Coupling Flood Hazard with Vulnerability Map for Flood Risk Assessment: A Case Study of Nyaung-U Township in Myanmar

T. W. Khaing, S. Tantanee*, W. Pratoomchai, and N. Mahavik

***Abstract*— *River flood is one of the major hazards in Myanmar. Flooding is a problem in Nyaung-U Township and occurs once or twice in every year due to its geographic location. The flood regularly occurs during the monsoon season. Flooding causes the loss of lives and properties, economic loss and health-related problems. Bagan city is a world heritage site in Nyaung-U Township. Bagan's world heritage site is the center of focus for Myanmar's growing tourist industry. Thus flood risk map and risk assessment are essentially needed for Nyaung-U Township. The objective of this study is to generate the flood hazard, vulnerability, risk map as well as the flood risk assessment of Nyaung-U Township. The hydraulic model of HEC-RAS was used to generate the flood hazard maps of the study area with the two-return period (10-year and 100-year). The flood frequency analysis has been done using the annual highest discharge of Nyaung-U and Chauk stations at the Ayeyarwaddy River by Normal, Log Normal, Pearson Type III and Log Pearson Type III distribution and Gumbel method. Eight influencing flood hazard factors and six influencing flood vulnerability factors have been considered to create flood hazard and vulnerability maps using GIS. In this study, the Analytic Hierarchy Process (AHP) method was used as a multi-criteria analysis of hazards and vulnerability for flood risk assessment and map. Finally, flood risk map has been generated by multiplying hazard and vulnerability in ArcGIS. The results show that very high risk regions were located near and along river in the western part of the study area. The very high and high-risk areas of the 10-year return period were 14.21km^2 and 21.98 km^2 respectively while a 100-year return period were 16.26 km^2 and 24.70 km^2 respectively of the Nyaung-U Township. Obtained Flood risk map can support valuable information to the decision maker for flood prevention and mitigation planning in Nyaung-U Township.*

***Keywords*— Hazard, vulnerability, flood risk assessment, AHP, GIS, Nyaung-U Township.**

1. INTRODUCTION

River floods are one of the most common natural hazards, causing devastating impacts worldwide [1], [2]. The impacts of flooding are expected to rise due to population increases; economic growth and climate change [3]. Floods are the most frequent (46%) of all the disasters. In the last decade of the 20th century, floods killed 100,000 persons and affected over 1.4 billion people around the world [4]. Climate change may rise the frequency or magnitude of flooding. The impact of flooding is mainly harmful in developing countries due to low levels of flood protection [3]

Myanmar, one of the most common disaster-prone country among the Asia-Pacific region due to its geographic location and effect of the tropical climate.

Myanmar suffered a number of natural disasters in the past decade. Common natural disasters in the area are cyclones, tropical storms, floods, earthquakes, landslides, droughts, and wildfires. Flood is one of the major hazards in Myanmar and the second largest disaster after the fire. In Myanmar, flooding usually occurred during the monsoon season (June to October) due to the heavy rainfall in the northern part of Myanmar [5],[6]. Over 2 million people are exposed to flood hazard in Myanmar every year. The 2015 floods caused damages and losses amounting to USD 1.5 billion [5].

According to the rainfall data and past flood events, there are 48 flood-prone townships in Myanmar [6]. Nyaung-U is one of the flood-prone areas. The main sources of river flood in the study area is the event of heavy rainfall continuously 3 or 4 days in the northern part of the country during the monsoon season. The large size of the catchment area and the big tributaries joining are basic factors of flooding in the study area. Poor landuse planning, zoning, and control of floodplain development; inadequate drainage, particularly in cities, and inadequate water resources management are also causes of flooding [7],[8],[9].

