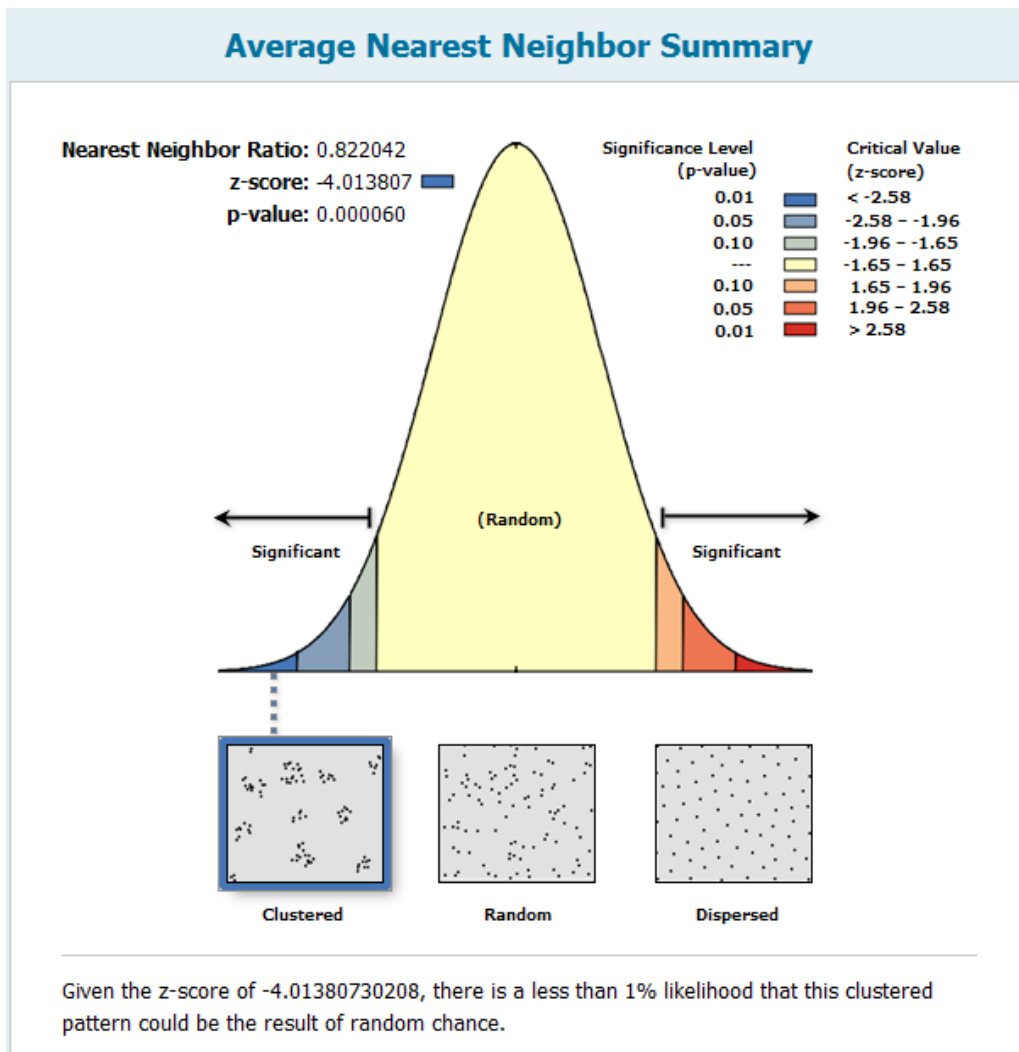
increases. Blue line decreases to the center of y-axis and values is increasing to the South. According to the trend, we can see as central area of Myanmar had lower rainfall and western costal area as Rakhine State, Delta area Ayeyarwady and southern coastal area Tanintharyi region had the highest rainfall.

3.3.3. Average Nearest Neighbor Analysis

Nearest Neighbor analysis is one of point pattern analysis and it tests observed distance between neighboring points and a theoretical, random pattern (Marschallinger, 2013d, p. 6). This used to determine a reasonably good lag size as every lag will have at least a few pairs of points in it. The selection of a lag size has important effects on the empirical semivariogram. For example, if the lag size is too large, short-range autocorrelation may be masked. If the lag size is too small, there may be many empty bins, and sample sizes within bins will be too small to get representative averages for bins (ArcGIS 10.3 Desktop Help).

So Average Nearest Neighbor analysis processed inputting as rainfall feature class **Rainfall_Jul_Aug** for the input feature class and the distance method as **Euclidean_Distance**. Figure 8 shows the result of Average Nearest Neighbor analysis summary. The analysis results return five values: observed mean distance, expected mean distance, nearest neighbor index, z-score, and p-value.

Observed mean distance is the average distance between nearest neighbors, and can be used as a lag size for semivariogram/covariance modeling and it is 44372.2323 Meters.



Average Nearest Neighbor Summary

| | |
|--------------------------------|-------------------|
| Observed Mean Distance: | 44372.2323 Meters |
| Expected Mean Distance: | 53978.0793 Meters |
| Nearest Neighbor Ratio: | 0.822042 |
| z-score: | -4.013807 |
| p-value: | 0.000060 |

Dataset Information

| | |
|-----------------------------|----------------------|
| Input Feature Class: | Rainfall_Jul_Aug |
| Distance Method: | EUCLIDEAN |
| Study Area: | 1619979972160.836426 |
| Selection Set: | False |

Figure 8. Average nearest neighbor summary of rainfall stations

The Nearest Neighbor Index is expressed as the ratio of the Observed Mean Distance to the Expected Mean Distance. The expected distance is the average distance between neighbors in a hypothetical random distribution. If the index is less than 1, the pattern exhibits clustering; if the index is greater than 1, the trend is toward dispersion or competition (ArcGIS 10.3 Desktop Help). The Nearest Neighbor ratio of rainfall point data is 0.822042, so the pattern can be determined as clustering.

Z-scores are standard deviations and p-value is probability. The z-score and p-value results are measures of statistical significance which to determine whether or not to reject the null hypothesis. For the Average Nearest Neighbor statistic, the null hypothesis states that features are randomly distributed (ArcGIS 10.3 Desktop Help). In Average Nearest Neighbor summary of rainfall point data, the z-score is -4.013807 that is less than -2.58 and the p-value is 0.000060 that is less than 0.01, so reject null hypothesis at 1% which means less than a 1% chance that, in the population, there is no spatial autocorrelation. 99% confident that spatial autocorrelation exists. Table 3 shows the uncorrected critical p-values and z-scores for different confidence levels.

| z-score (Standard Deviations) | p-value (Probability) | Confidence level |
|--|------------------------------|-------------------------|
| < -1.65 or > +1.65 | < 0.10 | 90% |
| < -1.96 or > +1.96 | < 0.05 | 95% |
| < -2.58 or > +2.58 | < 0.01 | 99% |

Table 3. The uncorrected critical p-values and z-scores for different confidence levels
(ArcGIS 10.3 Desktop Help)

3.3.4. Kriging Interpolation of Rainfall Data

As rainfall plays an important role in the hydrologic cycle which controls water supplies and water disasters, thus it is also important factor for 2015 flooding. 139 recorded rainfall points data were collected for July and August 2015. Since rainfall is never evenly distributed over the area of study due to the topographic variability, it is preferable to have as many rainfall stations as possible to estimate the areal rainfalls that represent the

actual rainfalls over the country. So, interpolation will process for rainfall estimation for country level. Among of the interpolation methods, Kriging interpolation analysis will be used in this study.

Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface (ArcGIS 10.3 Desktop Help).

Kriging combines deterministic and stochastic approaches to predicting a variable at unsampled locations. Mathematically, the Kriging algorithm provides a minimum error-variance estimate of any unsampled value. Since Kriging involves averaging, it is essentially a low pass filter that tends to smooth out details and extreme values, Originally, Kriging was primarily used to provide estimates for unsampled values; it is increasingly used to build probabilistic models of uncertainty about these unknown values (Marschallinger, 2013b, p. 3).

Kriging interpolation analysis will be processed as following steps for distribution of July 2015 and August total rainfall in Myanmar.

In figure 9 (a) Step 1 would be started with Geostatistical Wizard from geostatistical analyst and choose method as Kriging/Cokriging from Geostatistical methods. In the Input Data window, the rainfall point feature class named RainfallJulAug2015_ProjectUTM47 will be put to Source Dataset and Data Field as Total_RF_JulAug that is the total rainfall of July and August 2015 for each rainfall stations.

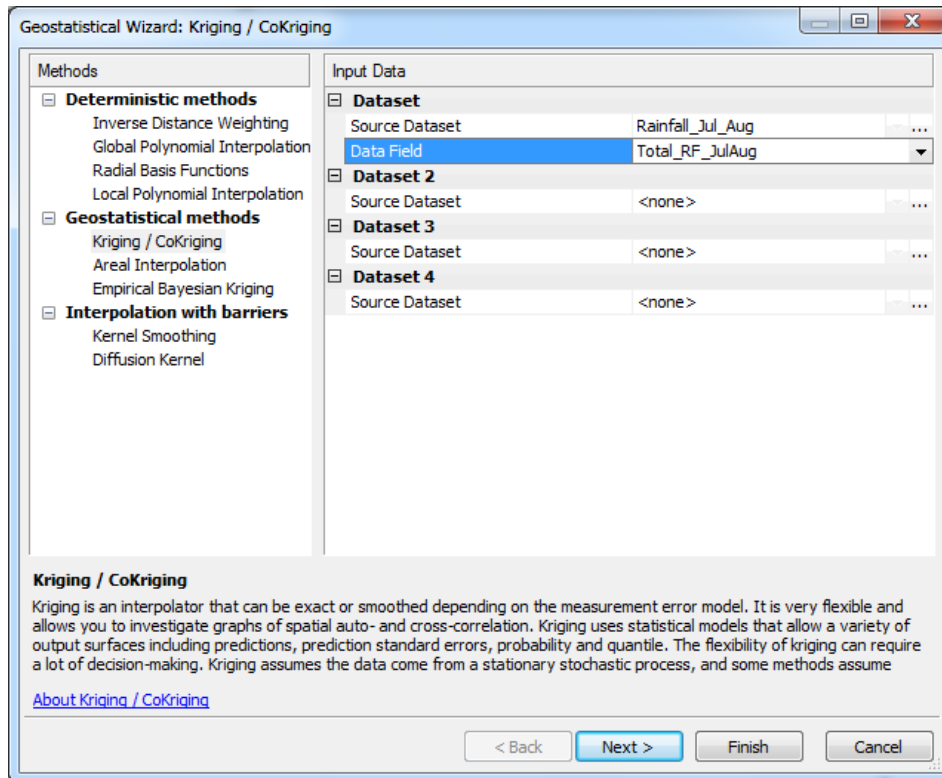


Figure 9 (a). Kriging Step 1

Step 2 in Figure 9 (b), chose the Kriging Type as Ordinary, Output Surface Type as Prediction and Order of trend removal as Second because an U-shaped curve was detected in the Trend Analysis.

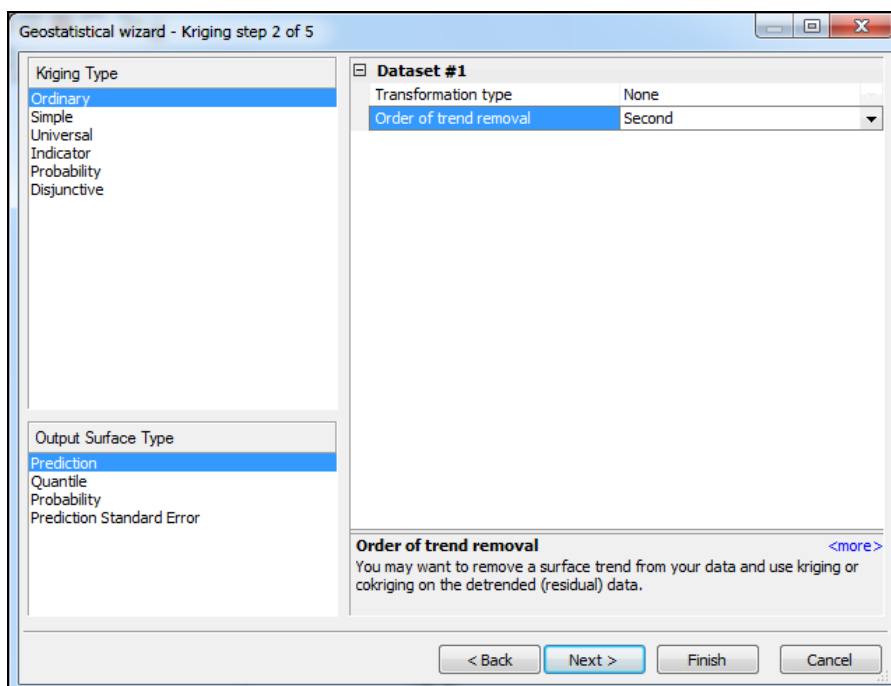


Figure 9 (b). Kriging Step 2

Step 3 in figure 9 (c). The geostatistical analyst maps the global trend in the dataset. The surface indicates the rapid change in the northeast-southwest directions and then gradually changes in southeast direction.

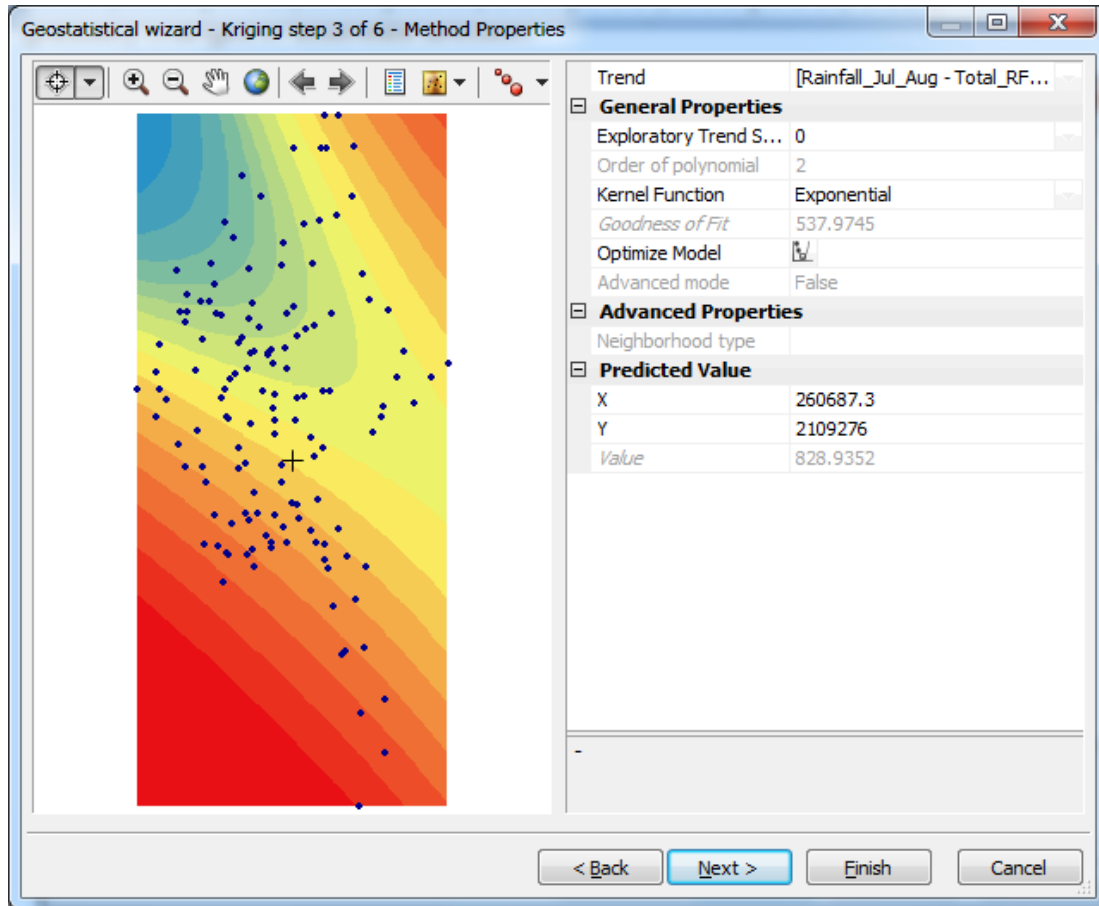


Figure 9 (c). Kriging Step 3 Method properties

In step 4, the semivariogram/covariance modeling is to determine the best fit for a model that will pass through the points in the semivariogram which is shown by the blue line in the diagram figure 9 (d). The semivariogram is a graphic representation used to provide a picture of the spatial correlation in the dataset. The Semivariogram/Covariance Modeling dialog box displays the semivariogram values as a surface that is showing the map on the bottom left of the dialog box and as a scatterplot relating semivariogram values to separation distance. By default, optimal parameter values are calculated for an omnidirectional (all directions) stable semivariogram model as shown in figure 9 (d).

There are several other types of semivariogram models and the most versatile and widespread model functions are:

- Spherical model
- Logarithmical model
- Exponential model
- Gaussian model
- Power model
- Wave model (Marschallinger, 2013a).

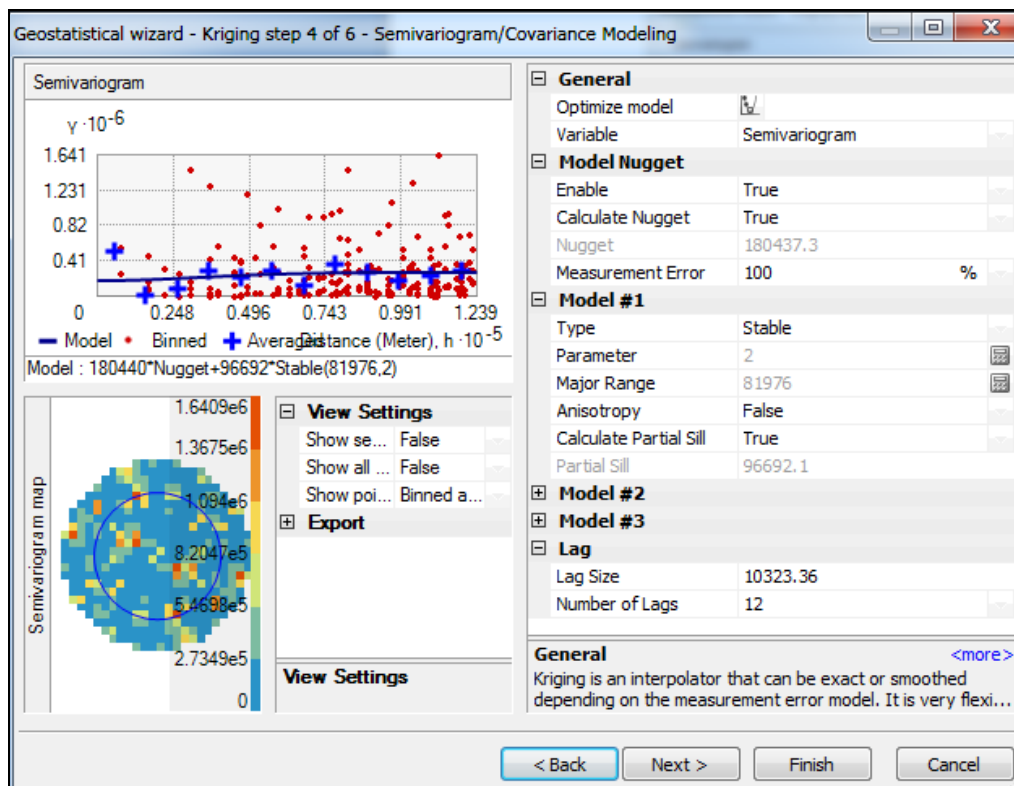


Figure 9 (d). Kriging Step 4 Semivariogram/ Covariance modelling, omnidirectional stable semivariogram model

The color scale represents the calculated semivariogram value on the semivariogram surface that provides the direct link with the empirical semivariogram values on the graph. The value of each cell in the semivariogram surface is color coded by showing lower values in blue and green and higher value in orange and red. The average value for each cell of the semivariogram surface is plotted on the semivariogram graph and presented as

a red point. After checking omnidirectional semivariogram, explore the dissimilarity in data points for a certain direction with the search direction tool to examine the directional influence on the semivariogram chart.

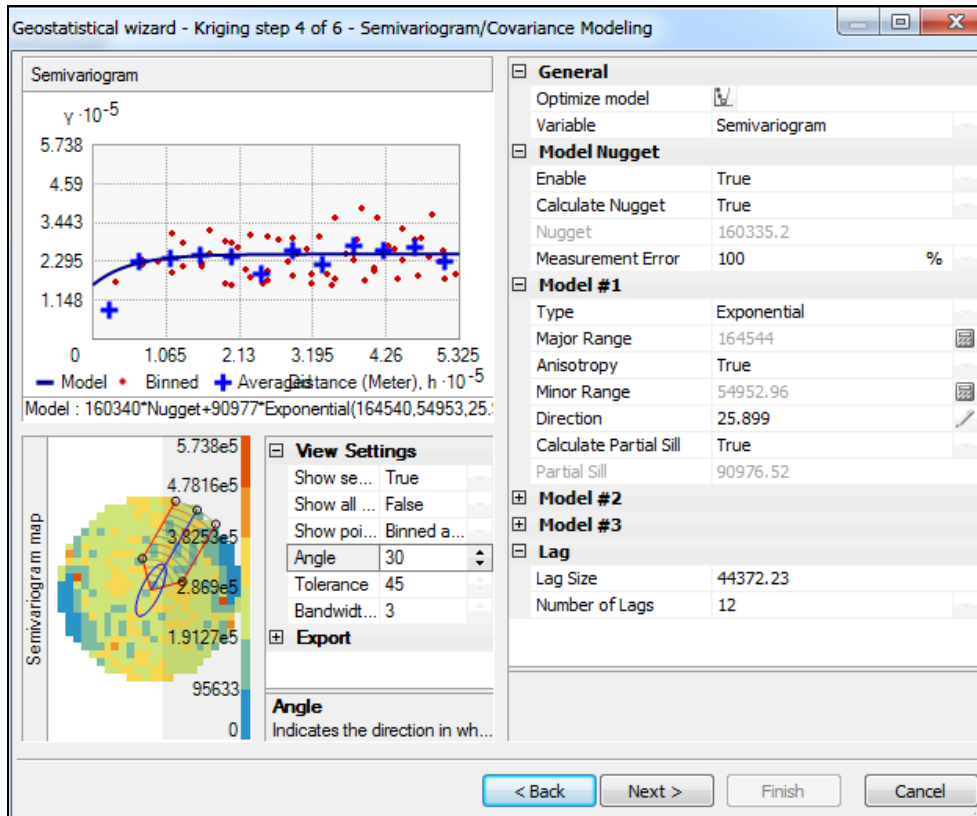


Figure 9 (e). Kriging Step 4 Semivariogram/ Covariance Modelling, Directional Semivariogram modelling

Figure 9 (e) shows the directional semivariogram modelling. Semivariogram / Covariance modeling for this rainfall data used the lag size value as 44372.2323 that was Observed Mean Distance from average nearest neighbor analysis. Then changed the show search direction from false to true, and changed the search direction angle under View Settings from 0 to 30. That angle value was determined as a good angle site appears U-shape trend during trend analysis. Keep the Tolerance is 45 and Bandwidth (lags) is 3. For the semivariogram model, choose model as Exponential and changed Anisotropy from false to true because of value changes different with directions in global

trend step 3. Changed the major axis direction as 25.899 to fit model and then processed searching neighborhood step.

After fitting model with the trend and directional influence in the data to describe the spatial autocorrelation, searching neighborhood to make a prediction that is to assume as locations get farther from the prediction location, the measured values have less spatial autocorrelation with the prediction location. There are several reasons to search neighborhoods that explained in the ArcGIS Help. They are:

- As these points have little or no effect on the predicted value, they can be eliminated from the calculation of that particular prediction point by defining a search neighborhood.
- It is also possible that distant locations may have a detrimental influence on the predicted value if they are located in an area that has different characteristics than those of the prediction location.
- A third reason to use search neighborhoods is for computational speed.