Among all kinds of natural hazards, the flood hazard is one of the most devastating, widespread and frequent in monsoon-dominated tropical and sub-tropical regions of this world [10],[11]. Flood hazard is the probability of occurrence of a potentially damaging flood event of a certain magnitude within a given time period and area [12]. According to reference [13], vulnerability assessment is the study of degree and magnitude of loss to a given element due to the occurrence of natural phenomena. The composition of the population, society, economy, and infrastructure are the major elements of risk [14],[15]. According to reference [13], total risk is

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the number of lives lost, a person injured, property damaged and adverse collective effect on economic activity due to natural phenomenon events. Flood vulnerability is one of the important components in risk management and flood damage assessment [16]. Around the world, especially dense populated areas in both low-lying river basins and coastal regions have been threatened by flood risk. [17].

Bagan city is a world heritage site in Nyaung-U Township and it is a very famous place in Myanmar. There are about 3500 Buddhist monuments (temples, stupas, monasteries, etc.). Bagan's world heritage site is the center of focus for Myanmar's growing tourist industry. Bagan is threatened by floods every year. Therefore, this study was conducted in Bagan city, Nyaung-U Township to assess the flood risk and flood risk reduction.

Many researchers around the world had been studied flood risk map and risk assessment using AHP and GIS. Reference [18] was used AHP and GIS to analysis for assessing flood risk for Quang Nam, Vietnam. Reference [19]-[20] were applied GIS and AHP model to analysis the flood risk for the Guanzhang urban area, china and the western province of Srilanka. Reference [21]-[22] were also applied AHP and GIS to develop the flood risk map and risk assessment.

In this study, the analytical hierarchy process (AHP), GIS and HEC-RAS model were applied to develop flood hazard, vulnerability and risk map of the study area. In flood hazard assessment, HEC-RAS hydraulic model was used to generate flood inundation map with the different return period. Flood frequency analysis is the main point to find out the occurrence probability of hazardous events. Among semi-quantitative approaches, various multi-criteria analysis (MCA) techniques have been used for flood susceptibility and vulnerability analysis and risk mapping [2],[23],[24]. AHP model is one of the MCA and it was used to calculate the weighting value of flood hazard and vulnerability indexes. GIS technology is very useful tools for the application of disaster management and risk reduction. In this study, GIS was used to generate the flood risk map. The results can support valuable information to the decision-maker of Nyaung-U Township to manage the flood risk reduction.

2. DESCRIPTION OF THE STUDY AREA

Nyaung-U is located on the eastern bank of the Ayeyarwaddy River, which includes 75 villages with the total area of 1459 km^2. It extends between 20° 5' N to 25° 18' N Latitude and 94° 39' E to 95° 13' E Longitude, as shown in Fig (1). Nyaung-U's high density of settlements are located in the western parts of the townships, very close to Ayerwaddy River. The population of the study area is 239,947 with a density of 164.5/km^2 [25]. The lowest elevation of the study area is 41m above MSL and the highest is 520m. Nyaung-U has generally low elevation near the river but generally elevated from the middle towards its eastern regions. The study area has a tropical climate and it is under the influence of monsoon storms. There are two seasons: wet and dry in the study area. The wet season, which is from May to October, coincides with the southwest monsoon. Meanwhile, the dry season is divided into the "winter" months of November to February, and "summer" months of March to April. Average minimum and maximum temperature of the study area are 10.22°C and 43.63°C. Annual normal rainfall is 618.9 mm based on the 30 years (1981-2010) historical record data [26].