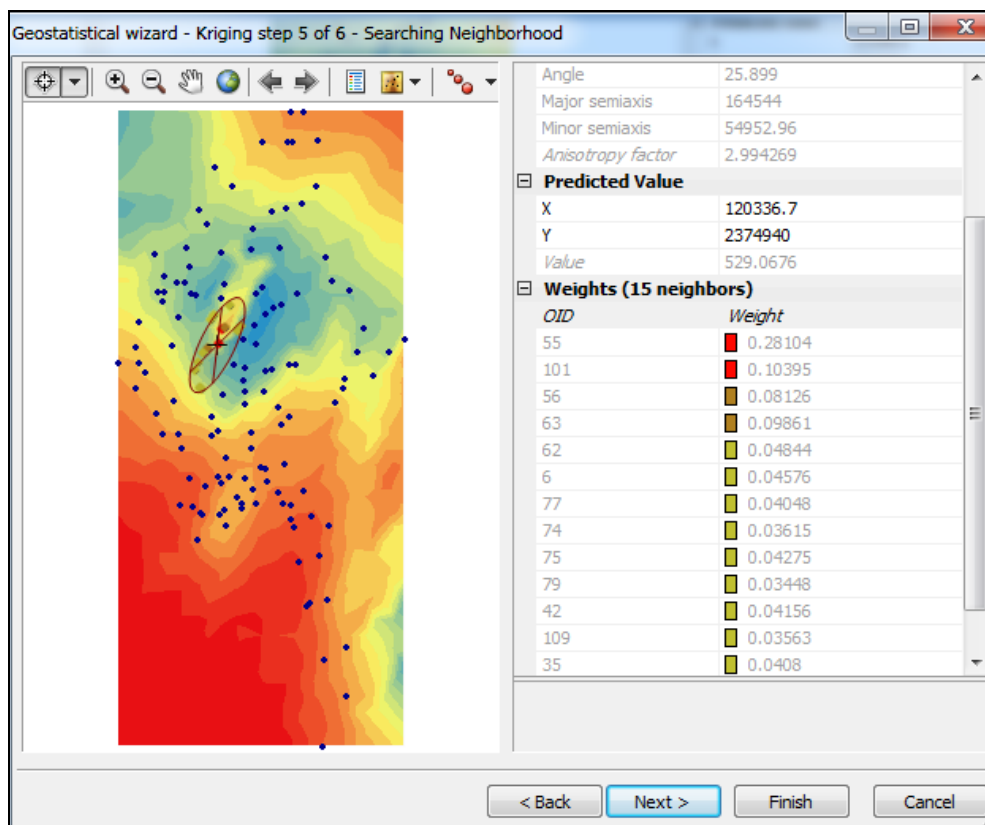


Figure 9 (f). Kriging Step 5 Searching neighborhood

Figure 9 (f) shows Kriging Step 5 searching neighborhood and the search neighborhood is specified as below:

- Neighborhood type: Standard
- Maximum neighbors = 5
- Minimum neighbors = 2
- Sector type (search strategy): Four Sectors with 45° offset
- Coordinates of test point (x = 120336.7, y = 2374940)
- Predicted value= 592.0676

Limit the data by defining a circle or ellipse to enclose the points that are used to predict a value at an unmeasured location. That circle or ellipse can be divided into sector from which equal number of points is selected to avoid bias in a particular direction. Four Sectors with 45° offset was used for this process.

The points selected in the data view window indicate the weights that associates with each measured value to predict a value for the location marked by the crosshair. In this process, two measured values are shown in red and they have weights of more than and equal to 10 percent. The larger the weight, the more impact that value will have on the prediction for the location at the crosshair.

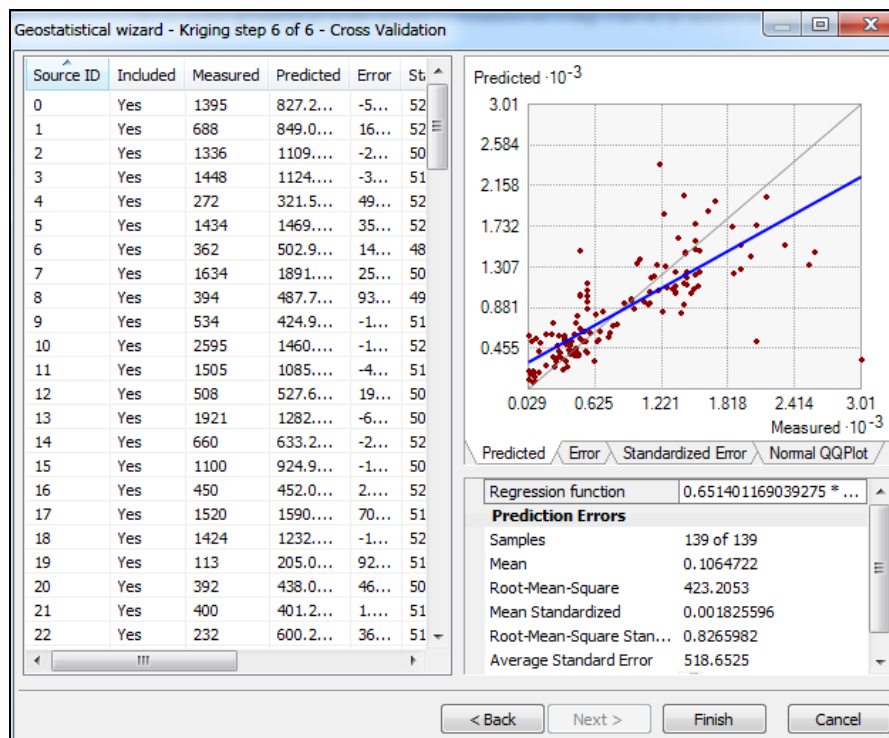


Figure 9 (g). Kriging Step 6 Cross Validation

Kriging result is checked by a cross validation procedure. Figure 9 (g) shows the cross validation by presenting prediction errors results with plots as Predicted, Standardized Error and QQ plot. To judge if a model provides accurate predictions, verify that

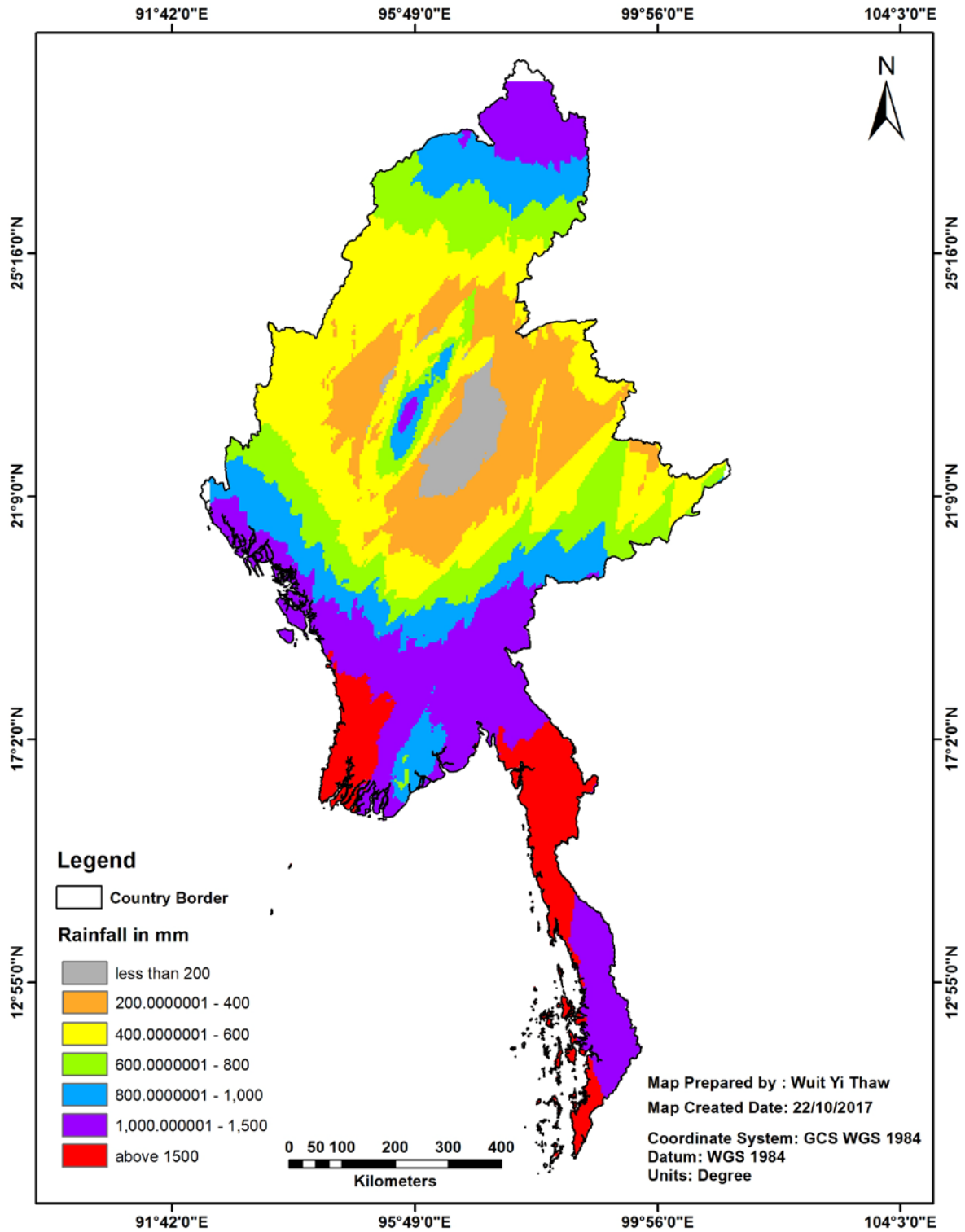
- The predictions are unbiased, indicated by a mean prediction error close to 0.
- The standard errors are accurate, indicated by a root-mean-square standardized prediction error close to 1.
- The predictions do not deviate much from the measured values, indicated by root-mean-square error and average standard error that are as small as possible. If the average standard errors are close to the root mean squared prediction errors that mean correctly assessing the variability in prediction. If the average standard errors are greater than the root mean squared prediction errors, overestimating the variability of prediction and vice versa if the average standard errors are less than the root mean squared prediction errors, underestimating the variability in predictions (ArcGIS 10.3 Desktop Help).

For this analysis, the total sample size is 139 points. The mean prediction error is 0.1064722 that is near to 0 so can conclude as prediction is unbiased. The mean standardized is 0.001825596, is also very close to 0. The root-mean-square standardized prediction error is 0.8265982, is close to 1 that can be determined as standard errors are accurate. The root mean square error is 423.2053 and average standard error is 518.6525, so average standard error is about 96 greater than root mean square error, that means there is a little overestimating the variability of prediction.

Then kriging result for total rainfall surface was processed successfully and extracted country area by using **Extract by Mask tool**.

3.3.5. Distribution of Total Rainfall in July and August 2015

Myanmar Distribution of Total Rainfall: July-August 2015



Map 7. Myanmar: Distribution of Total Rainfall in July and August 2015

Map 7 shows the Kriging interpolation surface for country level total rainfall distribution of July and August 2015. Rainfall level shows in millimeters by color coded. Total rainfall are less than 200 are presented in grey color, total rainfall above 200 to 400 are presented in orange color, total rainfall above 400 to 600 are presented in yellow color, total rainfall above 600 to 800 are presented in light green color, total rainfall above 800 to 1000 are presented in blue color, total rainfall above 1000 to 1500 are presented in purple color, and total rainfall above 1500 are presented in red color.

According to the result, the center of the middle area of country had high precipitation then gradually change to less precipitation in the central area of Myanmar then changed again to high precipitation to northern and southern part of the country. So lower Myanmar had the heavy rainfall during 2 months July and August 2015. Though middle area had the low precipitation than southern and northern part of Myanmar, these areas were affected during 2015 floods. The northern and eastern parts of the country are hilly and mountainous areas and the most of main rivers are flowing from north to south. So when intense rainfall in northern part, the central zone suffer riverine floods.

The hazard profile of Myanmar 2009 report described that there are different types of floods happen 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.

Riverine floods are the most common among all (MES et al., 2009, p. 49) and so it is important to define the drainage network structure.

3.4. Hydrological Analysis

Hydrology analysis can extract the information of drainage system to show the distribution of rivers and streams over the country.

Hydrology analysis was done as following process:

- Fill analysis
- Flow direction analysis
- Flow accumulation analysis
- Con analysis
- Stream order analysis
- Stream to feature analysis

3.4.1. Fill Operation

Fill analysis was done to remove small imperfections in the data (ArcGIS 10.3 Desktop Help). There is no limitation for z value in this analysis.

3.4.2. Flow Direction Operation

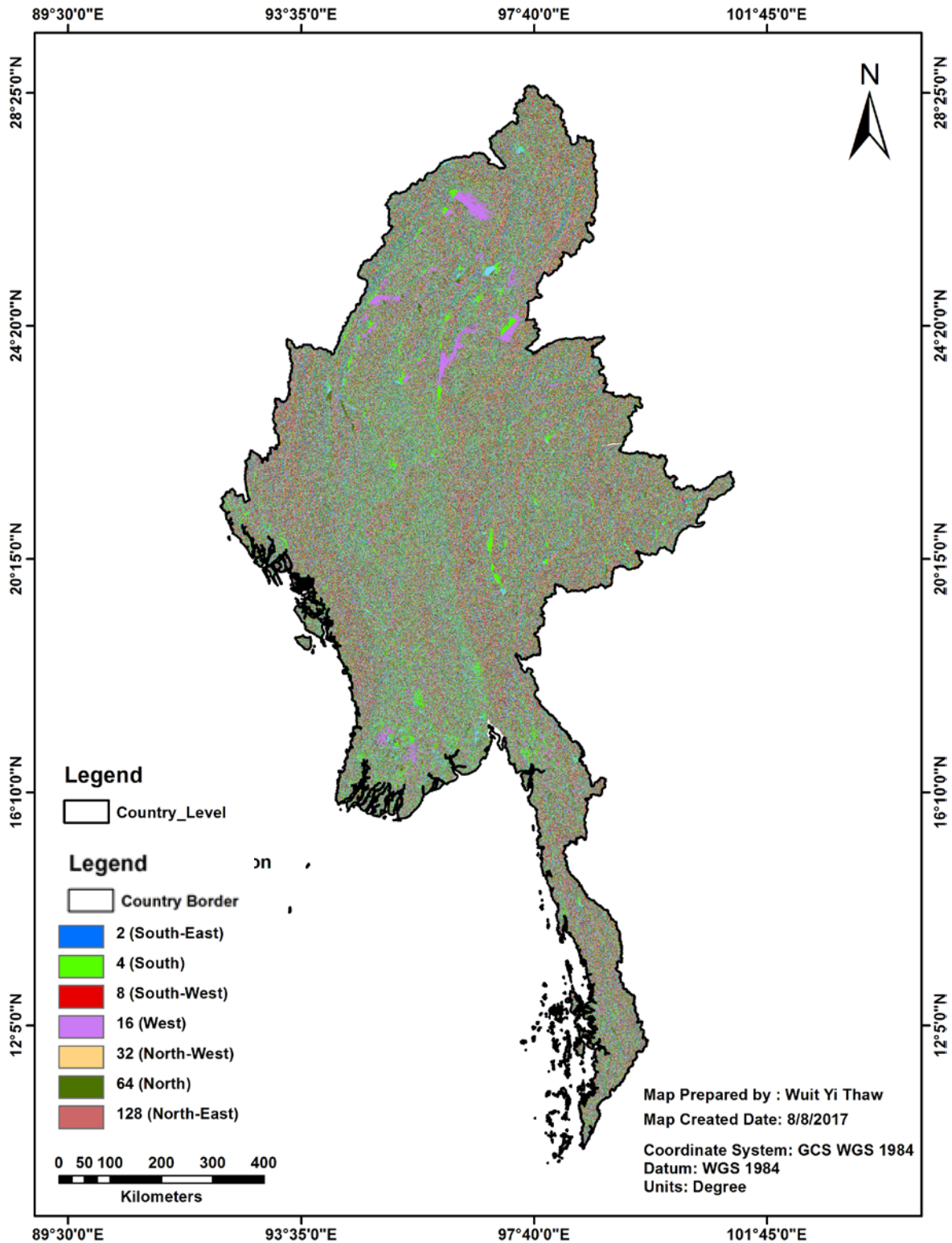
The Flow Direction, spatial analyst, creates a raster of flow direction from each cell to its steepest down slope neighbor (ArcGIS 10.3 Desktop Help). Flow direction was processed from the fill analysis result.

| | | |
|----|----|-----|
| 32 | 64 | 128 |
| 16 | | 1 |
| 8 | 4 | 2 |

Figure 10. Flow Direction, the values for each direction from the center(ArcGIS 10.3 Desktop Help)

Myanmar

Calculated Directions of Water Flow



Map 8. Myanmar: Calculated Direction of Water Flow

The water flow direction is important for flood analysis. Figure 10 shows the values for each direction from the center and Map 8 shows the result of flow direction analysis. There were 8 classes represented for 8 directions came out from this analysis. They are presented in separated colors, cyan for East direction, blue for South-East direction, light green for South direction, red for South-West direction, purple for West direction, light orange for North-West direction, dark green for North and dark pink for North-East direction. According to analysis result, 18% of flow direction is to West and purple spots can be seen significantly in the northern part of Myanmar, 17% of flow direction is to South and that light green spots can be seen separately distributed the whole country, then 15% is to North shown in dark green spots can be seen in the north-west of Myanmar. The result table with percentage can be seen in Table 4.

| Value | Direction | Count | Percentage |
|-------|------------|-----------|------------|
| 1 | East | 106705280 | 14 |
| 2 | South-East | 65752192 | 9 |
| 4 | South | 125710308 | 17 |
| 8 | South-West | 70675342 | 9 |
| 16 | West | 133424128 | 18 |
| 32 | North-West | 66358479 | 9 |
| 64 | North | 114715586 | 15 |
| 128 | North-East | 67118351 | 9 |

Table 4. Flow direction attribute table result with percentage of each direction

3.4.3. Flow Accumulation Operation

Flow accumulation, spatial analyst, creates a raster of accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster (ArcGIS 10.3 Desktop Help). In this analysis, used input raster as flow direction analysis result, no weight raster is provided and output data type as float. So, a weight of 1 is applied to each cell, and the value of cells in the output raster is the number of cells that flow into each cell (ArcGIS 10.3 Desktop Help).

3.4.4. Con Operation

Con analysis is to perform a conditional if/else evaluation on each of the input cells of an input raster (ArcGIS 10.3 Desktop Help). The input conditional raster used as flow accumulation analysis result and flow direction analysis result to both input true raster and input false raster field with no expression. The analysis is done to delineate a stream network.

3.4.5. Stream Order Operation

Then stream order analysis was processed to show the relative size of water network, first order, second order and third order. Stream ordering is a method of assigning a numeric order to links in a stream network. This order is a method for identifying and classifying types of streams based on their numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order. If the number is bigger, the stream size is larger (ArcGIS 10.3 Desktop Help).

In this analysis, for the input stream raster is putting the Con analysis result and for input flow direction raster is putting the flow direction analysis result and using STRAHLER method. STRAHLER method of stream ordering is proposed by Strahler in 1952. Stream order only increases when streams of the same order intersect. Therefore, the intersection of a first-order and second-order link will remain a second-order link, rather than creating a third-order link, see in figure 11 (ArcGIS 10.3 Desktop Help).

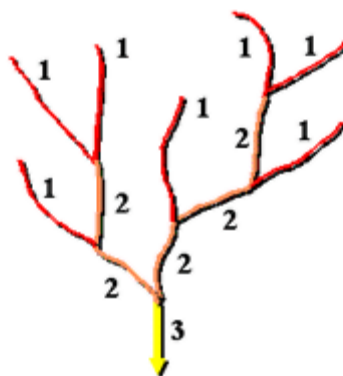


Figure 11. Strahler stream ordering method

3.4.6. Stream to Feature Operation

After stream order analysis, the result raster was converted to linear network using stream to feature tool. Stream to Feature was processed for vectorization of stream networks or any other raster representing a raster linear network for which directionality is known. The tool is optimized to use a direction raster to aid in vectorizing intersecting and adjacent cells (ArcGIS 10.3 Desktop Help). The very small creeks were count out in order to avoid visual complication. So the grid code will be selected from 9 and above of the stream network.

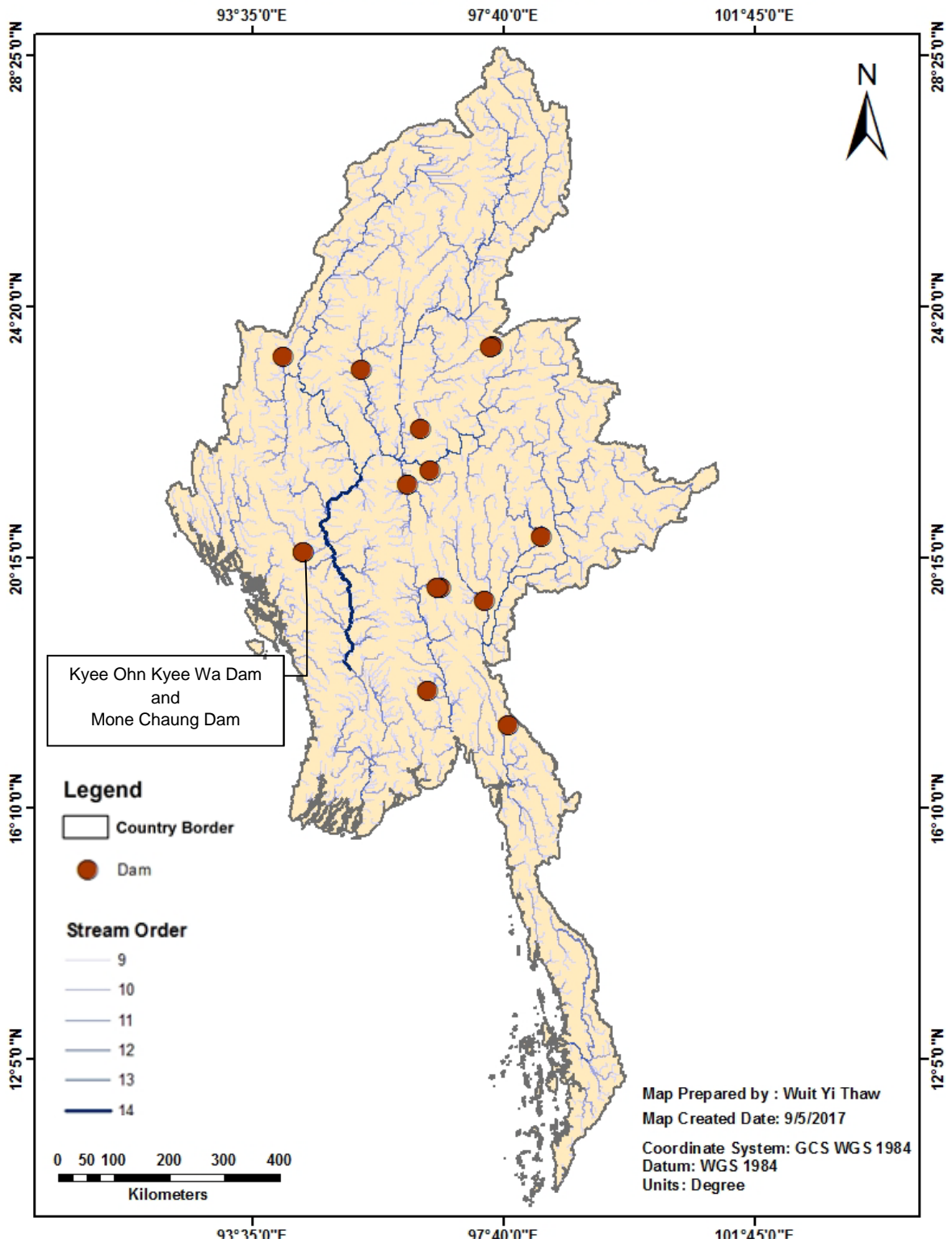
3.4.7. Dams on Drainage Network Map

Map 9 shows the distribution of dams on the drainage network. Several dams are built in Myanmar to store water for a variety of applications such as irrigation, municipal water supplies or to increase the amount of water available for generating hydroelectric power and so on. The map in this study can only present the main dams.

During cyclone Komen flooding period, the responsible from the Ministry of Agriculture, Livestock and Irrigation monitored the situation of Dam infrastructure and water volume level and also announced those information from the newspaper. Table 5 shows the water volume level situation of dams as of 2nd August 2015 from the Mirror newspaper and it was listed by overflow water level from high to low. Kyee Ohn Kyee Wa Dam and Mone Chaung Dam from Magway region that is dry zone which situated in the middle area of Myanmar, had high overtopping water level 30.5 foot and 28.2 foot respectively. Water storage volume level of dams, exceeding and releasing from outlet added a factor to cause the flood and flash flood.

Myanmar

Location of Major River Dams



Map 9. Myanmar: Location of Major River Dams

| No. | Name of Dam | Total Water Storage Capacity (acre-foot) | Overflow (feet) |
|-----|----------------------------|--|-----------------|
| 1 | Kyee Ohn Kyee Wa Dam | 319700 | 30.5 |
| 2 | Mone Chaung Dam | 674407 | 28.2 |
| 3 | Yazagyo Dam | 52000 | 9.2 |
| 4 | Kin Tat Dam | 38295 | 8.1 |
| 5 | Man Dam | 120000 | 5 |
| 6 | Salin Dam | 133000 | 4.7 |
| 7 | Myauk Ya Mar Yay Ku Dam | 122900 | 4.6 |
| 8 | Myauk Ya Mar Dam | 14057 | 4.1 |
| 9 | Pae Gyi Dam | 8100 | 3.1 |
| 10 | Pyaing Chaung Dam | 25205 | 3 |
| 11 | Nyaung Kaing Dam | 17594 | 2.8 |
| 12 | Yay Bote Dam | 28474 | 2.75 |
| 13 | Maday Dam | 53908 | 2.7 |
| 14 | Shauk Chaung Dam | 1140 | 2.4 |
| 15 | Pyin Pone Gyi Dam | 11130 | 2.1 |
| 16 | Thein Yin Dam | 20260 | 2 |
| 17 | Wun Chaung Dam | 1667 | 2 |
| 18 | Taung Khin Yan Dam | 11726 | 1.8 |
| 19 | Ma Zin Dam | 26186 | 1.7 |
| 20 | Thae Kaw Dam | 52500 | 1.55 |
| 21 | Laiva Dam | 1954 | 1.5 |
| 22 | Min Myin Dam | 19010 | 1.3 |
| 23 | Baw Ni Dam | 35200 | 1.2 |
| 24 | Taung Na Win Yay Htein Dam | 21196 | 1.15 |
| 25 | Pathi Dam | 30500 | 1.1 |
| 26 | Yin Shay Dam | 2600 | 1.1 |
| 27 | Sa Lat Htaw Dam | 18912 | 0.9 |
| 28 | Lin Pan Dam | 10180 | 0.8 |
| 29 | Shwe Pyi 3 Dam | 3700 | 0.8 |
| 30 | Kyay Pin Aet Dam | 44000 | 0.6 |
| 31 | Khawar Dam | 12550 | 0.6 |
| 32 | Nga Hmway Dam | 2380 | 0.5 |
| 33 | Sint Ku Chaung Gaung Dam | 2229 | 0.5 |
| 34 | Thapanseik Dam | 2880000 | 0.4 |
| 35 | Min Yae Chaung Dam | 2350 | 0.4 |
| 36 | Kan Daunt Dam | 719 | 0.3 |

Table 5. Water storage situation of Dams as of 2nd August 2015 Mirror Newspaper

There are four major rivers in Myanmar, namely Ayeyarwady, Chindwin, Sittaung and Thanlwin. While the existing intricate river systems provide easy access of water transportation and nutrient carried from upriver replenish the ground for agriculture creating prosperous urban centers along the waterways so the flooding in these rivers devastates the lives of the inhabitants. During floods, increased sedimentation occurred and the Ayeyarwady delta region experienced a floodplain type of flooding, with relatively low flood levels but over a large area (Government of the Union of Myanmar, 2015).

3.5. Population Density

Population density information is crucial because knowing the population in a flood zone is critical to determine potential damage following a disaster and also for necessary aid, shelter requirements and recovery process. The township population density in square kilometer was calculated by using the following formula.

$$\text{Population Density by Township} = \frac{\text{Population of Township}}{\text{Area of Township}}$$

3.5.1. Calculating the area of township

The area of township by geographical calculation is required to calculate population density. Reprojected townships feature class from the Geographic Coordinate System WGS 1984 to Projected Coordinate System WGS 1984 UTM Zone 47N. And then the area of township in square kilometer was calculated by using **Calculate Geometry** as shown in figure 12 and the result in attribute table view can be seen in Figure 13.

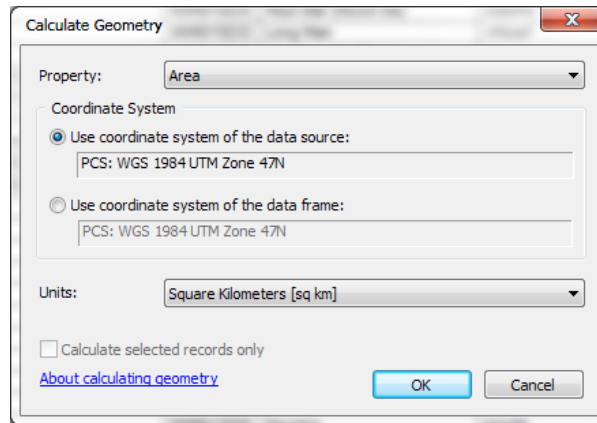


Figure 12. Calculating area of township by using Calculate Geometry

| OBJECTID | Shape * | ST | ST_PCODE | DT | DT_PCODE | TS | TS_PCODE | Area_SqKm |
|----------|---------|--------------------|----------|----------------|-----------|-------------------------|-----------|-------------|
| 1 | Polygon | Yangon Region | MMR013 | Yangon (North) | MMR013D00 | Hlegu | MMR013004 | 1510.153499 |
| 2 | Polygon | Yangon Region | MMR013 | Yangon (South) | MMR013D00 | Cocokyun | MMR013032 | 33.81132 |
| 3 | Polygon | Ayeyarwady Region | MMR017 | Myaungmya | MMR017D00 | Myaungmya | MMR017014 | 1146.479633 |
| 4 | Polygon | Ayeyarwady Region | MMR017 | Labutta | MMR017D00 | Mawlamyinegyun | MMR017018 | 1217.747885 |
| 5 | Polygon | Yangon Region | MMR013 | Yangon (West) | MMR013D00 | Seikkan | MMR013045 | 1.173283 |
| 6 | Polygon | Yangon Region | MMR013 | Yangon (East) | MMR013D00 | Pazundaung | MMR013016 | 1.067445 |
| 7 | Polygon | Yangon Region | MMR013 | Yangon (South) | MMR013D00 | Seikgyikanaungto | MMR013031 | 12.100896 |
| 8 | Polygon | Yangon Region | MMR013 | Yangon (West) | MMR013D00 | Dagon | MMR013043 | 4.895151 |
| 9 | Polygon | Yangon Region | MMR013 | Yangon (East) | MMR013D00 | Dawbon | MMR013014 | 3.11178 |
| 10 | Polygon | Yangon Region | MMR013 | Yangon (West) | MMR013D00 | Kyeemyindaing | MMR013038 | 4.456426 |
| 11 | Polygon | Kayin State | MMR003 | Kawkareik | MMR003D00 | Kawkareik | MMR003006 | 2412.035325 |
| 12 | Polygon | Yangon Region | MMR013 | Yangon (East) | MMR013D00 | Yankin | MMR013010 | 4.791166 |
| 13 | Polygon | Yangon Region | MMR013 | Yangon (West) | MMR013D00 | Hlaing | MMR013040 | 10.174323 |
| 14 | Polygon | Yangon Region | MMR013 | Yangon (East) | MMR013D00 | Dagon Myothit (Seikkan) | MMR013021 | 77.117875 |
| 15 | Polygon | Yangon Region | MMR013 | Yangon (East) | MMR013D00 | Dagon Myothit (North) | MMR013019 | 24.17637 |
| 16 | Polygon | Yangon Region | MMR013 | Yangon (North) | MMR013D00 | Insein | MMR013001 | 29.878339 |
| 17 | Polygon | Ayeyarwady Region | MMR017 | Myaungmya | MMR017D00 | Einme | MMR017015 | 746.797477 |
| 18 | Polygon | Yangon Region | MMR013 | Yangon (North) | MMR013D00 | Hmawbi | MMR013003 | 471.135407 |
| 19 | Polygon | Ayeyarwady Region | MMR017 | Patheingyi | MMR017D00 | Kyongpyaw | MMR017005 | 823.596642 |
| 20 | Polygon | Ayeyarwady Region | MMR017 | Hinthada | MMR017D00 | Zalun | MMR017009 | 627.175942 |
| 21 | Polygon | Bago Region (East) | MMR007 | Bago | MMR007D00 | Daik-U | MMR007007 | 1284.480377 |
| 22 | Polygon | Ayeyarwady Region | MMR017 | Hinthada | MMR017D00 | Ingapu | MMR017013 | 1676.86901 |
| 23 | Polygon | Bago Region (West) | MMR008 | Thayarwady | MMR008D00 | Minhla | MMR008009 | 677.948115 |
| 24 | Polygon | Bago Region (West) | MMR008 | Thayarwady | MMR008D00 | Zigon | MMR008011 | 256.130927 |
| 25 | Polygon | Bago Region (East) | MMR007 | Taungtha | MMR007D00 | Kyaukkya | MMR007011 | 2022.951971 |
| 26 | Polygon | Bago Region (West) | MMR008 | Pyaw | MMR008D00 | Thegon | MMR008005 | 777.767043 |
| 27 | Polygon | Bago Region (East) | MMR007 | Taungtha | MMR007D00 | Oktwin | MMR007013 | 1436.152872 |
| 28 | Polygon | Kayah State | MMR002 | Bawlake | MMR002D00 | Mese | MMR002007 | 1809.617773 |
| 29 | Polygon | Magway Region | MMR009 | Thayet | MMR009D00 | Kamma | MMR009015 | 1144.903759 |
| 30 | Polygon | Bago Region (East) | MMR007 | Taungtha | MMR007D00 | Yedashe | MMR007010 | 2618.652227 |
| 31 | Polygon | Magway Region | MMR009 | Thayet | MMR009D00 | Sinbaunowe | MMR009017 | 2056.877285 |

Figure 13. The attribute table view of Area of Township in Square Kilometers

Using Join method between area of township shape file and population by township table to proceed population density. The township population density was calculated as township population divided by the area of township using **Field Calculator**.

3.5.2. Population density by township

Figure 14 shows the frequency distribution histogram of the population density data. It was created to choose classification method of population density map. The histogram showed L Curve distribution graph so that represent the skew data. Mathematic sequences that are geometric and arithmetic progression suitable for the skew data (Loidl & Traun, 2015). For this population density data, the geometric progression is suitable method to visualize on map.

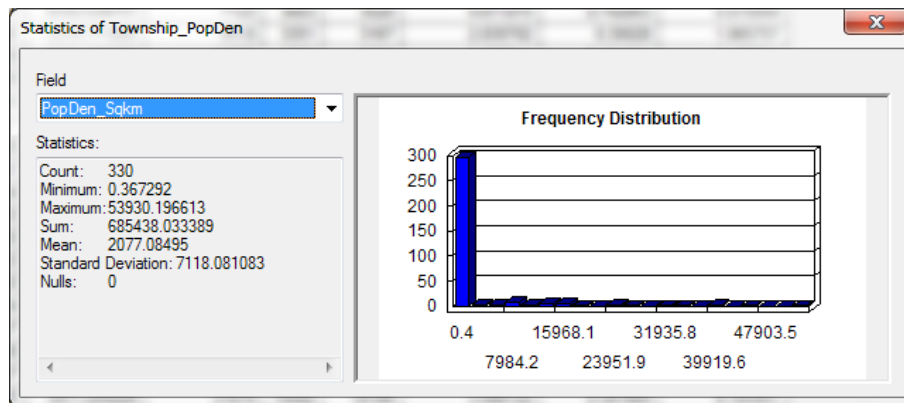
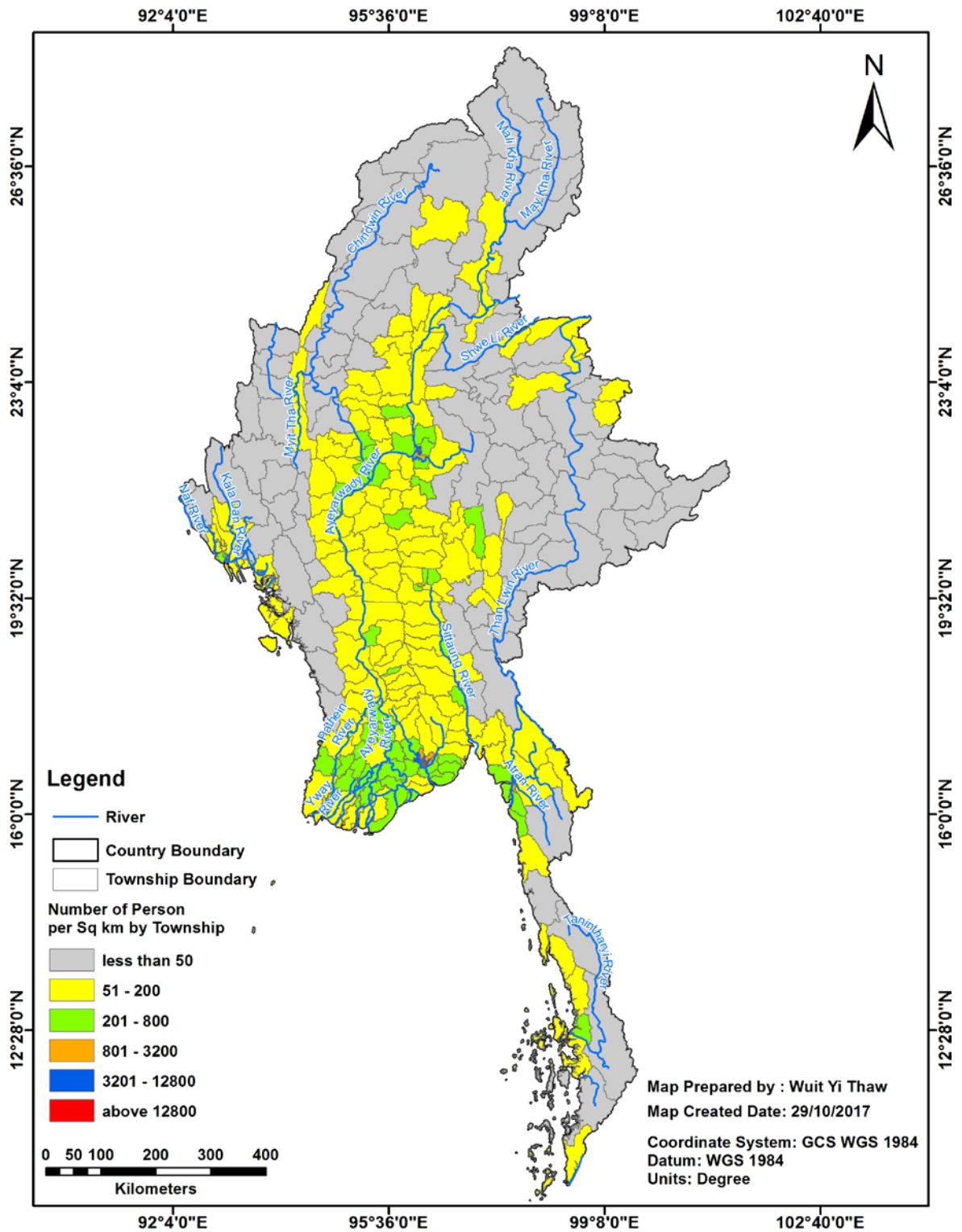


Figure 14. Statistics of population density

Map 10 shows the population density by township level of Myanmar. The areas where population density is less than 50 per sq km are hill area with the forest, and also mountainous areas. The most populated areas are along the river valley of Ayeyarwady river, Sittaung river, Kaladan river in Rakhine State, Shweli river in Shan State and Ayeyarwady delta area. These areas are more populated than hilly and mountainous areas because flat land areas are good for water and road transportation, also rich in marine products. Moreover, Myanmar is a agriculture country, these areas contain fertile soil and easy water supply for plantation. Another reason is security because most armed groups are based in the hilly and mountainous areas and conflicts happen frequently. Some populated areas are situated near borders to marchantile with neighbouring countries. So those areas will high affected when flooding, especially the populated areas along river valley and delta region.

Myanmar

Townships wise Population Density - 2014



Map 10. Myanmar: Townships wise Population Density - 2014

3.6. Assessment of Damage and Loss

Flood damage assessment has great importance in flood disaster mitigation. After a flood event, damage assessment is important for many purposes such as flood relief work, estimation of financial supports for affected people, etc., (Dutta & Herath, 1999, p. 1). In this paper, 2015 flood loss and damage data was collected at about 1 month after disaster from the most of available sources and consolidated them to the dataset. So, this assessment is based on the review of secondary data from reports, publications, newspaper articles, and additional informative material produced by NGOs, international organizations and development/humanitarian agencies were collected and analyzed.

3.6.1. Damage in Transportation Sector: Road and Railway Networks

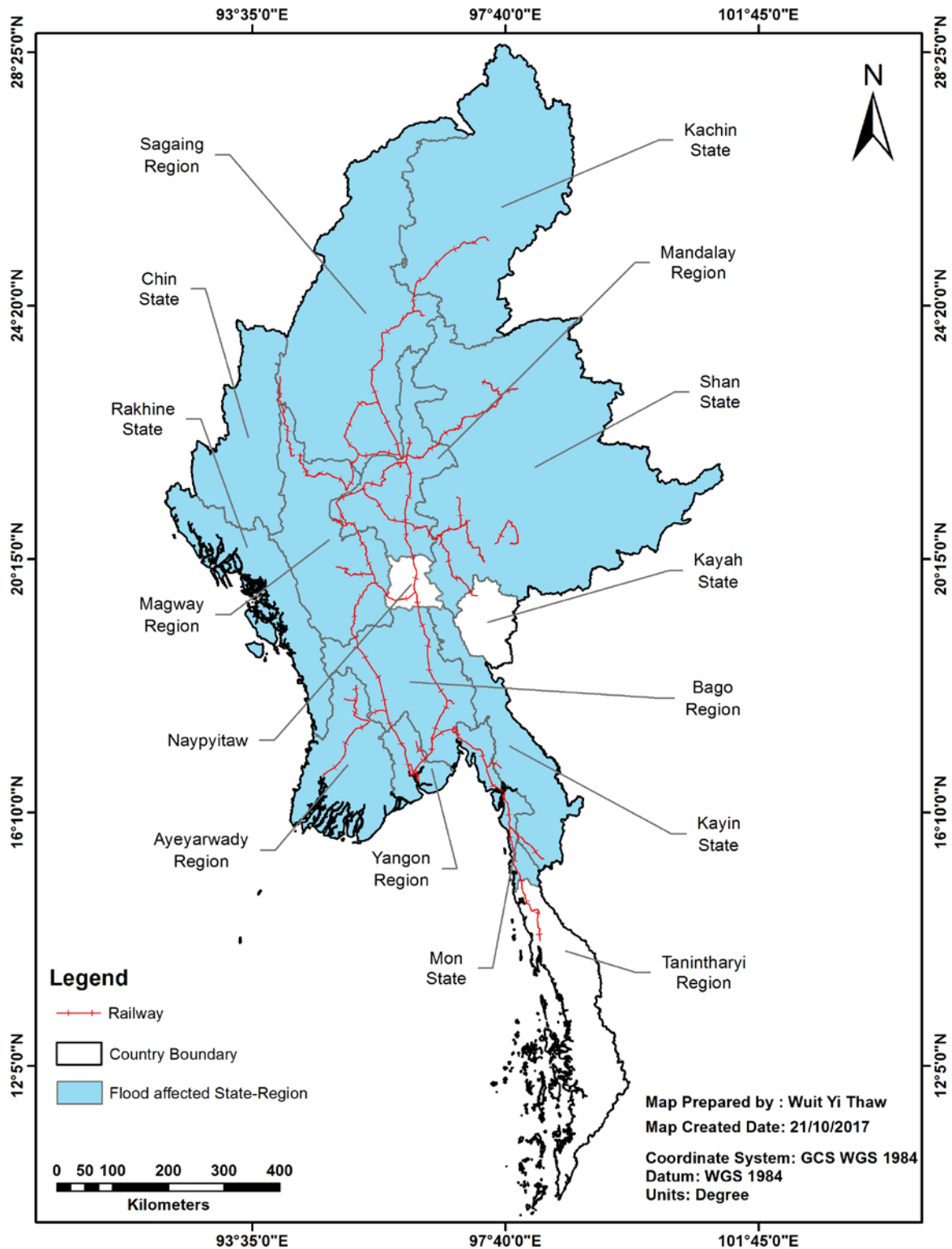
Cyclone storm Komen brought heavy rainfall that cause flooding and landslides. As a result, there were extensive physical damages on transport infrastructure throughout country. Damages in Myanmar in the 2015 disaster were not homogenous because the damages had different characteristics that were depending on whether they were caused by floods, heavy rains, mud or rockslides, etc. Landslides caused major destruction in infrastructure, including transportation and communications. In the mountainous areas of Chin State suffered extreme landslide and 9 townships had affected, 4 townships from Mindat district in Southern Chin State and 5 townships from Hakha and Falam disctrict in Northern Chin State. A landslide was damaged most of the main road of Chin State, villages, water sources and downtown area (Reliefweb, 2015b).

The immediate effects in the transport sector included the following:

- (i) Severance of road and rail transportation links,
- (ii) Disruption of market access, particularly between the south and north of the country

(iii) Loss of access in urban and especially rural communities to social facilities such as health and education (Government of the Union of Myanmar, 2015, p. 125).

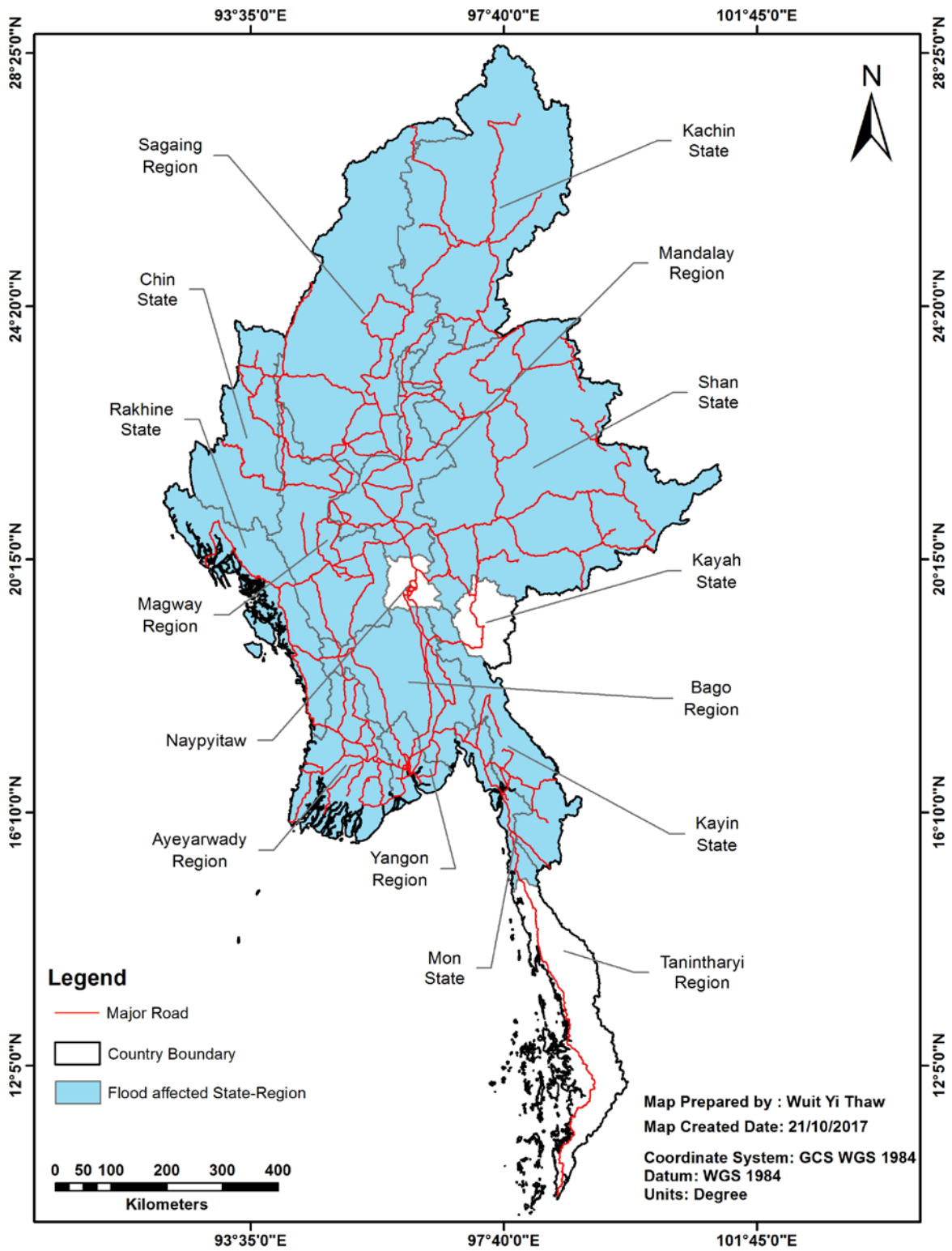
Myanmar Distribution of Railway Network



Map 11. Myanmar: Distribution of Railway Network (MIMU, 2010)

Myanmar

Distribution of Road Network



Map 12. Myanmar: Distribution of Road Network (MIMU, 2010)

Total damage and losses in the transport sector is 3 percent of all affected sectors. The majority of damage occurred in the west of the country, State-Region included as Chin State, Sagaing Region, Rakhine State, Bago Region, and Magway Region (Government of the Union of Myanmar, 2015, p. 125).

The rail network in Myanmar consists of 5,934 km of track, with 83 km of the network in urban areas and Railway Network and Affected States-Regions by 2015 Flood is shown in map 11.

Map 12 shows the major road network and affected States-Regions by 2015 flood. Myanmar’s public road network comprises 157,059 km across 14 states, with 34,724 km that is 22 percent paved Road access is highest in Yangon Region, Mandalay Region, and Magway Region, where a mere 3 percent of rural residents are without access, while in Rakhine and Kayin, 59 percent of rural residents are not connected (Government of the Union of Myanmar, 2015, p. 126).

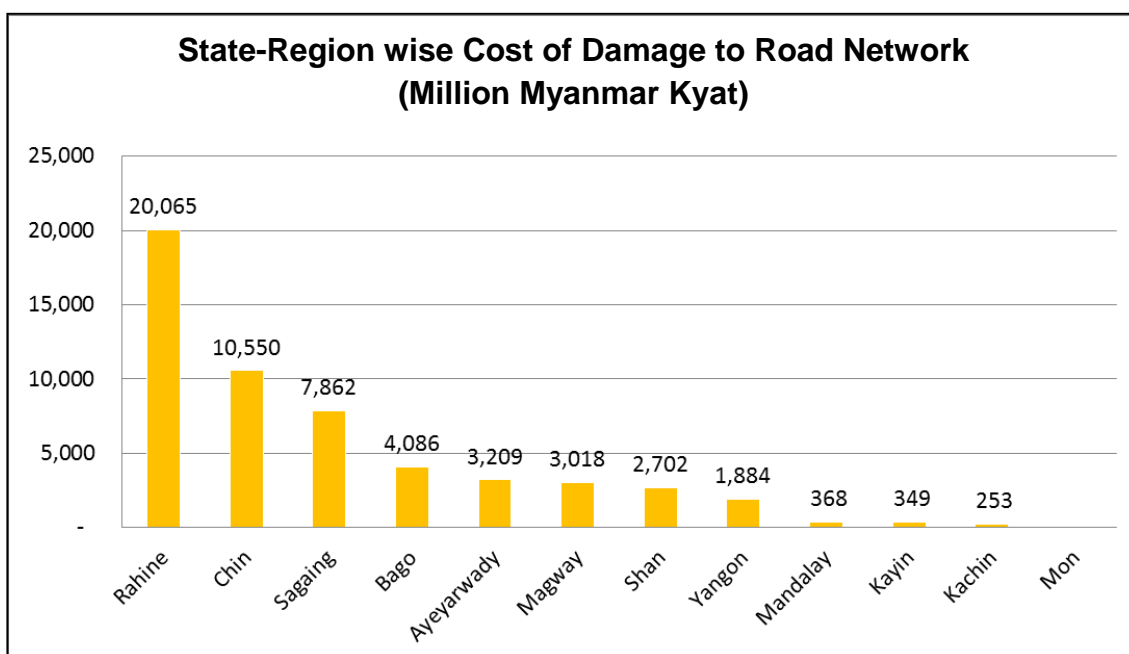


Figure 15. Myanmar: State-Region wise Cost of Damage to Road Network in Million Myanmar Kyat (RRD, 2015)

The government estimates that 972 kilometers or 604 miles of rural road and 824 bridges were destroyed across the country (Reliefweb, 2015a). According to the data from Relief and Resettlement Department (RRD), the total amount of damage to road assets is about 54,347 million kyats and about 20,065 million kyats in Rakhine State that is 36.92% of the total amount of damages to road assets. Figure 15 shows the road damaged costs by State-Region in graph and no data could provide Mon State.

3.6.2. Township wise Population Affected by 2015 Floods

Up to 5.2 million people were exposed to the floods and landslides in the 40 most heavily affected townships. An estimated 1.6 million individuals were recorded as having been temporarily displaced from their homes by the disaster, and 132 lost their lives. Within the 40 most-affected townships, 775,810 individuals have been displaced, representing approximately half of the total displaced population (Government of the Union of Myanmar, 2015, p. 188).

| | 40 most-affected townships | 178 moderately affected townships |
|------------------------------|----------------------------|-----------------------------------|
| Township population | 5,195,863 | 30,634,992 |
| People temporarily displaced | 775,810 | 886,146 |

Table 6 Population in Affected Townships (Government of the Union of Myanmar, 2015, p. 188).

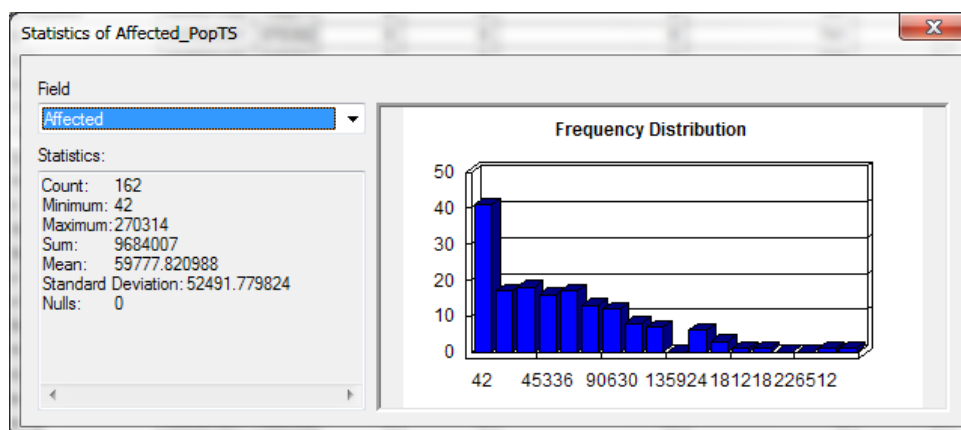
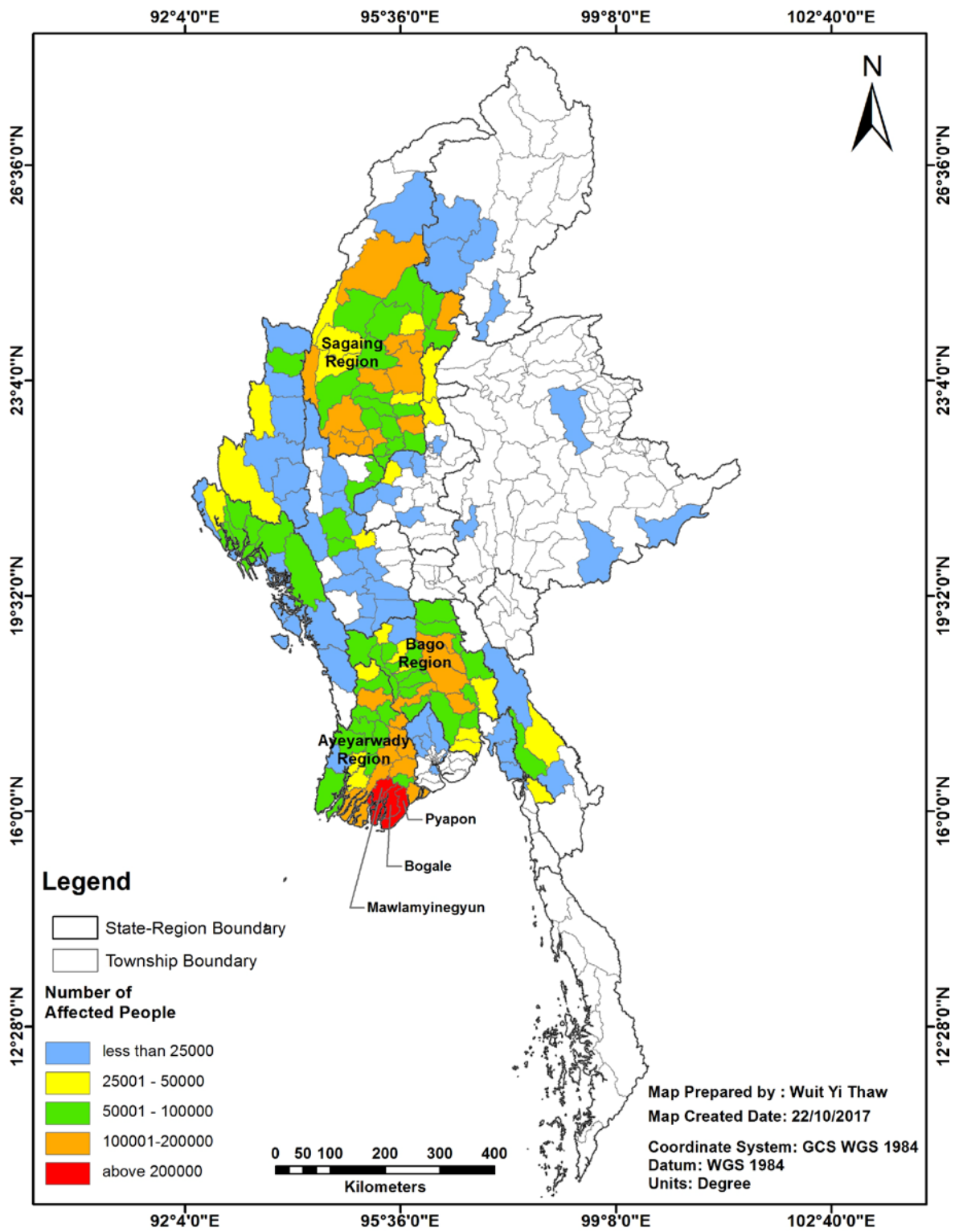


Figure 16. Statistics of affected population in township

Myanmar

Township wise Population Affected by 2015 Floods



Map 13. Myanmar: Township wise Population Affected by 2015 Floods (MIMU; UNDP)

Figure 16 shows the statistic of township level population affected by 2015 floods. The minimum affected population is 42 people and the maximum is 270,314 people. The data is positively skew and it is presented by mapping in the map 13. According to the data from MIMU and MDLD database, the highest number of affected people living in Bogale, Pyapon and Mawlamyinegyun townships from Ayeyarwady delta area. The 84% of township population in Bogale (total population; 322,665, affected population; 270,314) , 78% in Pyapon (total population; 314,122, affected population; 243,640) and 68% in Mawlamyinegyun (total population; 311,340, affected population 211,094) were affected by 2015 floods.

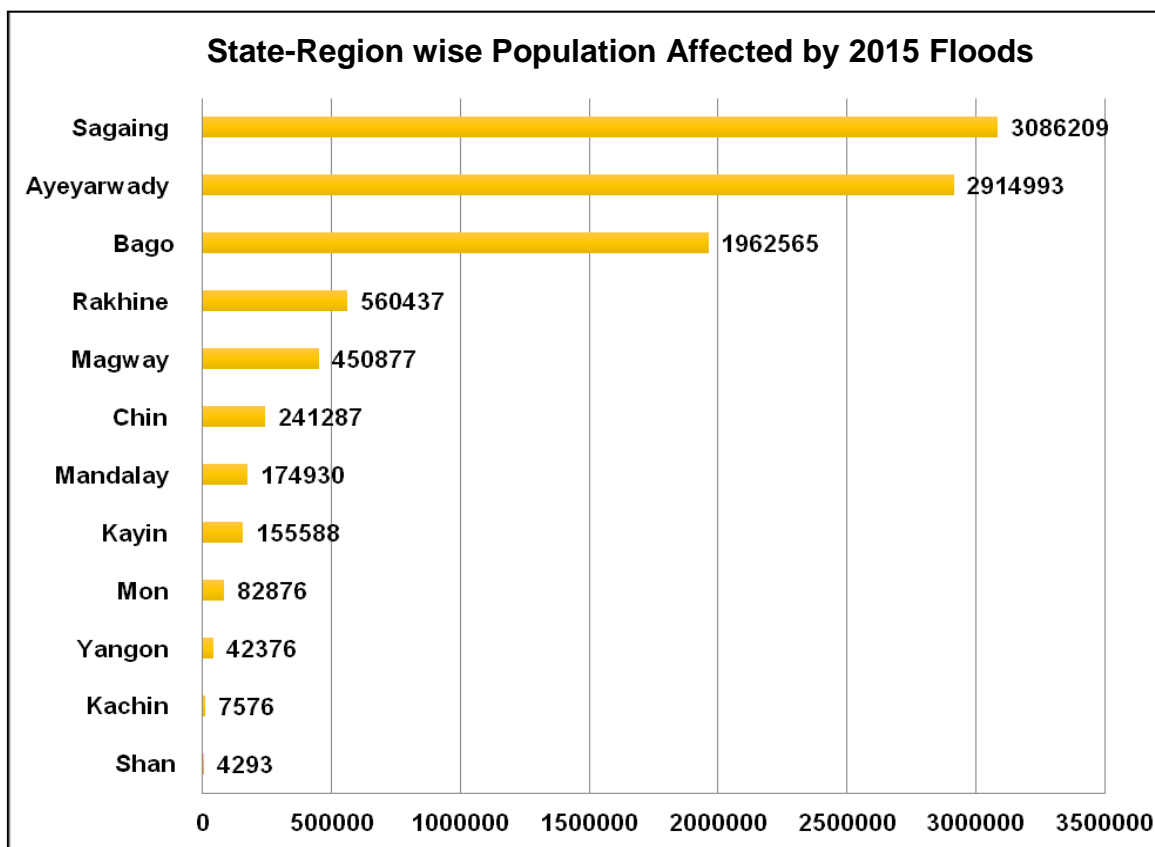


Figure 17. Myanmar: State-Region wise Population Affected by 2015 Floods (MIMU; UNDP)

Figure 17 presents the affected population in State-Region. The most floods affected people were from Sagaing Region, Ayeyarwady Region and Bago Region. Total population of Sagaing Region is 5,320,299 and 58% of population in the region was affected, that was 32% of Union affected population. Total population of Ayeyarwady

Region is 6,184,829 and 47% of population in the region was affected, that is 30% of Union affected population. And the total population of Bago Region is 4,867,373 and 40% of population in the region was affected, that was 20% of Union affected population. Total estimated population affected by 2015 floods of government data is about 1.7 million but MIMU and MDLD data shows about 9 million people.

3.6.3. Damage to Houses

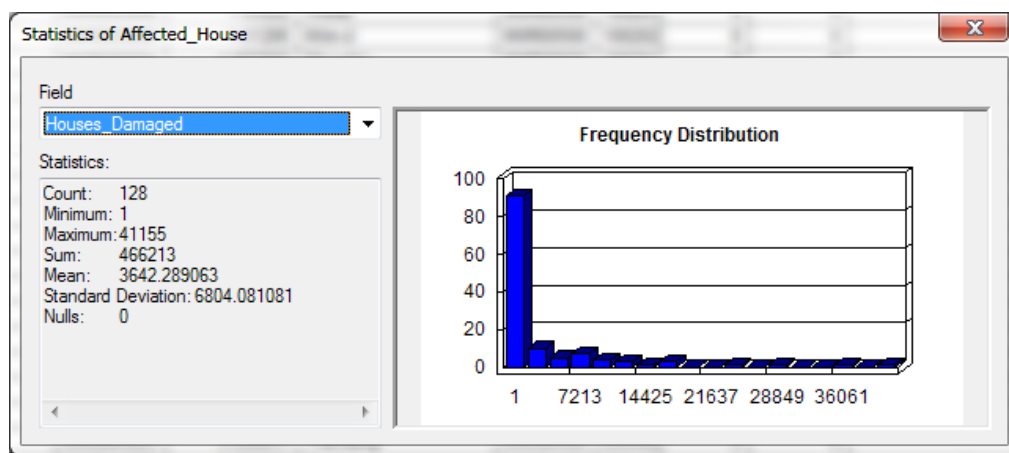


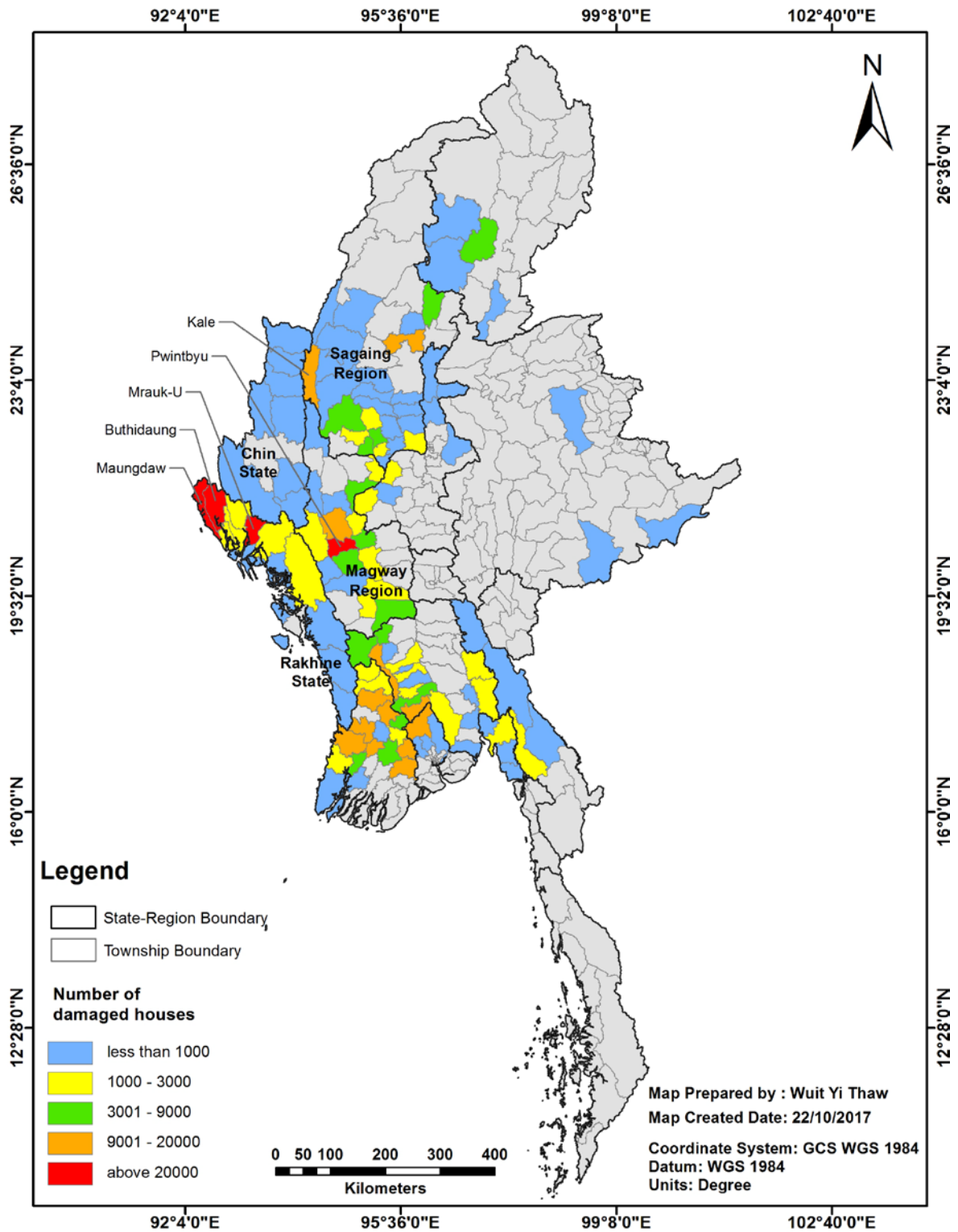
Figure 18. Statistic of Damage to Houses

The statistic of houses damages data (assumed total of destroy and damage houses) was collected from MDLD database and shown in figure 18. Damaged houses in minimum was 1 house and 41,155 houses in maximum. The frequency distribution is positively skew and these data are presented by mapping in map 14. According to the data from MDLD database, the townships of the high damaged to houses were Mrauk-U, Buthidaung and Maungdaw from Rakhine State, Pwintbyu from Magway Region and Kale from Sagaing Region. The 9% of the township level damaged to houses in Mrauk-U, 8% in Buthidaung, 6% each in Maungdaw and Pwintbyu and 4% in Kale.

Figure 19 shows graph of the destroyed and damaged houses data in State-Region that data was collected from MIMU as of 31 August 2015. Rakhine State, Ayeyarwady Region, Sagaing Region, Bago Region and Magway Region had high number of houses were destroyed and damaged by 2015 floods.

Myanmar

Township wise Houses Damaged by 2015 Floods



Map 14. Myanmar: Township wise Houses Damaged by 2015 Floods (UNDP)

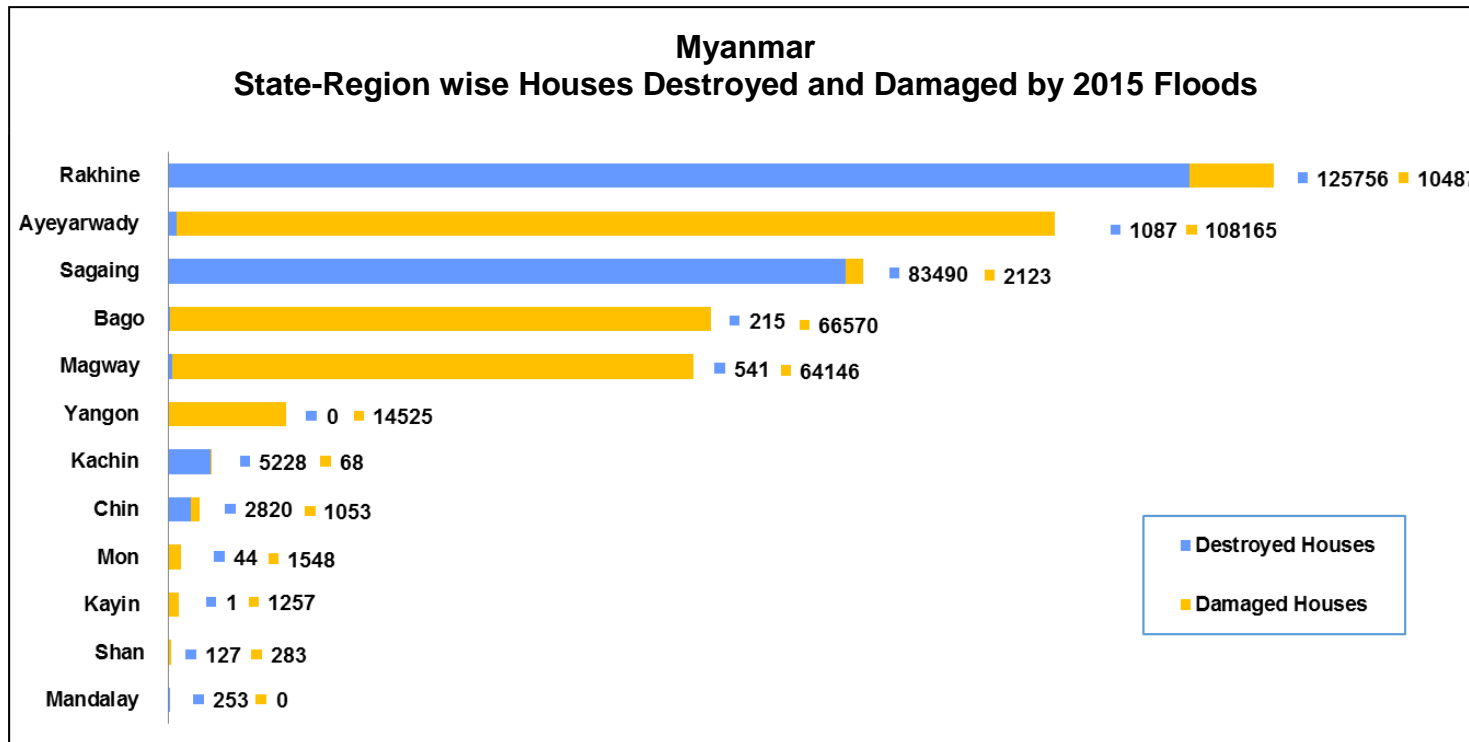


Figure 19. Myanmar: State-Region wise Houses Damaged and Destroyed by 2015 Floods (MIMU, 2015b)

There was needed to relocate at least 4,500 households in Chin State and Sagaing Region. Total 2,987 houses were destroyed by landslides in Chin State and over 1,600 houses destroyed by flooding in Kale Township, Sagaing Region as per National Natural Disaster management Committee in October (Government of the Union of Myanmar, 2015, p. 192). The 79% of all destroyed houses were found in Rakhine and Chin States (Government of the Union of Myanmar, 2015, p. 196). During this 2015 flooding, 40 most-affected townships account for 92% of destroyed houses and 49% of displaced people (Government of the Union of Myanmar, 2015, p. 198).

3.6.4. Damage to Education Centers

In the 2015/2016 school year, the basic education system consists of 45,355 primary and post primary schools, 13,334 middle schools, and 3,511 high schools (Government of the Union of Myanmar, 2015, p. 73). According to the government post disaster assessment, 4,116 schools were affected in 11 States-Regions as a result of the floods and landslides. Some of those, 213 schools were fully destroyed and 430 were structurally damaged.

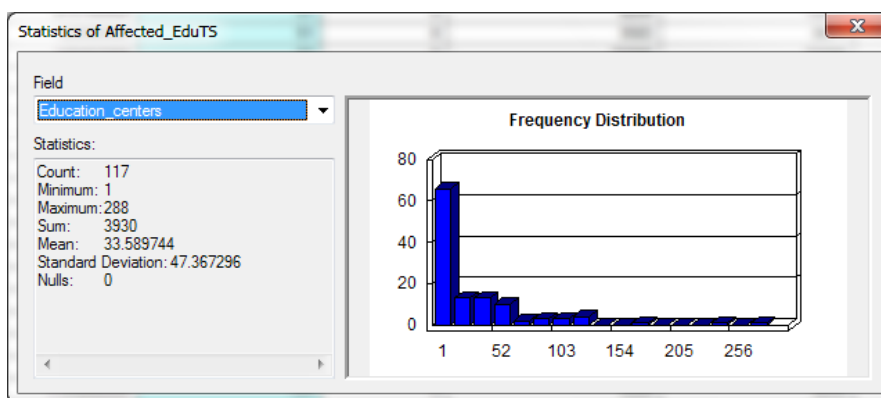


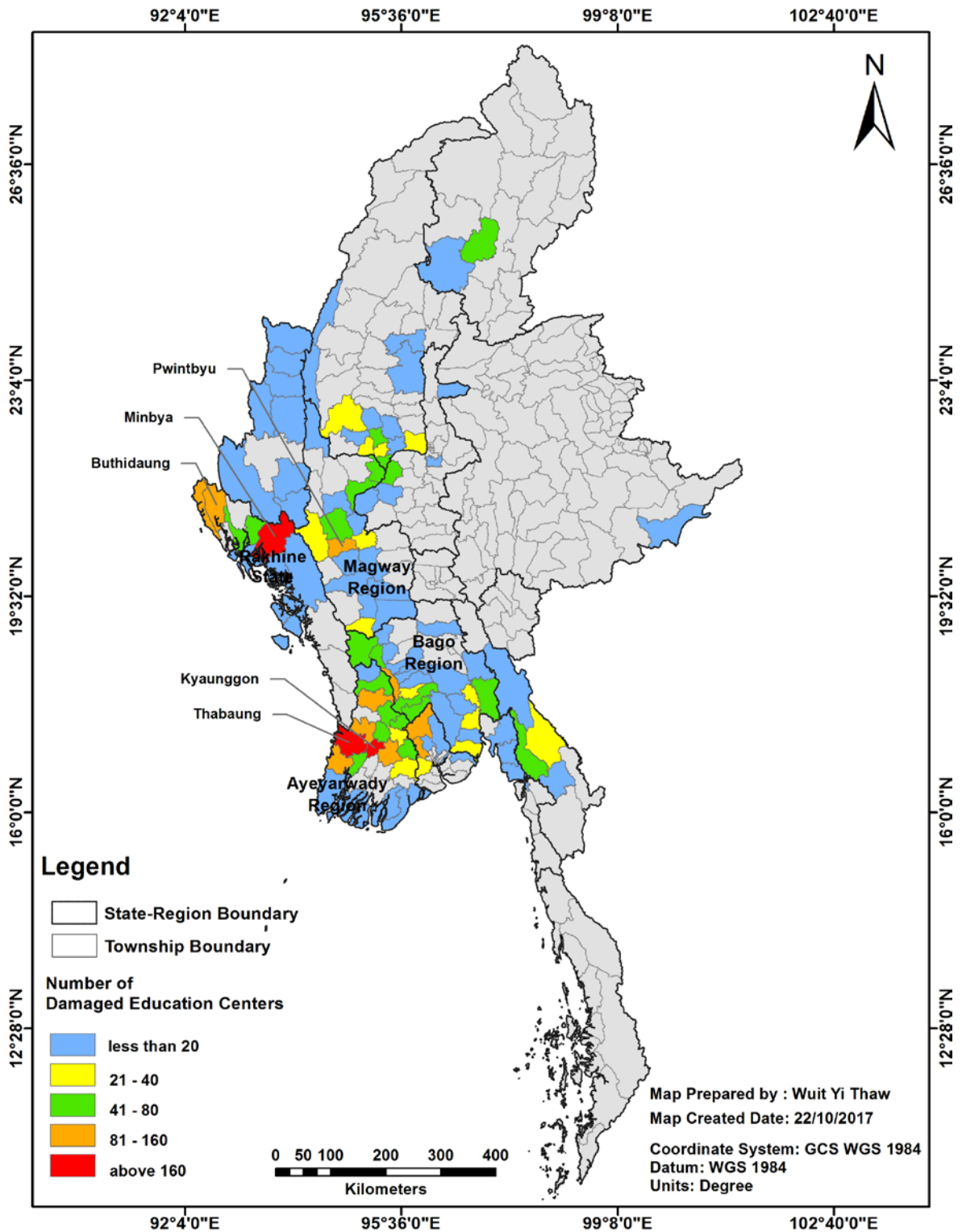
Figure 20. Statistics of Damage to Education Centers

Figure 20 presents the statistics of education centers damages from MDLD database and the minimum damage was 1 and the maximum schools damages were 288. Data is showing positively skew and that is mapped in map 15. According to MDLD database, the most damaged townships were Thabaung: 288, Kyaunggon: 185 in Ayeyarwady Region, Minbya: 251, Buthidaung: 136 in Rakhine State and Pwintbyu: 136 in Magway Region and that was about 25% of total damaged education centers.

Overall States-Regions school destroyed/damaged data was collected from MIMU as of 31 August 2015 and presented in graph at figure 21. The data was showing the most affected regions was Ayeyarwady Region, second was Rakhine State, third was Bago Region, and then Magaway Region. But in the government post disaster needs assessment report, the most-affected states were Rakhine State: 66 schools destroyed and Chin State: 47 schools destroyed. In Chin State, 4 percent of all schools were destroyed, the highest share of schools destroyed. The most damage affected States/Regions are Ayeyarwady Region with 110 and Rakhine State with 226 schools.

And total of 31 monastic schools were also damaged in the country (Government of the Union of Myanmar, 2015, p. 74).

Myanmar Township wise Education Centers Damaged by 2015 Floods



Map 15. Myanmar: Township wise Educations centers Damaged by 2015 Floods(UNDP)

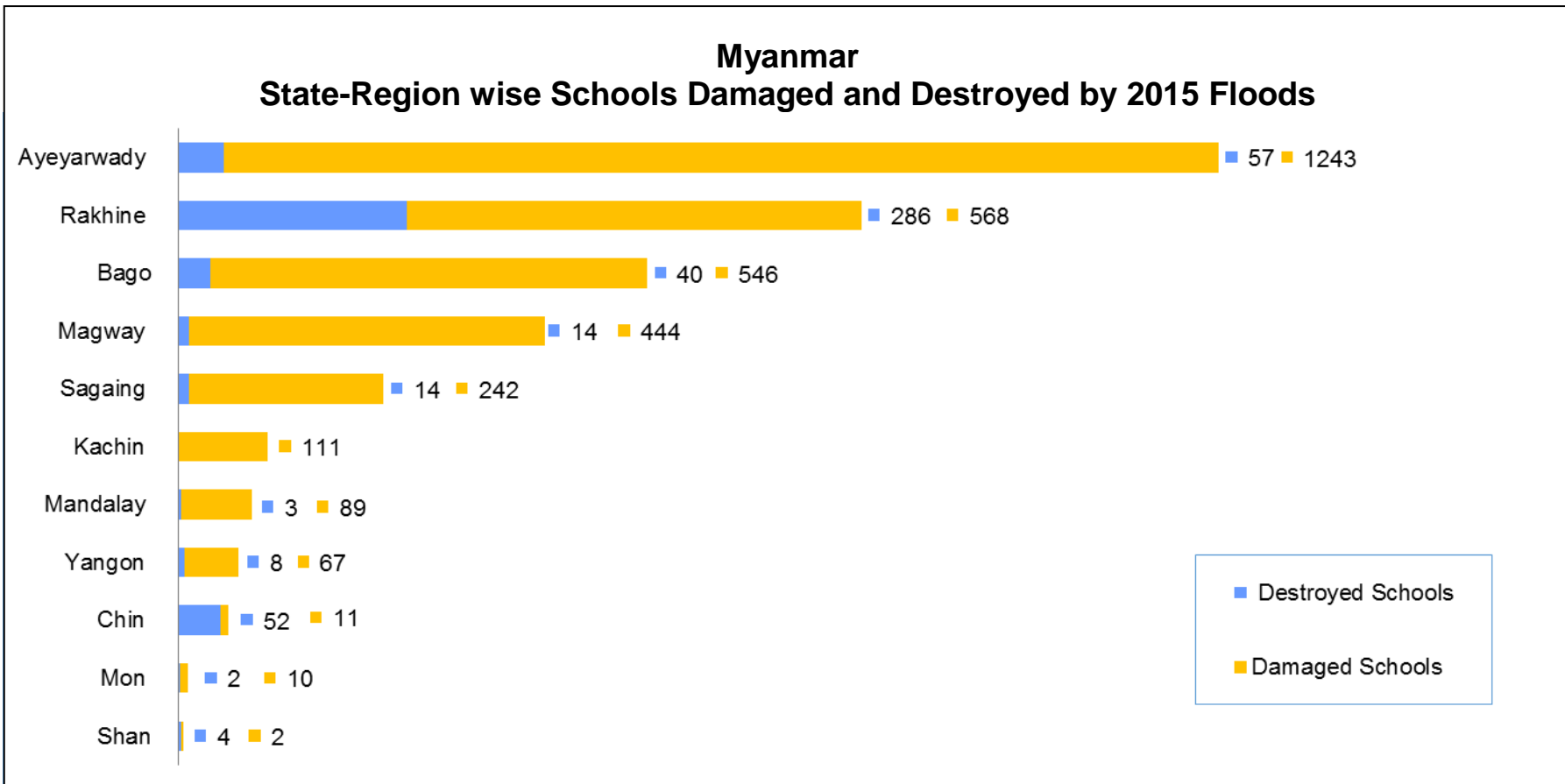


Figure 21. Myanmar: State-Region wise Schools Damaged and Destroyed by 2015 Floods (MIMU, 2015c)

The total loss and damage for the education sector in Myanmar is estimated to be MMK 50,493 million. The highest damage is estimated in Rakhine and amounted to MMK 13,640 million. In Chin and Sagaing Regions, where landslides occurred and/or whole communities were washed away by floodwater, schools need to be relocated to safer places for reconstruction (Government of the Union of Myanmar, 2015, p. 78).

3.6.5. Damage to Health Care Facilities

The social sector health had sustained low amounts in damage and losses, but significantly harms the population's quality of life and living conditions. Post disaster needs assessment report from government described that there were 24 rural health centers and sub-centers have been totally destroyed by the disaster. More than 200 facilities have been partially destroyed, of which 21 are township and station hospitals, and two are public health offices (Government of the Union of Myanmar, 2015, p. 64).

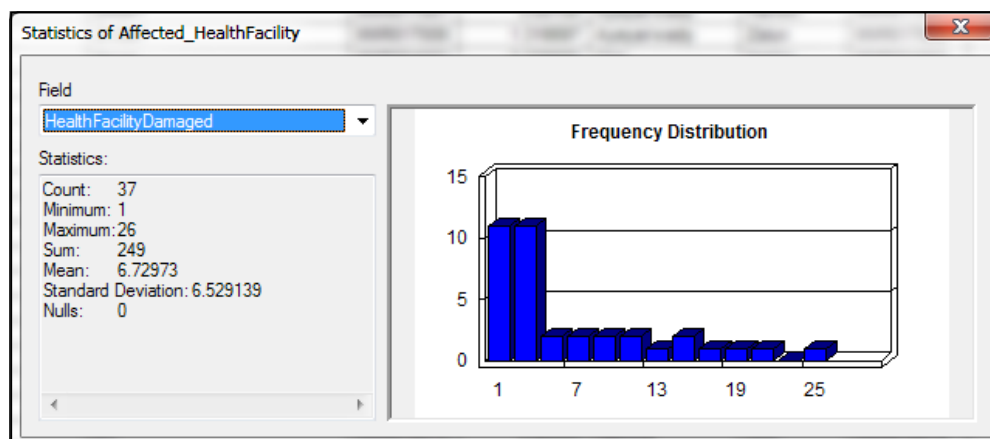
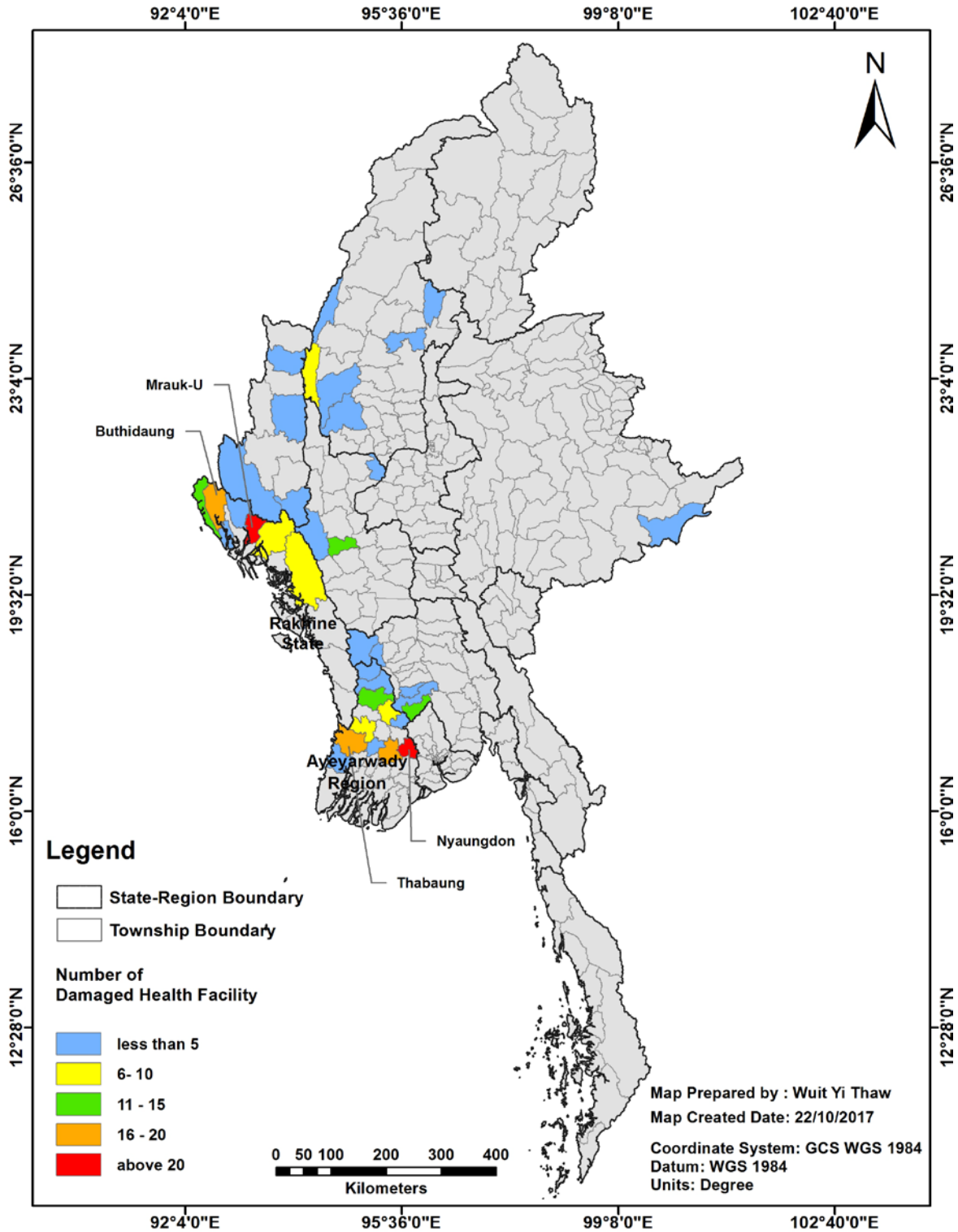


Figure 22. Statistics of Damage to Health Care Facilities

Damaged health facilities township level baseline data was collected from MIMU and statistics is shown in Figure 22. The minimum damaged health facility in township was 1 and the maximum were 26 and total damages were 249. Frequency distribution of data shows positively skew. Then for visualisation, mapping these data can be seen in Map 16.

There were two townships, the number of health facilities damages above 20, in Nyandon township from Ayeyarwady delta region and in Mrauk-U township from Rakhine State.

Myanmar Township wise Damage to Health Care Facilities by 2015 Floods



Map 16. Myanmar; Township wise Damage to Health Care Facilities by 2015 Floods (MIMU)

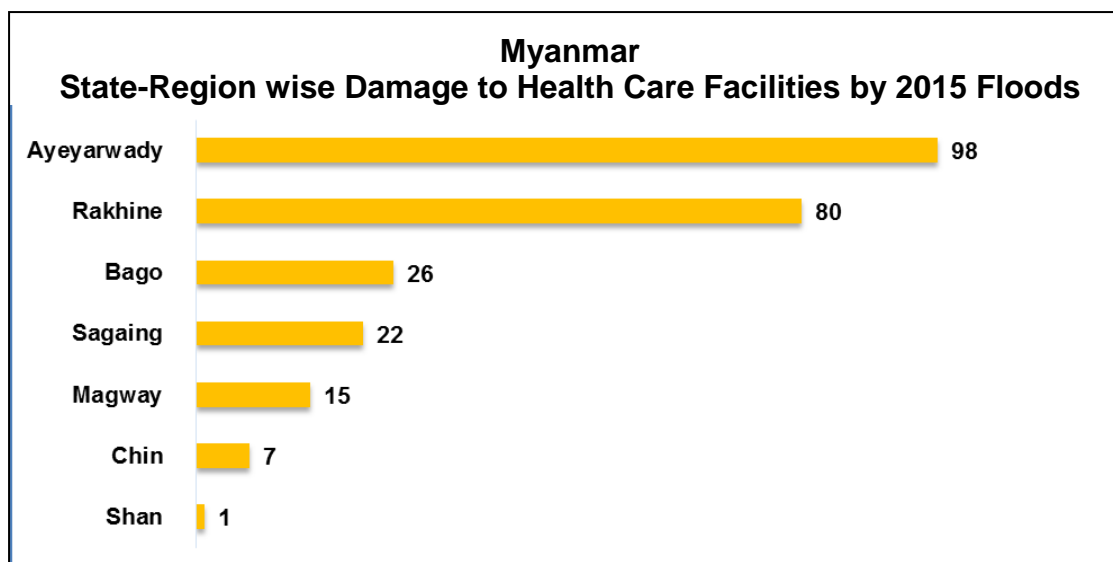


Figure 23. Myanmar: State-Region wise Damage to Health Care Facilities by 2015 Floods (MIMU)

Figure 23 presents the status of damaged health facilities in State-Region. The most affected Region was Ayeyarwady Region with 39% of the Union level health facility damages. Rakhine State was second affected with 32% of the Union level damages.

3.6.6. Loss and Damage in Agriculture and Livestock Sector

Myanmar is regarded as agriculture based country as it accounts for 40.2 percent of the GDP (MES et al., 2009). In 2015, there had extensive impact on the agriculture sector by floods and landslides. The floods hit major agricultural areas, including Regions in Sagaing, Magway, Ayeyarwady, and Bago, which jointly account for around 89 percent of the national production of crops (Government of the Union of Myanmar, 2015, p. 13). Damages in the agriculture sector also include the impact of landslides on 5,523 acres or 2,235.1 ha cultivated with paddy rice, tea, rubber, corn, and other crops in Chin and Shan States (Government of the Union of Myanmar, 2015, pp. 18-19). According to the report of the Ministry of Agriculture and Irrigation (MOAI), the farmland area 1,485,391 acres or 601,116.3 ha had been flooded. They mention that these areas represented around 20.4% of the total affected cultivated area 7.30 million acres or 2.95 million ha. Of this flooded area 485,013 acres or 196,277.8 ha were totally destroyed and are not expected to yield any crop.

Myanmar: State-Region wise Farmland Damaged and Destroyed by 2015 Floods (Acres)

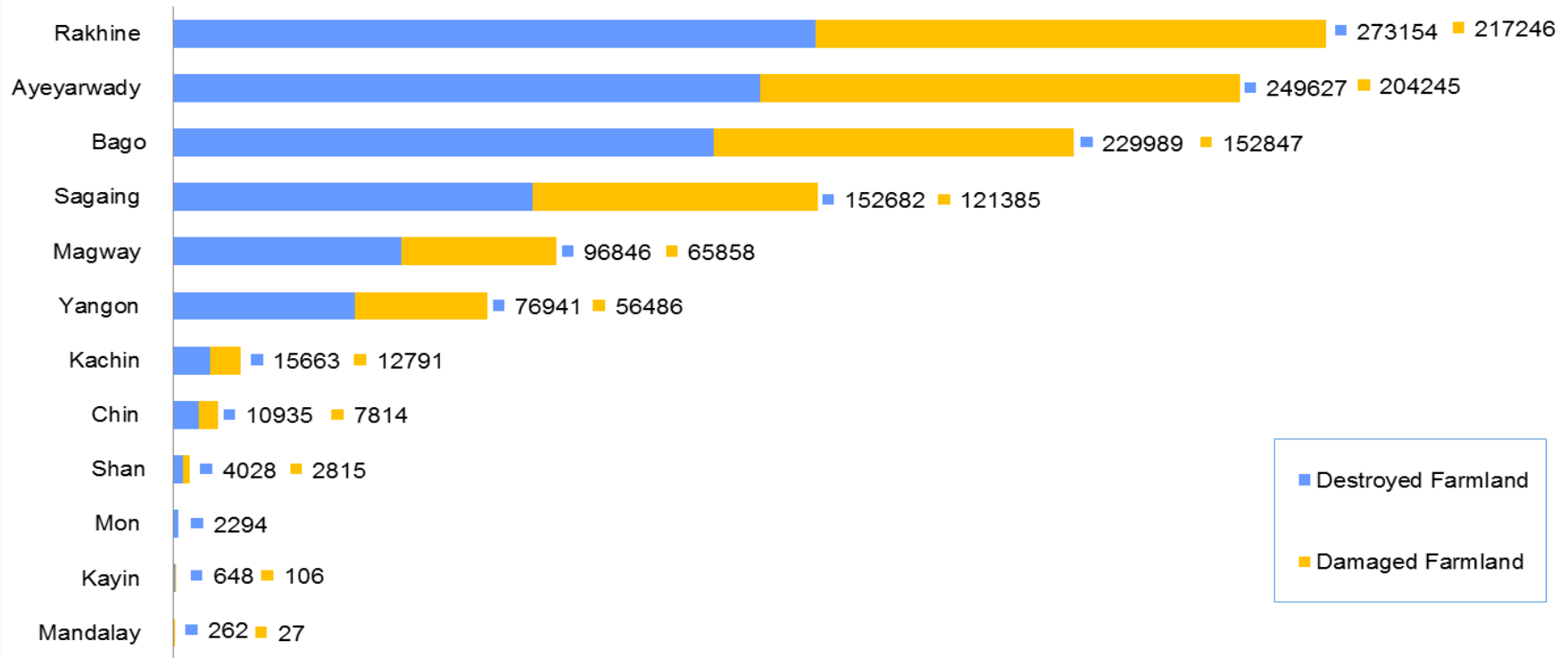


Figure 24. Myanmar: State-Region wise Farmland Damaged and Destroyed by 2015 Floods(MIMU, 2015a)

The figure 24 shows the farmland destroyed/damage acres in State-Region and data was collected from MIMU as of 31 August 2015. The five highest destroyed and damaged of farmland in State-Region were Rakhine State; 25%, Ayeyarwady; 23%, Bago; 20%, Sagaing; 14%, and Magway; 8% respectively.

The main crop affected was paddy in terms of absolute impacted area. The most paddies had already been transplanted in the middle of the monsoon season when cyclone Komen hit to Myanmar. The report from government of Myanmar described that the estimated monsoon paddy area 1,328,050 acres or 537,442.7 ha that is 27.4% of the cultivated area was flooded. Out of that area, paddy production in 930,710.0 acres or 376,644 ha will be at least 5 percent lower than expected for a regular monsoon season. The production is totally lost in 397,340 acres or 160,797.8 ha that is 8.2 percent of the cultivated area for 2015 (Government of the Union of Myanmar, 2015, p. 18).

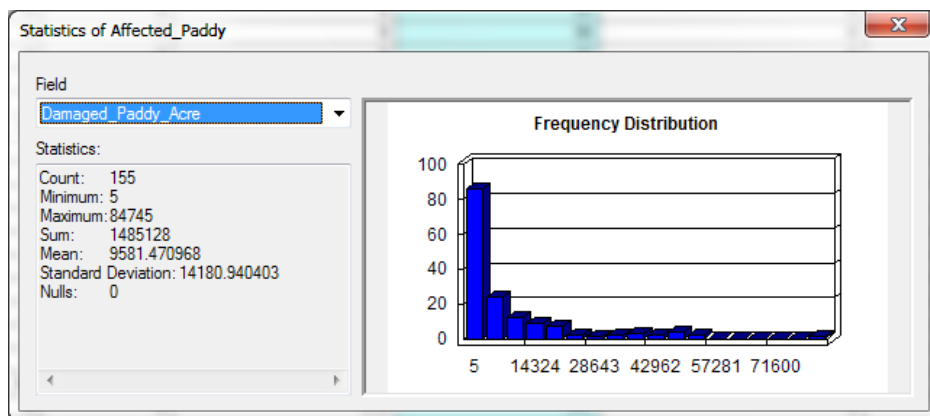
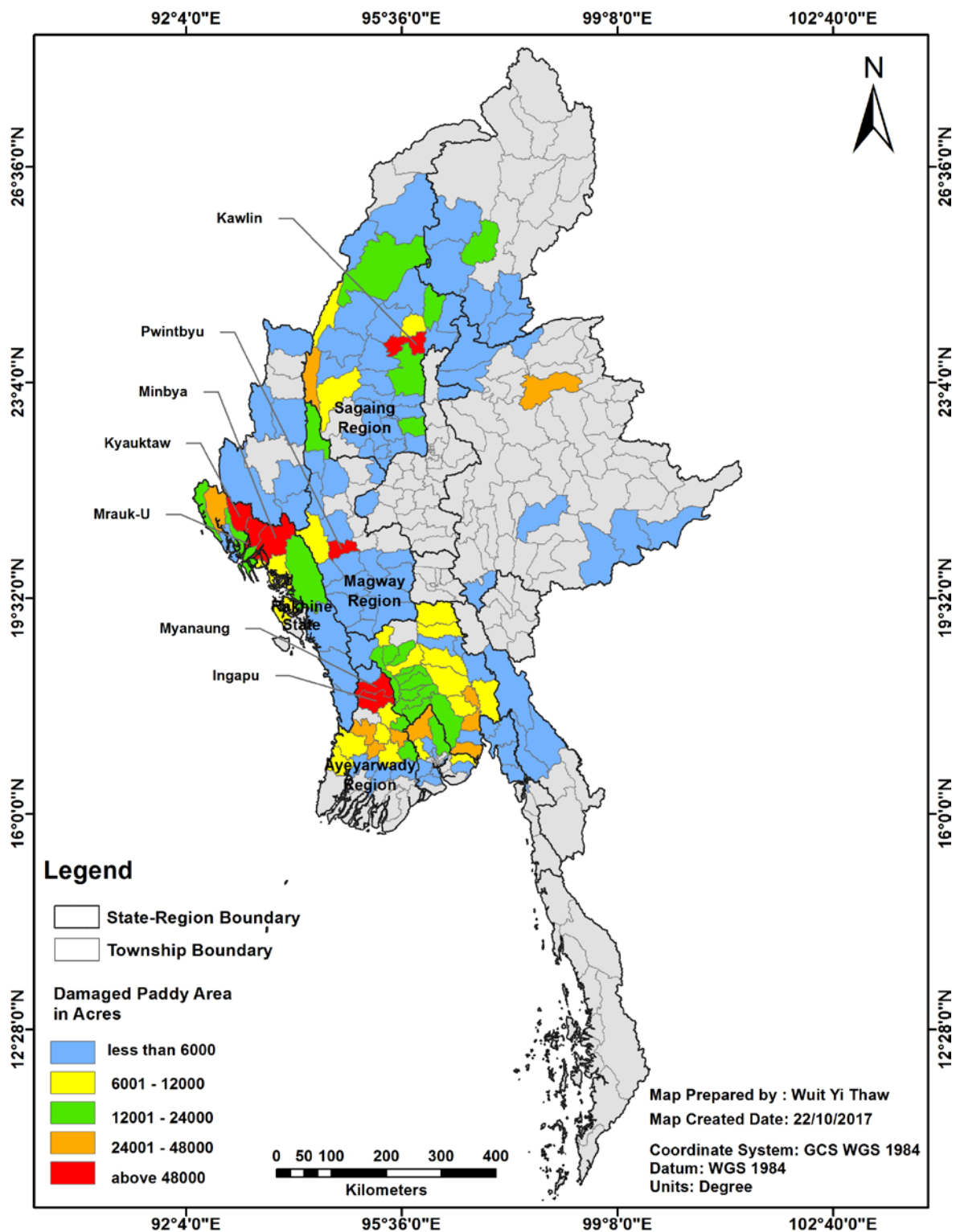


Figure 25. Statistics of Damage to Paddy Cultivation Areas (Acres)

The township level data for damaged paddy acres were collected from MDLD database and the statistics of this data presented in figure 25. The minimum damages were 5 acres and the maximum were 84745 acres. Then mapping to visualise the damages status in geographically is shown in map 17. The most affected townships damages above 48000 paddy acres were Mrauk-U, Kyauktaw and Minbya from Rakhine State, Myanaung and Ingapu from Ayeyarwady Region, Kawlin from Sagaing Region and Pwintbyu from Magway Region. They were 27% of Union paddy damages.

Myanmar

Township wise Paddy Cultivation Area Damaged by 2015 Floods (Acres)



Map 17. Myanmar: Township wise Paddy Cultivation Area Damaged by 2015 Floods
in Acres(UNDP)

Most of the lost paddy plantations are in Ayeyarwady Region 252,193 acres or 102,058.9 ha, Bago Region 48,984 acres or 19,823.1 ha, Sagaing Region 41,813 acres or 16,921.1 ha, and Yangon Region 38,055 acres or 15,400.3 ha. Those Regions contain around 70 percent of the total area cultivated with monsoon paddy 2015 3,387,309 acres or 1,370,795.2 ha (Government of the Union of Myanmar, 2015).

Livestock also plays a critical role in the smallholder mixed crop-livestock systems that prevail in Myanmar and livestock production accounts for around 7.5 percent of the overall GDP. According to the 2014 Population Census, 8.2 million smallholder households are engaged in keeping and/or breeding livestock and/or poultry.

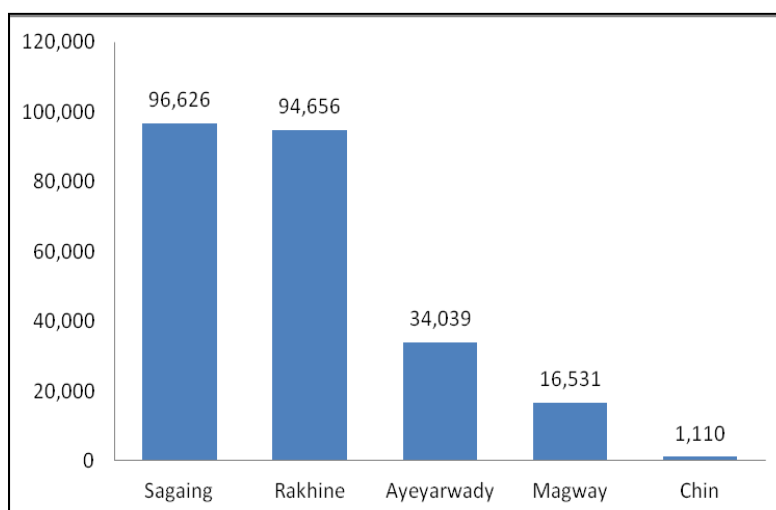


Figure 26. State-Region wise Loss of Livestock

| State/Region | Cows | Buffalo | Goats | Pigs | Poultry | Total animals lost |
|--------------|-------|---------|-------|-------|---------|--------------------|
| Ayeyarwady | 183 | 15 | 5 | 543 | 33,293 | 34,039 |
| Chin | 54 | n/a | 67 | 99 | 890 | 1,110 |
| Magway | 129 | n/a | 215 | 442 | 15,745 | 16,531 |
| Rakhine | 5,080 | 2,969 | 4,029 | 4,858 | 77,720 | 94,656 |
| Sagaing | 334 | 25 | 26 | 870 | 95,371 | 96,626 |
| Grand Total | 5,780 | 3,009 | 4,342 | 6,827 | 223,019 | 242,977 |

Table 7 State-Region wise Loss of Livestock Types (Ministry of Agriculture and Irrigation; Ministry of Livestock, 2015, p. 30)

Rakhine State is recorded to have been the most affected in terms of non-poultry animal losses with about 20,000 head of cows, buffalo, pigs and goats killed. The States-Regions most affected by losses of poultry are Sagaing, Rakhine and Ayeyarwady (Ministry of Agriculture and Irrigation; Ministry of Livestock, 2015). Total number of livestock losses (death) by 2015 floods is shown figure 26 and categorized in table 7. So, the most affected areas were Sagaing Region; 40% and Rakhine State; 39% of national livestock losses.

Total damages in the livestock subsector have been estimated at MMK 7,627.4 million, of which damages due to dead animals are MMK 7,470.5 million. Regions most affected by damages due to dead animals are Rakhine State: MMK 6,099.7 million, Sagaing Region: MMK 660.4 million and Ayeyarwady Region: MMK 296.5 million. Damages to private infrastructure have been estimated at MMK 108.2 million, and damages to private animal shelters at MMK 48.8 million. Estimates of losses amount to MMK 10,150.5 million; the most significant of these are reductions in revenues from available draught power MMK 8,265.3 million , meat production MMK 1,122.2 million, and egg production MMK 540.7 million (Government of the Union of Myanmar, 2015, p. 21).

3.6.7. Summary of the Loss and Damage Caused by 2015 Floods

According to the assessment, 2015 flooding in Myanmar had generated highest loss and damages. 12 of 14 States-Regions were affected and flooding started from July and ended late July demanding deaths, destroyed farmland, roads, rail tracks, bridges, schools, health centers and houses. Many buildings were inundated and some of them were totally destroyed by river bank erosions and some by land slide.

The summary of State-Region level losses and damages data can be seen in the table 7. Table 8 represents the table 7 data for severity in percentage. With the limited data availability, analysis could only based on the number of vulnerable persons, destroyed/damaged of education centers, farmland, houses, health facilities, road and

losses in livestock (death). According to the analysis, all types of losses and damages had happen in Rakhine State, Ayeyarwady Region, Sagaing Region, Magway Region and Chin State. There Rakhine State, Ayeyarwady Region and Sagaing Region regarded as the most affected areas with average percentages of 27.01%, 24.14% and 19.02% respectively.

| State-Region | Affected Persons | Education Centers (no. Of destroyed / damaged) | FarmLand(destroyed / damaged in Acres) | Houses (no. Of destroyed/ damaged) | Health Facility (no. Of damaged) | Livestock (no. Of death) | Road Damaged (in Million MMK) |
|--------------|------------------|--|---|------------------------------------|----------------------------------|--------------------------|-------------------------------|
| Rakhine | 560437 | 854 | 490400 | 136243 | 80 | 94656 | 20065.147 |
| Ayeyarwady | 2914993 | 1300 | 453872 | 109252 | 98 | 34039 | 3208.787 |
| Sagaing | 3086209 | 256 | 274067 | 85613 | 22 | 96626 | 7862.433 |
| Bago | 1962565 | 586 | 382836 | 66785 | 26 | 0 | 4086.0173 |
| Magway | 450877 | 458 | 162704 | 64687 | 15 | 16531 | 3017.674 |
| Chin | 241287 | 63 | 18749 | 3873 | 7 | 1110 | 10550.184 |
| Yangon | 42376 | 75 | 133427 | 14525 | 0 | 0 | 1884.33 |
| Kachin | 7576 | 111 | 28454 | 5296 | 0 | 0 | 253.35 |
| Shan | 4293 | 6 | 6843 | 410 | 1 | 0 | 2702.294 |
| Mandalay | 174930 | 92 | 289 | 253 | 0 | 0 | 368.013 |
| Kayin | 155588 | 0 | 754 | 1258 | 0 | 0 | 349 |
| Mon | 82876 | 12 | 2294 | 1592 | 0 | 0 | 0 |

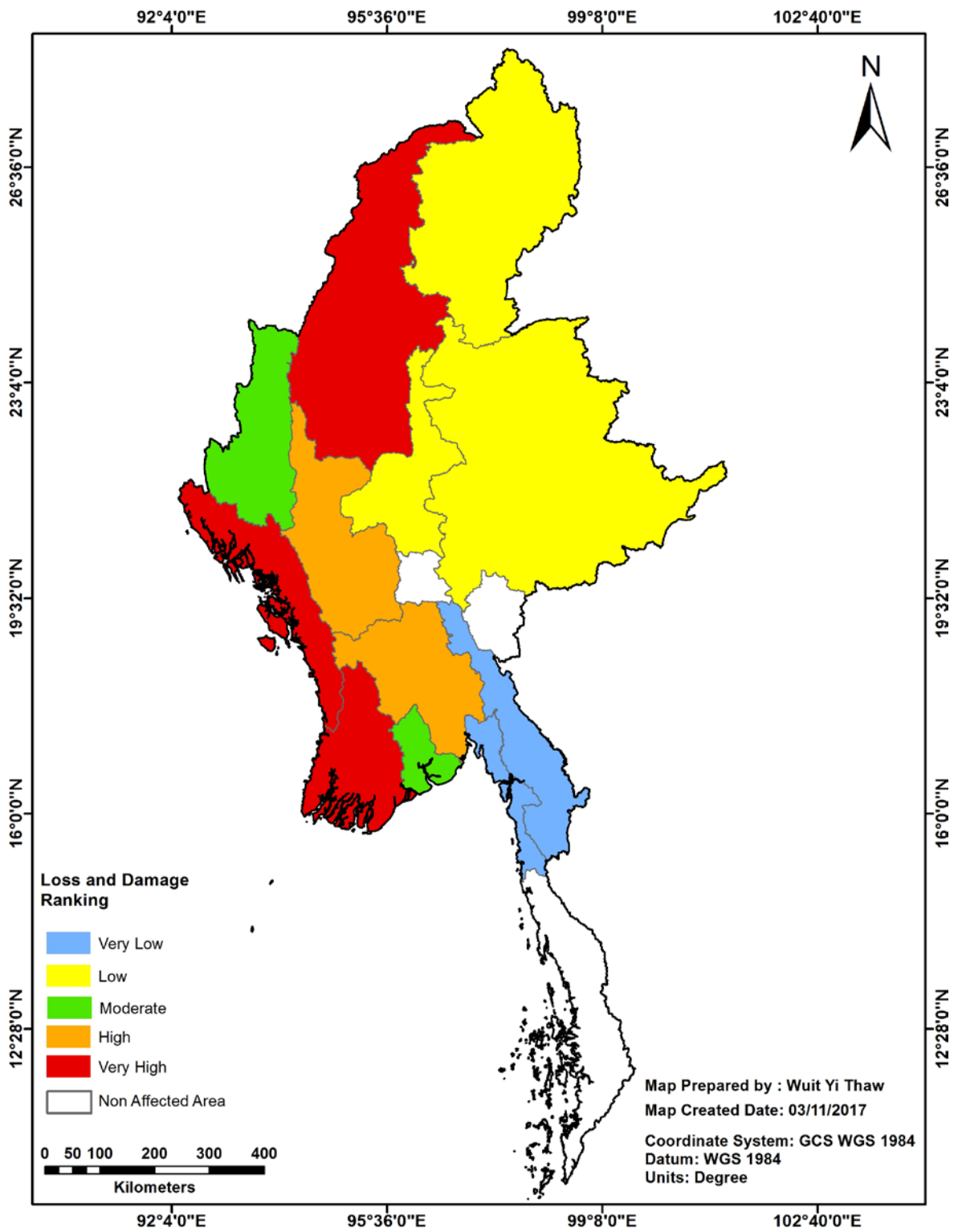
Table 8 Myanmar: State-Region wise Total Losses and Damages Caused by 2015 Floods (data sources: MIMU, RRD, MDLD, Government of Myanmar)

| State-Region | Affected Persons | Education Centers (no. Of destroyed /damaged) | FarmLand (destroyed / damaged in Acres) | Houses (no. Of destroyed /damaged) | Health Facility (no. Of damaged) | Livestock (no. Of death) | Road Damaged (in Million MMK) | Average Percentage |
|--------------|------------------|---|---|-------------------------------------|----------------------------------|--------------------------|-------------------------------|--------------------|
| | % | % | % | % | % | % | % | % |
| Rakhine | 5.79 | 22.40 | 25.09 | 27.82 | 32.13 | 38.96 | 36.92 | 27.01 |
| Ayeyarwady | 30.10 | 34.09 | 23.22 | 22.31 | 39.36 | 14.01 | 5.90 | 24.14 |
| Sagaing | 31.87 | 6.71 | 14.02 | 17.48 | 8.84 | 39.77 | 14.47 | 19.02 |
| Bago | 20.27 | 15.37 | 19.59 | 13.64 | 10.44 | 0.00 | 7.52 | 12.40 |
| Magway | 4.66 | 12.01 | 8.32 | 13.21 | 6.02 | 6.80 | 5.55 | 8.08 |
| Chin | 2.49 | 1.65 | 0.96 | 0.79 | 2.81 | 0.46 | 19.41 | 4.08 |
| Yangon | 0.44 | 1.97 | 6.83 | 2.97 | 0.00 | 0.00 | 3.47 | 2.24 |
| Kachin | 0.08 | 2.91 | 1.46 | 1.08 | 0.00 | 0.00 | 0.47 | 0.86 |
| Shan | 0.04 | 0.16 | 0.35 | 0.08 | 0.40 | 0.00 | 4.97 | 0.86 |
| Mandalay | 1.81 | 2.41 | 0.01 | 0.05 | 0.00 | 0.00 | 0.68 | 0.71 |
| Kayin | 1.61 | 0.00 | 0.04 | 0.26 | 0.00 | 0.00 | 0.64 | 0.36 |
| Mon | 0.86 | 0.31 | 0.12 | 0.33 | 0.00 | 0.00 | 0.00 | 0.25 |

Table 9 Myanmar: State-Region wise Percentage of Total Losses and Damages Caused by 2015 Floods (Sources: MIMU, RRD, MDLD, Government of Myanmar)

Myanmar

State-Region wise Level of Losses and Damages caused by 2015 Floods



Map 18. Myanmar: State-Region wise Level of Losses and Damages caused by 2015 Floods

Map 18 represents the loss and damages of affected State-Region by color ranking based on table 8 average percentage result. The value 19% and above represents very high affected area and shown in red color. The value 12% and 8% represents high affected area and shown in orange color. The value 4% and 2% represents moderate affected area and shown in green color. The value less than 1% and above 0.5% represents the low affected area and shown in yellow. The value less than 0.5% represents very low affected area and shown in blue.

Sagaing Region situated in the dry zone but this area was one of the most affected areas by 2015 floods. Tha Phan Seik dam is in the Sagaing Region and it is one of the largest dams in Southeast Asia. It is built on the Mu river. Due to heavy rainfall, Dam reached to outflow level and released more water from outlet. By this way, the area in the downstream of Tha Phan Seik Dam suffered floods. In these days, UNOSAT-UNITAR provided the flooded area with satellite image based maps including the downstream of Tha Phan Seik Dam. In this study, the potential flash flood area in the downstream of Tha Phan Seik Dam was calculated as a model to evaluate the infrastructure damages to determine if any spatial similarities exist which may be an indicator of predicting areas in the future for disaster risk reduction.

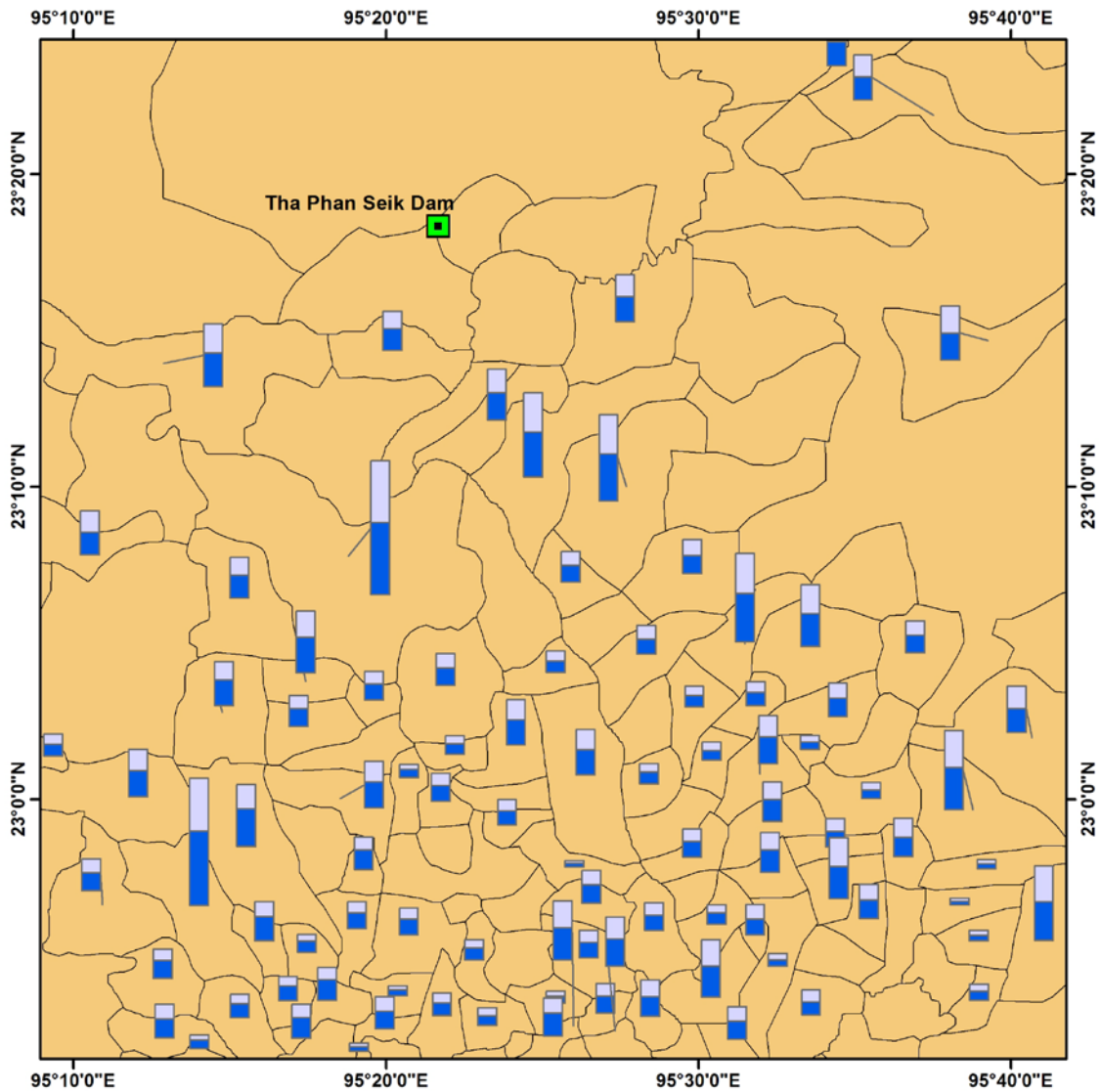
3.7. Potential Flood Risk Area in the downstream of the Tha Phan Seik Dam

This part is considered to generate potential flood risk area map for the selected area. The extend of selected area is latitude from 22° 51' 57.6" N to 23° 24' 12.118" N and longitude from 95° 9' 12.259" E to 95° 41' 36.051" E in the downstream of the Tha Phan Seik Dam that areas was suffered flash flood in 2015 flooding.

To understand the geographically structure of selected area, the distribution of population by village tract is shown in map 19 and the structure of drainage network and elevation in the downstream of the Tha Phan Seik Dam is shown in map 20. Elevation layer of selected area was extracted from ASTER DEM 30m country level.

In the village tract population map, there are more crowded village tract in the Southern part of Dam but village tracts are sparse in the Eastern part of Dam. Elevation map presented the elevation level with color coded in 5 classes. According to the elevation map, we can see the downstream area has the lower elevation than dam and lowest elevation of the selected area less than 130 meters can be seen along stream order level 10 presented with dark blue line in the map then increasing to high elevation to east and west part again. East direction from dam has the highest elevation of that area above 250 meters. So, people living in the village tracts situated low elevation level and near drainage network have the high potential to suffer floods as include important fact about dam overflow.

Population Distribution by Village Tracts in the Downstream Areas of Tha Phan Seik Dam

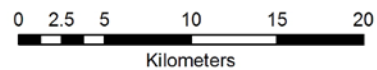


Legend

- Village Tract
- Population Male
- Population Female

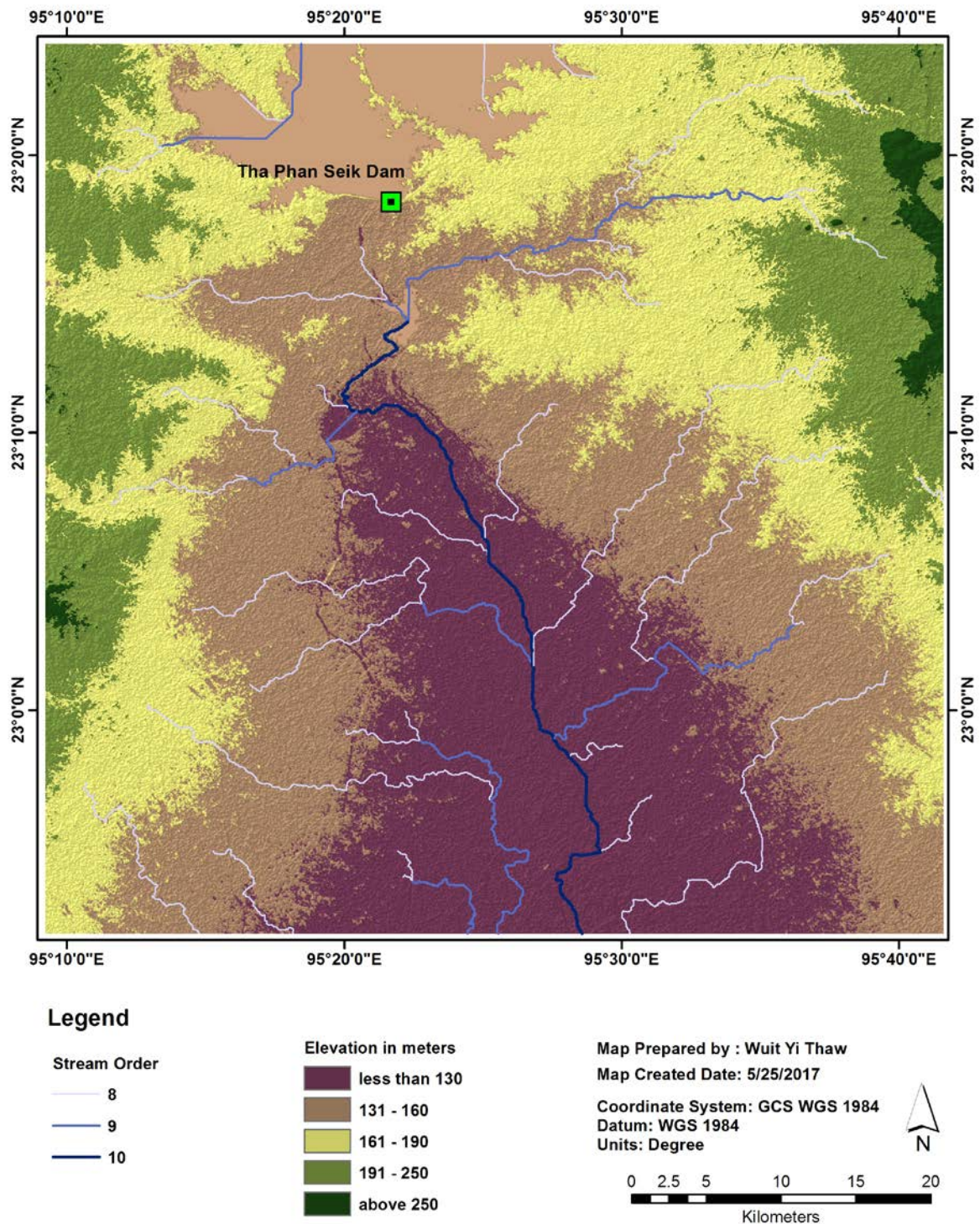
Map Prepared by : Wuit Yi Thaw
Map Created Date: 5/25/2017

Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree



Map 19. Population Distribution by Village Tracts in the Downstream Areas of Tha Phan Seik Dam

Elevation and Drainage Network in the Downstream Areas of Tha Phan Seik Dam



Map 20. Elevation and Drainage Network in the Downstream Areas of
Tha Phan Seik Dam

In this study, considering elevation, slope and proximity to the river as the parameters to generate potential flood risk area map of the selected area using Analytical Hierarchical Process (AHP). AHP is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information (Ojinnaka, Baywood, & Gift, 2015, p. 7).

Therefore, each of the parameters was reclassified into three classes from high to low representing by number 1, 2, 3 and 3 represented highest floods potential risk through the ranking process. Then, the potential flood risk area map will be generated through by overlaying the reclassified data of all the parameters using raster calculator as below formula.

Potential Flood Risk Area
in the downstream of
the Tha Phan Seik Dam $= \sum [\text{Reclassified (Elevation, slope and Distance to Drainage)}]$

3.7.1. Reclassification of Elevation and Slope

The reclassification of elevation layer, DEM values presented in meters and reclassified by assuming as low elevation have the high potential flood risk. So the elevation level less than equal to 150 were lower areas likely for the high flood risk area that were represented with the value 3, between 150 and 250 were likely moderately flood risk area that were represented with the value 2 and above 250 were likely the low flood risk area that were represented with value 1.

Then reclassification also on the slope layer. Slopes of 0 to 10 degrees have flatter land and steeper slopes are indicated by increased degrees. For slope, three elevation rankings were determined: areas with less than 10 degree slopes were represented with 1 for most favorable areas or areas least likely to experience flash flooding, areas that consisted of 10-15 degree slopes were represented with 2 for moderately favorable areas

moderately likely to experience flash flooding, or areas that consisted of greater than 15 degree slopes were represented with 3 for areas most likely to experience flash flooding.

3.7.2. Identification of Potential Flood Risk Area

Multiple ring buffers were processed buffers for the stream layer that were created to exhibit the proximity of each infrastructure possible damage site to a stream within the analysis. Three buffer zones were created as 100, 200 and 300 feet respectively.

Then, the buffer output generated polygons were converted to raster with output cell size of 90 feet by using Euclidean Allocation that straight-line distance tool used to display the proximity of the damage site locations to streams.

The output raster buffer layer consisted of a 300 foot set-back distance. Assuming 3 levels to reclassify: the areas between 300 and 200 feet were represented value with 1 for the most favorable areas to least likely experience flash flooding, the areas between 200 and 100 feet were given a value of 2 for the moderately likely to experience flash flooding. The closest to a stream was the areas less than 100 feet were given a value of 3 for the last favorable and most likely to experience flash flooding.

3.7.3. Identification of Potential Flood Risk Area

The four reclassification layers elevation, slope percentage and stream proximity resulted in 9 classes. Each raster was ranked in three classifications as the values of 1 were ranked as the locations least likely flash flooding risk, the values of 2 were ranked as moderate conditions likely flash flooding risk and the values of 3 were ranked as the most likely to experience flash flooding. They were added together using the spatial analyst Raster Calculator as shown as in figure 27 and result attribute table is shown in figure 28.

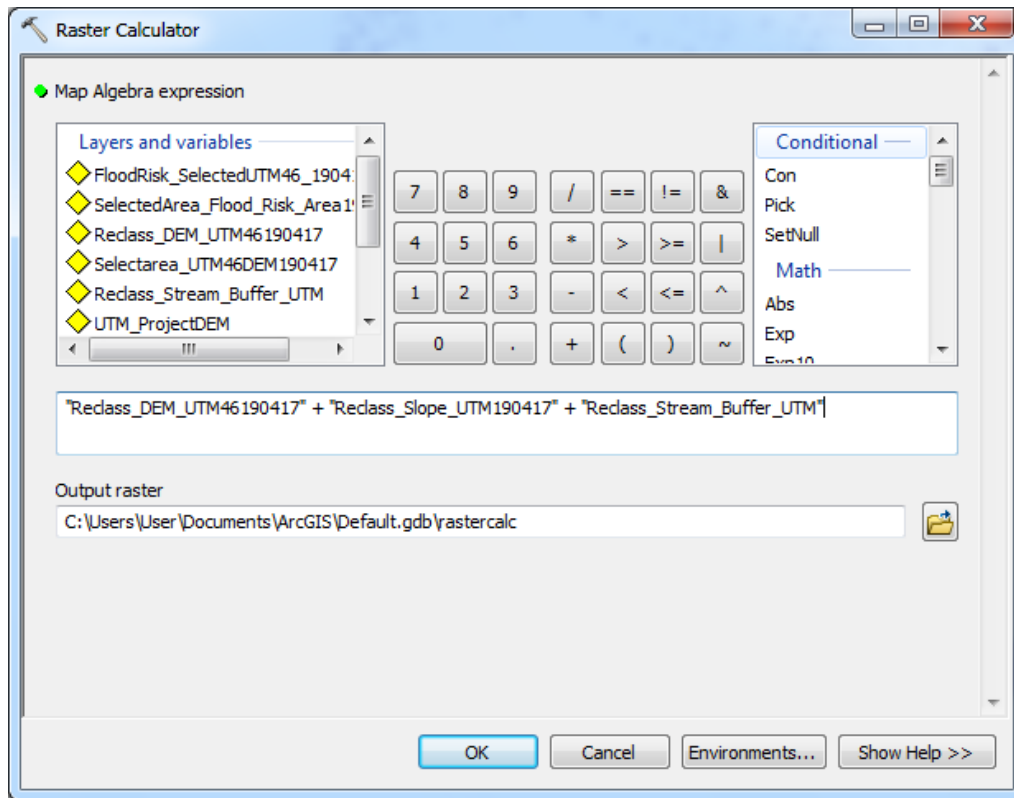


Figure 27. Calculation for Identifying Potential Flood Risk Areas based on the 9 Classified input Rasters Datasets in Raster Calculator

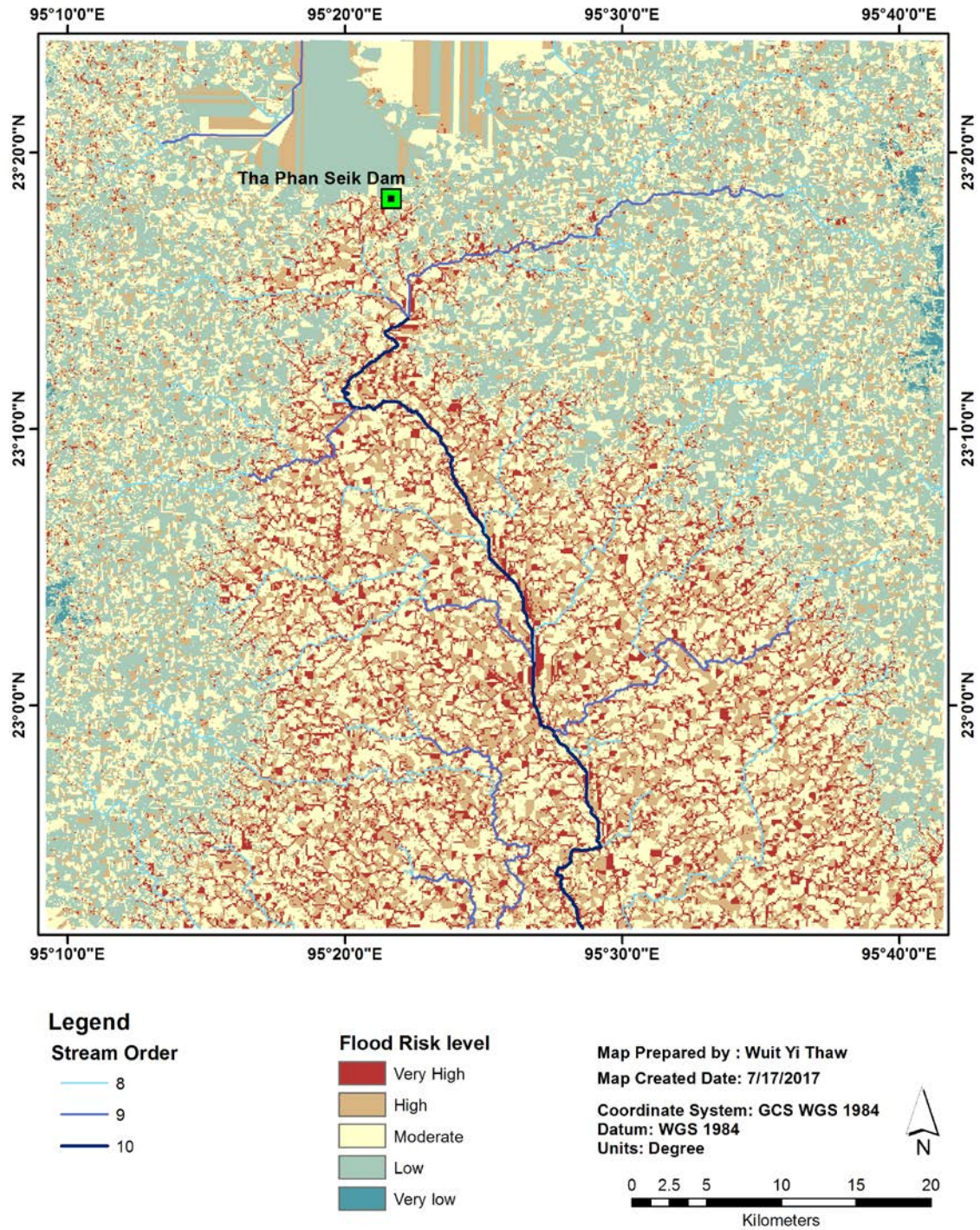
| OBJECTID * | Value | Count |
|------------|-------|--------|
| 1 | 3 | 1527 |
| 2 | 4 | 113612 |
| 3 | 5 | 154995 |
| 4 | 6 | 98291 |
| 5 | 7 | 34387 |
| 6 | 8 | 1673 |
| 7 | 9 | 235 |

Figure 28. Result of the potential flood risk raster attribute table

The result values in 7 grids and the values were starting from 3 to 9. Then the values were reclassified potential flood risk degree to 5 symbologies: the locations of the values from 9,8 and 7 for Very High, the value 6 for High, value 5 for Moderate, the value 4 for Low and the value 3 for Very low. Map 21 shows the potential flood risk area in degree with drainage network in downstream of the Tha Phan Seik Dam. The most of very high and

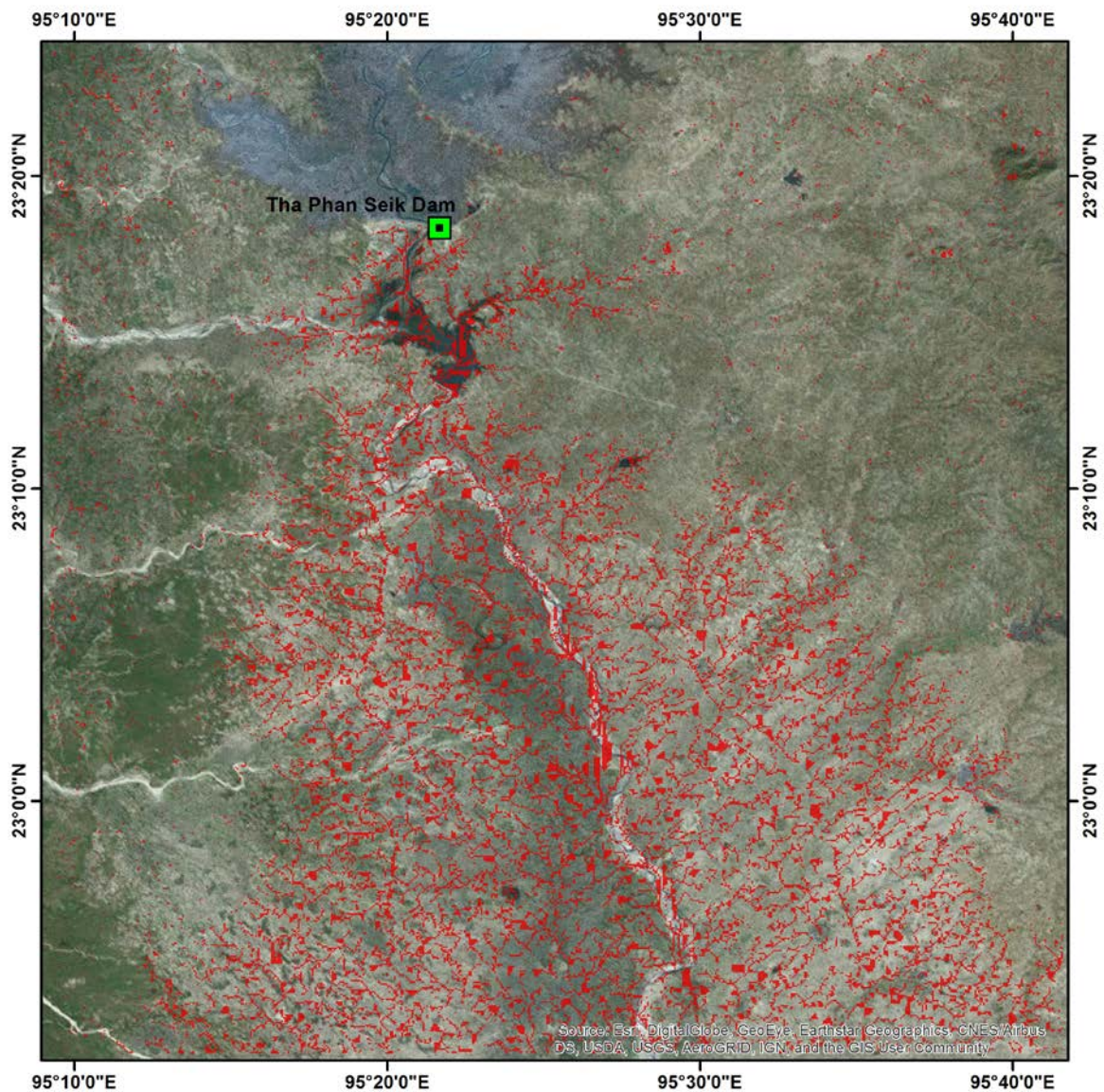
high potential flash flood areas are along drainage network. Map 22 shows the highest potential flood risk area of the selected region with satellite image based layer.

Potential Flood Risk Level in the Downstream Areas of Tha Phan Seik Dam



Map 21. Potential Flood Risk Level in the Downstream Areas of Tha Phan Seik Dam

Areas having Highest Potential Flood Risk Level in the Downstream Areas of Tha Phan Seik Dam



Legend

 Highest potential flood risk area

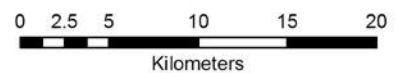
Map Prepared by : Wuit Yi Thaw

Map Created Date: 5/25/2017

Coordinate System: GCS WGS 1984

Datum: WGS 1984

Units: Degree

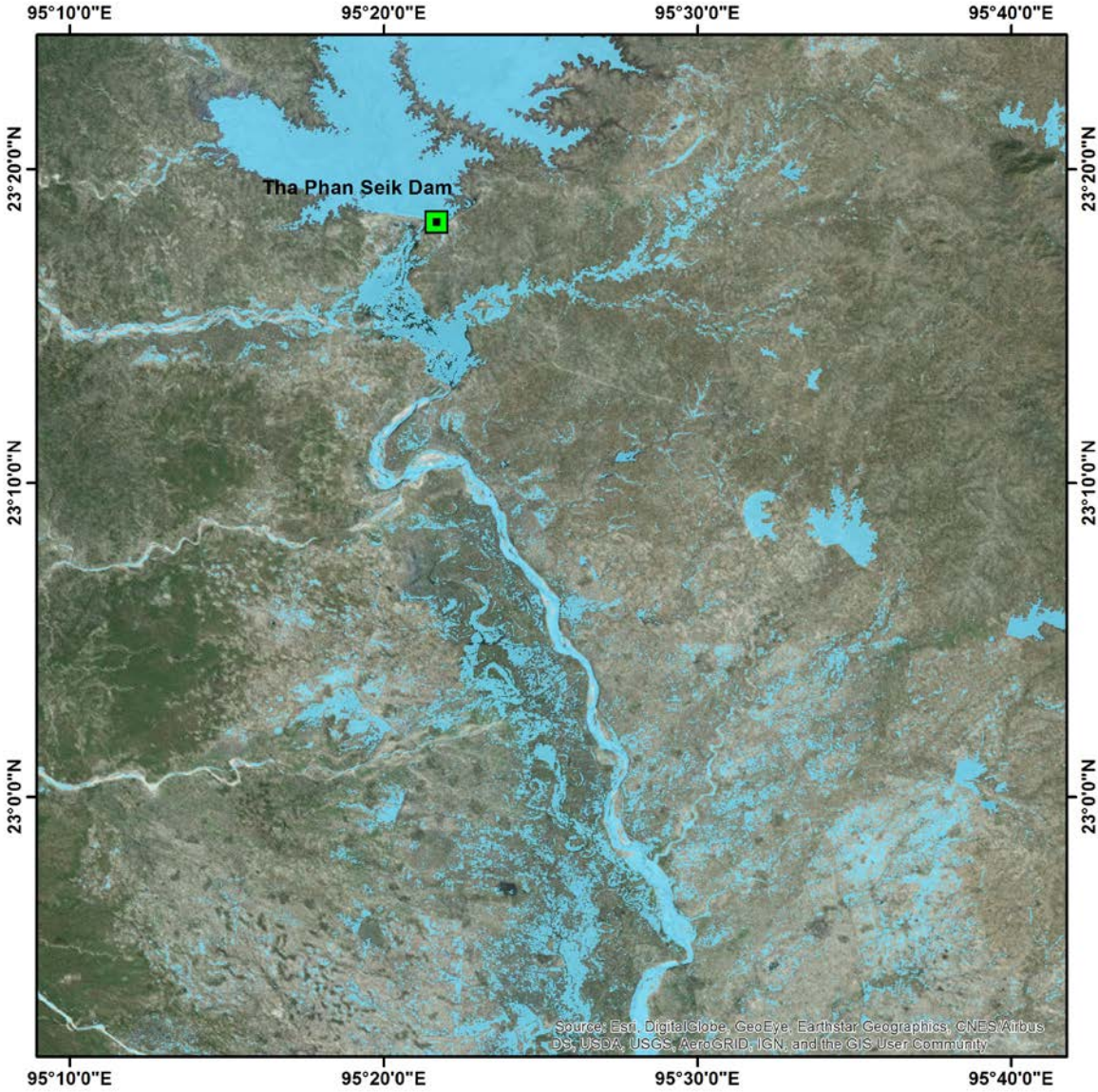


Map 22. Areas having Highest Potential Flood Risk Level in the Downstream Areas of Tha Phan Seik Dam draped on satellite image


The villages underlying potential flash flood risk degree very high and high were extracted by using select by location method and the extracted villages list that can be seen in Appendix B.

During 2015 flooding, UNOSAT/UNITAR provided satellite imagery and related geographic information research and analysis to the UN humanitarian and development agencies and their implementing partners. They also released the geodatabase and maps to present the flood situation that was calculated from Santinal-1 satellite image. By using the dataset as of 18 July 2015 from UNOSAT/UNITAR that was the maximum flooded time in the area, map 23 was created to present the actual flood situation for that time with showing blue areas as flooded area in the downstream of the Tha Phan Seik Dam. The Myanmar Information Management Unit (MIMU) released the list of probable flood-affected villages at 07 December 2015 and the extracted list for the selected area can be seen in Appendix C.

Areas Flood on 18 July 2015 in the Downstream Areas of Tha Phan Seik Dam



Legend

 flooded area from Sentinel1
18 July 2015 image
distributed by UNOSAT

Map Prepared by : Wuit Yi Thaw
Map Created Date: 5/25/2017

Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree



Map 23. Areas Flood on 18 July 2015 in the Downstream Areas of Tha Phan Seik Dam
draped on satellite image

Chapter-4: Conclusions

On 31 July, the President declared Chin and Rakhine States, and Magway and Sagaing regions as natural disaster zones. Some places were left for several days without any helps.

In order to GIS approach for assessing the damage caused by 2015 flood in Myanmar, the damage and losses in different sectors, the rainfall data, land use/land cover data, and satellite images to assess and analyze are necessary to input for this study. The challenges for the data collection are:

- 1) Data consistence: loss and damage data and information were released from different organizations such as the main organizations UN agencies and Government departments and it is difficult to decide the most probable data as data are varying by different sources and it makes confusing.
- 2) Data centralization: most of the departments cannot provide data and sometimes the data are under control and needs several processes such as a lot of request forms and steps. Even if they delivered the data, the history data is not much available that is for only one or two years history data can available.
- 3) Geographical data: Myanmar administrative structure has five admin levels as shown in Figure 1, some of the village tracts level and villages' geographical GPS locations are still missing. The landuse / landcover map, soil map, transportation network for road and railway are not updated.

After Nargis cyclone which made big loss, damages and deaths in 2008, the Government became to know the important of data and information for recovery and planning. Though centralized database system is generated, it is still needed to get collect perfect historical data from different sectors. The flooding in 2015 is also big disaster as it was suffered in 12 States and Regions among 14 States and Regions in Myanmar. This paper analyzes the situation of the 2015 flood from GIS point of view. Showing the damage and loses data by mapping, calculated the population density by State/Region map, processed the

drainage network and dam structure map, estimated the rainfall intensity for the heaviest rainfall period July and August 2015 map, and generated the potential flood risk area and vulnerable villages of the sample area. This study is hopefully support for the future disaster preparedness, disaster reduction and it would support to sustainable development planning in agriculture, livelihood and education sectors and also for village and urbanization planning.

The following pictures are showing the Kale town status in 2015 Myanmar flooding.



Kalay Town before flood



Kale Town Hall before 2 Aug,2015



Kale Town Hall 2 Aug,2015



An aerial view shows the flooded area of Kale Town, Sagaing Region, Upper Myanmar, 2 Aug, 2015.

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APPENDICES

Appendix A: Rainfall data of July 2015 and August 2015

| No. | Longitude | Latitude | July 2015 Rainfall | August 2015 Rainfall | Total July and August 2015 Rainfall |
|-----|-----------|-----------|--------------------|----------------------|-------------------------------------|
| 1 | 94.047913 | 19.795368 | 821 | 574 | 1395 |
| 2 | 95.216843 | 19.358553 | 380 | 308 | 688 |
| 3 | 96.483893 | 17.335828 | 649 | 687 | 1336 |
| 4 | 97.337354 | 19.174138 | 632 | 816 | 1448 |
| 5 | 97.23441 | 24.25493 | 129 | 143 | 272 |
| 6 | 97.239311 | 17.21987 | 639 | 795 | 1434 |
| 7 | 94.821152 | 20.902779 | 162 | 200 | 362 |
| 8 | 98.196364 | 14.077525 | 795 | 839 | 1634 |
| 9 | 93.680344 | 22.911051 | 158 | 236 | 394 |
| 10 | 94.135818 | 22.174213 | 253 | 281 | 534 |
| 11 | 94.579964 | 17.593689 | 763 | 1832 | 2595 |
| 12 | 95.652588 | 18.229889 | 714 | 791 | 1505 |
| 13 | 93.604834 | 22.640108 | 233 | 275 | 508 |
| 14 | 95.458183 | 17.649578 | 716 | 1205 | 1921 |
| 15 | 95.695465 | 25.99243 | 410 | 250 | 660 |
| 16 | 96.041801 | 17.099867 | 537 | 563 | 1100 |
| 17 | 94.910878 | 24.8644 | 182 | 268 | 450 |
| 18 | 97.636909 | 16.880764 | 645 | 875 | 1520 |
| 19 | 97.444878 | 18.06496 | 570 | 854 | 1424 |
| 20 | 97.298103 | 22.618938 | 12 | 101 | 113 |
| 21 | 94.02977 | 23.193301 | 150 | 242 | 392 |
| 22 | 94.300359 | 23.199801 | 172 | 228 | 400 |
| 23 | 95.51886 | 23.203053 | 91 | 141 | 232 |
| 24 | 96.331668 | 24.181633 | 42 | 146 | 188 |
| 25 | 98.23996 | 16.555531 | 746 | 1106 | 1852 |
| 26 | 99.6036 | 21.291885 | 136 | 216 | 352 |
| 27 | 97.036713 | 22.541719 | 35 | 51 | 86 |
| 28 | 93.5544 | 19.4239 | 763 | 502 | 1265 |
| 29 | 96.130333 | 21.613251 | 28 | 1 | 29 |
| 30 | 92.97282 | 20.843957 | 694 | 422 | 1116 |
| 31 | 97.747467 | 22.952765 | 90 | 283 | 373 |
| 32 | 98.119627 | 13.975223 | 795 | 839 | 1634 |
| 33 | 97.20993 | 19.67424 | 547 | 332 | 879 |
| 34 | 97.565811 | 20.925358 | 91 | 86 | 177 |
| 35 | 97.589371 | 27.283951 | 788 | 557 | 1345 |

Rainfall data of July 2015 and August 2015 (Continue)

| No. | Longitude | Latitude | July 2015 Rainfall | August 2015 Rainfall | Total July and August 2015 Rainfall |
|-----|-----------|-----------|--------------------|----------------------|-------------------------------------|
| 36 | 94.926959 | 20.14027 | 180 | 163 | 343 |
| 37 | 96.096861 | 21.993206 | 35 | 51 | 86 |
| 38 | 95.649398 | 16.730231 | 226 | 328 | 554 |
| 39 | 92.36776 | 20.818966 | 694 | 422 | 1116 |
| 40 | 94.41201 | 23.635118 | 218 | 254 | 472 |
| 41 | 97.625931 | 16.484591 | 645 | 875 | 1520 |
| 42 | 95.863113 | 20.881887 | 133 | 207 | 340 |
| 43 | 94.875183 | 20.171606 | 180 | 163 | 343 |
| 44 | 93.973654 | 21.371757 | 292 | 280 | 572 |
| 45 | 94.494197 | 22.877808 | 89 | 218 | 307 |
| 46 | 96.940384 | 25.302744 | 331 | 314 | 645 |
| 47 | 96.505402 | 22.921391 | 61 | 62 | 123 |
| 48 | 96.373198 | 24.779057 | 22 | 106 | 128 |
| 49 | 99.247238 | 20.505438 | 185 | 265 | 450 |
| 50 | 96.669991 | 23.11422 | 107 | 138 | 245 |
| 51 | 95.139633 | 22.121679 | 41 | 14 | 55 |
| 52 | 93.18844 | 20.591845 | 585 | 361 | 946 |
| 53 | 97.724777 | 16.25812 | 776 | 1291 | 2067 |
| 54 | 94.929767 | 16.599261 | 576 | 660 | 1236 |
| 55 | 98.609778 | 12.441122 | 594 | 775 | 1369 |
| 56 | 95.391792 | 21.457451 | 143 | 98 | 241 |
| 57 | 95.575851 | 21.92514 | 776 | 1291 | 2067 |
| 58 | 97.390355 | 25.387488 | 352 | 298 | 650 |
| 59 | 97.720215 | 20.889118 | 650 | 108 | 758 |
| 60 | 96.79895 | 22.33003 | 24 | 60 | 84 |
| 61 | 95.077309 | 17.399274 | 734 | 1187 | 1921 |
| 62 | 96.721507 | 17.953233 | 632 | 816 | 1448 |
| 63 | 94.910108 | 21.195434 | 170 | 251 | 421 |
| 64 | 95.082268 | 21.335001 | 129 | 171 | 300 |
| 65 | 92.854607 | 21.304407 | 583 | 391 | 974 |
| 66 | 94.733028 | 16.77924 | 674 | 745 | 1419 |
| 67 | 96.435722 | 18.48438 | 455 | 665 | 1120 |
| 68 | 96.782188 | 20.124392 | 262 | 180 | 442 |
| 69 | 95.370257 | 24.080886 | 196 | 243 | 439 |
| 70 | 97.415903 | 27.299338 | 788 | 557 | 1345 |
| 71 | 95.68322 | 16.2843 | 150 | 335 | 485 |
| 72 | 95.221029 | 18.82151 | 313 | 244 | 557 |
| 73 | 96.208946 | 19.736099 | 263 | 221 | 484 |
| 74 | 96.456341 | 22.013972 | 17 | 50 | 67 |

Rainfall data of July 2015 and August 2015 (Continue)

| No. | Longitude | Latitude | July 2015 Rainfall | August 2015 Rainfall | Total July and August 2015 Rainfall |
|-----|-----------|-----------|--------------------|----------------------|-------------------------------------|
| 75 | 95.962311 | 21.880079 | 17 | 50 | 67 |
| 76 | 95.698486 | 22.56996 | 1987 | 1023 | 3010 |
| 77 | 96.877666 | 17.923038 | 632 | 816 | 1448 |
| 78 | 94.69162 | 20.6637 | 162 | 200 | 362 |
| 79 | 92.885506 | 20.137266 | 666 | 487 | 1153 |
| 80 | 95.973709 | 21.819019 | 28 | 1 | 29 |
| 81 | 94.31534 | 24.211492 | 226 | 251 | 477 |
| 82 | 96.202965 | 20.130411 | 157 | 171 | 328 |
| 83 | 95.546135 | 20.001873 | 123 | 422 | 545 |
| 84 | 97.035979 | 20.774773 | 177 | 268 | 445 |
| 85 | 96.433144 | 18.939529 | 370 | 573 | 943 |
| 86 | 93.656189 | 23.370575 | 206 | 240 | 446 |
| 87 | 94.360773 | 18.460999 | 1077 | 783 | 1860 |
| 88 | 97.367798 | 16.919701 | 639 | 881 | 1520 |
| 89 | 95.786285 | 17.654413 | 716 | 835 | 1551 |
| 90 | 94.239723 | 18.853531 | 750 | 673 | 1423 |
| 91 | 96.137466 | 20.4305 | 157 | 197 | 354 |
| 92 | 97.854233 | 15.251858 | 962 | 1189 | 2151 |
| 93 | 95.430489 | 22.76914 | 55 | 44 | 99 |
| 94 | 95.556656 | 17.478098 | 150 | 335 | 485 |
| 95 | 93.45 | 22.9 | 158 | 236 | 394 |
| 96 | 94.66667 | 22.83333 | 122 | 178 | 300 |
| 97 | 96.5 | 21.5 | 7 | 29 | 36 |
| 98 | 96.1833 | 20.8 | 115 | 139 | 254 |
| 99 | 96.83333 | 20.7167 | 177 | 268 | 445 |
| 100 | 93.75 | 18.83333 | 679 | 347 | 1026 |
| 101 | 95.4167 | 18.98333 | 313 | 244 | 557 |
| 102 | 95.518982 | 21.851851 | 263 | 221 | 484 |
| 103 | 95.004158 | 16.57185 | 1293 | 1243 | 2536 |
| 104 | 95.5 | 16.58333 | 226 | 328 | 554 |
| 105 | 96.23333 | 17.63333 | 762 | 651 | 1413 |
| 106 | 96.18333 | 16.9 | 223 | 329 | 552 |
| 107 | 96.1667 | 16.76667 | 223 | 329 | 552 |
| 108 | 96.5667 | 16.9 | 468 | 534 | 1002 |
| 109 | 96.9 | 17.53333 | 748 | 809 | 1557 |
| 110 | 95.25 | 22.25 | 7 | 24 | 31 |
| 111 | 97.52234 | 28.16888 | 815 | 531 | 1346 |
| 112 | 97.90137 | 28.16888 | 724 | 525 | 1249 |
| 113 | 98.36829 | 27.31809 | 645 | 537 | 1182 |

Rainfall data of July 2015 and August 2015 (Continue)

| No. | Longitude | Latitude | July 2015 Rainfall | August 2015 Rainfall | Total July and August 2015 Rainfall |
|------------|------------------|-----------------|---------------------------|-----------------------------|--|
| 114 | 98.33533 | 26.01236 | 408 | 409 | 817 |
| 115 | 97.90686 | 25.50774 | 281 | 231 | 512 |
| 116 | 98.63196 | 23.97621 | 332 | 281 | 613 |
| 117 | 98.85718 | 23.3019 | 257 | 177 | 434 |
| 118 | 99.36255 | 23.01908 | 170 | 109 | 279 |
| 119 | 99.79102 | 21.95833 | 121 | 179 | 300 |
| 120 | 100.56006 | 21.24842 | 214 | 274 | 488 |
| 121 | 101.05444 | 21.62679 | 180 | 277 | 457 |
| 122 | 100.10962 | 20.58651 | 216 | 304 | 520 |
| 123 | 99.1648 | 20.21066 | 186 | 436 | 622 |
| 124 | 98.93958 | 19.81839 | 385 | 838 | 1223 |
| 125 | 97.57727 | 19.40961 | 817 | 670 | 1487 |
| 126 | 98.00024 | 17.27197 | 615 | 937 | 1552 |
| 127 | 98.76929 | 16.27796 | 941 | 1074 | 2015 |
| 128 | 98.47266 | 15.41132 | 1011 | 1310 | 2321 |
| 129 | 98.71985 | 14.17386 | 733 | 789 | 1522 |
| 130 | 99.25818 | 12.77966 | 747 | 563 | 1310 |
| 131 | 99.26917 | 11.41542 | 636 | 539 | 1175 |
| 132 | 98.5833 | 9.9667 | 526 | 674 | 1200 |
| 133 | 94.85266 | 15.85039 | 580 | 849 | 1429 |
| 134 | 94.35828 | 16.83609 | 914 | 779 | 1693 |
| 135 | 92.90808 | 22.00927 | 412 | 366 | 778 |
| 136 | 93.33105 | 23.99127 | 269 | 266 | 535 |
| 137 | 94.64941 | 25.27947 | 132 | 277 | 409 |
| 138 | 95.13831 | 26.53939 | 498 | 246 | 744 |
| 139 | 96.59399 | 27.28881 | 689 | 370 | 1059 |

Appendix B: Villages list underlying potential flood risk degree Very High and High

| No | District | Township | Village Tract | Villages | Risk Degree |
|----|----------|----------|------------------|-------------------------|-------------|
| 1 | Shwebo | Kanbalu | Kar Boe | Kar Boe | Very High |
| 2 | Shwebo | Kanbalu | Poke Par | Poke Par | Very High |
| 3 | Shwebo | Kanbalu | Kyauk Se Kan | Kyauk Se Kan | Very High |
| 4 | Shwebo | Taze | Aung Swar | Kan Hpyu | Very High |
| 5 | Shwebo | Taze | Nga Tan | Shwe Hlan | Very High |
| 6 | Shwebo | Taze | Kha Paung Kyaing | Kha Paung Kyaing | Very High |
| 7 | Shwebo | Taze | Shwe Ku | Shwe Ku | Very High |
| 8 | Shwebo | Taze | War Ya Nge | War Ya Nge | Very High |
| 9 | Shwebo | Kanbalu | Wet Toe (North) | Mei Za Li Kone | High |
| 10 | Shwebo | Kanbalu | Tauk Ka Shat | Kan Gyi Kone | High |
| 11 | Shwebo | Kanbalu | Nyaung Pin Gyi | Nyaung Pin Gyi | High |
| 12 | Shwebo | Kanbalu | Kyoe Kyar | Kyoe Kyar | High |
| 13 | Shwebo | Kanbalu | Htan Kone | Htan Kone | High |
| 14 | Shwebo | Kanbalu | San Da Yar | San Da Yar Ywar Thit | High |
| 15 | Shwebo | Kanbalu | Pay Kone (South) | Chaung Kyar | High |
| 16 | Shwebo | Kanbalu | Su Poke Kone | Su Poke Kone | High |
| 17 | Shwebo | Kanbalu | Htein Taw | Htein Taw (South) | High |
| 18 | Shwebo | Kanbalu | Htein Taw | Ywar Ma | High |
| 19 | Shwebo | Kanbalu | Bu Gyi | Bu Gyi (North) | High |
| 20 | Shwebo | Kanbalu | Poke Par | Pyin Taw | High |
| 21 | Shwebo | Kanbalu | Htan Ta Pin | Htan Ta Pin | High |
| 22 | Shwebo | Kanbalu | Ya Thar | Min Kone | High |
| 23 | Shwebo | Kyunhla | Pay Kone | Pay Kone | High |
| 24 | Shwebo | Ye-U | Mon Taing Pin | Mon Taing Pin | High |
| 25 | Shwebo | Ye-U | In Pin | Aung Thar Yar | High |
| 26 | Shwebo | Taze | Nga Tan | Nga Tan | High |
| 27 | Shwebo | Taze | In Taing | In Taing | High |
| 28 | Shwebo | Taze | Ka La Zin | Ka La Zin | High |
| 29 | Shwebo | Taze | Ka La Zin | Tat Thit | High |
| 30 | Shwebo | Taze | Kyaung Sin Aing | Kyaung Sin Aing | High |

Villages list underlying potential flood risk degree Very High and High (Continue)

| No | District | Township | Village Tract | Villages | Risk Degree |
|----|----------|----------|-------------------|-----------------------|-------------|
| 31 | Shwebo | Taze | Kar Paung Kya | Kar Paung Kya (East) | High |
| 32 | Shwebo | Taze | Kar Paung Kya | Kar Paung Kya (West) | High |
| 33 | Shwebo | Taze | Na Nwin Taw | Na Nwin Taw (West) | High |
| 34 | Shwebo | Taze | Na Nwin Taw | See Thar | High |
| 35 | Shwebo | Taze | Nyaung Zee Kone | Nyaung Zee Kone | High |
| 36 | Shwebo | Taze | Shwe Ka Taw | Shwe Ka Taw | High |
| 37 | Shwebo | Taze | Shwe Ku | Tha Yet Kone | High |
| 38 | Shwebo | Taze | Toke Ta Loke | Toke Ta Loke (North) | High |
| 39 | Shwebo | Taze | Toke Ta Loke | Nar Taung Kya | High |
| 40 | Shwebo | Taze | Thit Taw Pauk | Thit Taw Pauk (South) | High |
| 41 | Shwebo | Taze | Ywar Thar Yar | Ywar Thar Yar | High |
| 42 | Shwebo | Taze | Yae U Kone | Yae U Kone | High |
| 43 | Shwebo | Taze | Ywar Shey (North) | Hpet Than Kone | High |
| 44 | Shwebo | Taze | Zee Pauk | Zee Pauk | High |

**Appendix C: The probable flood-affected villages as of
07 December 2015 from MIMU**

| No. | District | Township | Village Tract | Village |
|------------|-----------------|-----------------|-----------------------|--------------------|
| 1 | Shwebo | Kanbalu | Inn Ma | Pin Te |
| 2 | Shwebo | Kanbalu | Wet Toe (North) | Wet Toe (North) |
| 3 | Shwebo | Kanbalu | Wet Toe (North) | Mei Za Li Kone |
| 4 | Shwebo | Kanbalu | Kyoe Kyar | Kyoe Kyar |
| 5 | Shwebo | Kanbalu | Boke Taw | Boke Taw |
| 6 | Shwebo | Kanbalu | Thin Pan Taw | Thin Pan Taw |
| 7 | Shwebo | Kanbalu | Thin Pan Taw | Ka Zun Inn |
| 8 | Shwebo | Kanbalu | Ywet Kyan | Ywet Kyan (South) |
| 9 | Shwebo | Kanbalu | Tha But Kone | Tha But Kone |
| 10 | Shwebo | Kanbalu | Nyaung Zin Lay | Nyaung Zin Lay |
| 11 | Shwebo | Kanbalu | Su Poke Kone | Su Poke Kone |
| 12 | Shwebo | Kanbalu | Htein Taw | Htein Taw (North) |
| 13 | Shwebo | Kanbalu | Htein Taw | Htein Taw (South) |
| 14 | Shwebo | Kanbalu | Htein Taw | Yi Dway |
| 15 | Shwebo | Kanbalu | Kaing Yoe | In Gar Daunt |
| 16 | Shwebo | Kanbalu | Si Son Gyi | Si Son Gyi |
| 17 | Shwebo | Kanbalu | Kha Ohn Tar | Kha Ohn Tar |
| 18 | Shwebo | Kanbalu | Kha Ohn Tar | Pay Gyi |
| 19 | Shwebo | Kanbalu | Poke Par | Poke Par |
| 20 | Shwebo | Kanbalu | Kyauk Se Kan | Kyauk Se Kan |
| 21 | Shwebo | Kanbalu | Ya Thar | Min Kone |
| 22 | Shwebo | Kanbalu | Hpoke Kone | Su Tat |
| 23 | Shwebo | Kanbalu | Hpoke Kone | Ma Gyi Kone |
| 24 | Shwebo | Ye-U | Yae Myet | Yae Myet |
| 25 | Shwebo | Ye-U | Mon Taing Pin | Zee Kan |
| 26 | Shwebo | Ye-U | Pay Gyi | Pay Gyi |
| 27 | Shwebo | Taze | Chaung Yoe | Hpan Khar Zin |
| 28 | Shwebo | Taze | Chaung Son (North) | Chaung Son (North) |
| 29 | Shwebo | Taze | Chaung Son (North) | Inn Shey |
| 30 | Shwebo | Taze | Dei Yauk | Dei Yauk |
| 31 | Shwebo | Taze | Nga Tan | Nga Tan |

The probable flood-affected villages as of 07 December 2015 from MIMU (Continue)

| No. | District | Township | Village Tract | Village |
|-----|----------|----------|-------------------|-----------------------|
| 32 | Shwebo | Taze | Kone Yoe | Kone Yoe (East) |
| 33 | Shwebo | Taze | Kan Gyi Kone | Kan Gyi Kone |
| 34 | Shwebo | Taze | Kyaung Sin Aing | Kyaung Kone |
| 35 | Shwebo | Taze | Kan Htu Ma | Pu Tein Kone |
| 36 | Shwebo | Taze | Kar Paung Kya | Kar Paung Kya (East) |
| 37 | Shwebo | Taze | Kar Paung Kya | Kar Paung Kya (West) |
| 38 | Shwebo | Taze | Nga Nu Chaung | Nyaung Yin (East) |
| 39 | Shwebo | Taze | Na Nwin Taw | Na Nwin Taw (East) |
| 40 | Shwebo | Taze | Na Nwin Taw | See Thar |
| 41 | Shwebo | Taze | Nyaung Zee Kone | Nyaung Zee Kone |
| 42 | Shwebo | Taze | Shwe Ku | Tha Yet Kone |
| 43 | Shwebo | Taze | San Swea | Daung Kway |
| 44 | Shwebo | Taze | Toke Ta Loke | Thar Kay Ta |
| 45 | Shwebo | Taze | Toke Ta Loke | Nar Taung Kya |
| 46 | Shwebo | Taze | Ta Poe | Ta Poe |
| 47 | Shwebo | Taze | Thit Taw Pauk | Thit Taw Pauk (South) |
| 48 | Shwebo | Taze | Thit Say Kone | Thit Say Kone (North) |
| 49 | Shwebo | Taze | Thit Say Kone | Thit Say Kone (South) |
| 50 | Shwebo | Taze | War Ya Nge | War Ya Nge |
| 51 | Shwebo | Taze | War Ya Nge | In Ta Khar |
| 52 | Shwebo | Taze | Ywar Ma | Ywar Ma |
| 53 | Shwebo | Taze | Ywar Thar Yar | Htan Taw Su |
| 54 | Shwebo | Taze | Ywar Shey (North) | Et Gyi |
| 55 | Shwebo | Taze | Zee Pauk | Leik Chan |
| 56 | Shwebo | Taze | Nyaung Zee Kone | Sa Bae Hpyu (West) |
| 57 | Shwebo | Taze | Toke Ta Loke | Toke Ta Loke (South) |