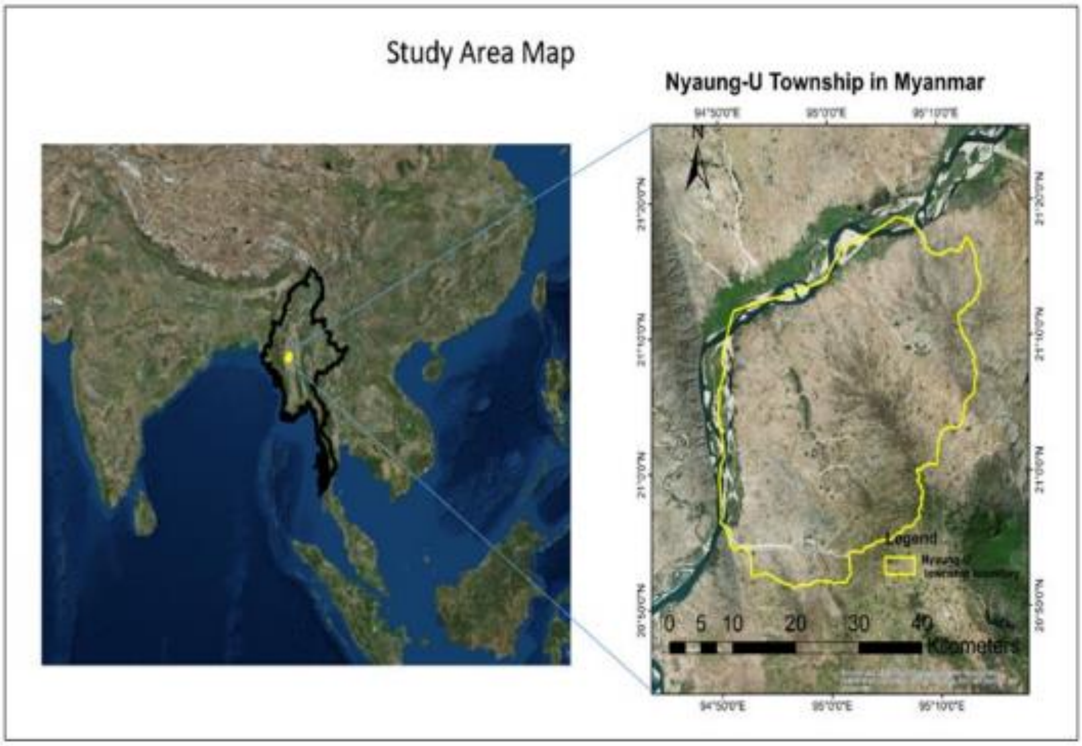


Fig. 1. Location map of the Study Area (Nyaung-U Township).

3. DATA USED

To generate the flood hazard and vulnerability map, the following data were collected from different sources. The list of required data and sources for this analysis is shown in Table 1.

Table 1. List of the required data sources

No.	Data	Sources	Resolution	Year
1	Topographic Map	Survey Department	1:250000	2007
2	Soil Map	FAO Global soil		
3	Demographic data	Immigration & National Registration Department		2018
4	SRTM DEM	https://earthexplorer.usgs.gov/	30m	
5	Landsat 8 OLI	https://earthexplorer.usgs.gov/	30m	
6	Rainfall, Water Level and Discharge data	Department of Meteorology and Hydrology		1976 - 2018
7	Flood duration map	GPS survey work and questionnaire		

4. METHODOLOGY

In this study, the AHP, HEC-RAS, and GIS technique were used to produce flood hazard maps, flood vulnerability map, and flood risk maps for the Nyaung-U Township. To achieve this,

Satellite data and GIS tools were used to generate the relevant thematic layers of factors. The methodology of this study is shown in figure (2).

4.1 Flood Frequency Analysis

Flood frequency analysis is a technique used by hydrologists to estimate flow values corresponding to specific return periods or probabilities along a river. Flood frequency analysis is one of the methods for flood forecasting techniques. To predict the design flood, there are numerous methods for frequency distributions to carry out the statistical analysis. The Gumbel, Normal, Log-Normal, Pearson Type III, and Log Pearson Type III methods were carried out for the flood frequency analysis in this study. The above five distribution methods were used to calculate the different return periods of 10 and 100 years. The selection of a suitable probability distribution for estimation of maximum flood discharge is performed through D-index and the Log Normal distribution was chosen to use as input data in HEC-RAS.

4.2 Flood Hazard Analysis

The relative importance of each factor considered for flood index was specified from literatures and the information obtained from experts. Therefore, eight factors of land use, elevation, slope, rainfall, soil, flood duration, drainage density, and flood depth were used for flood hazard analysis.

4.2.1 Land use map

Land use has an important influence on flood occurrence. Landsat 8 OLI satellite image of December 2018 was used to classify the land use layer using a supervised classification method in ArcGIS. The image was at a spatial resolution of 30 m. The four land use classes were classified as cultivation, water body, build-up area and bush/tree (Fig.3a).

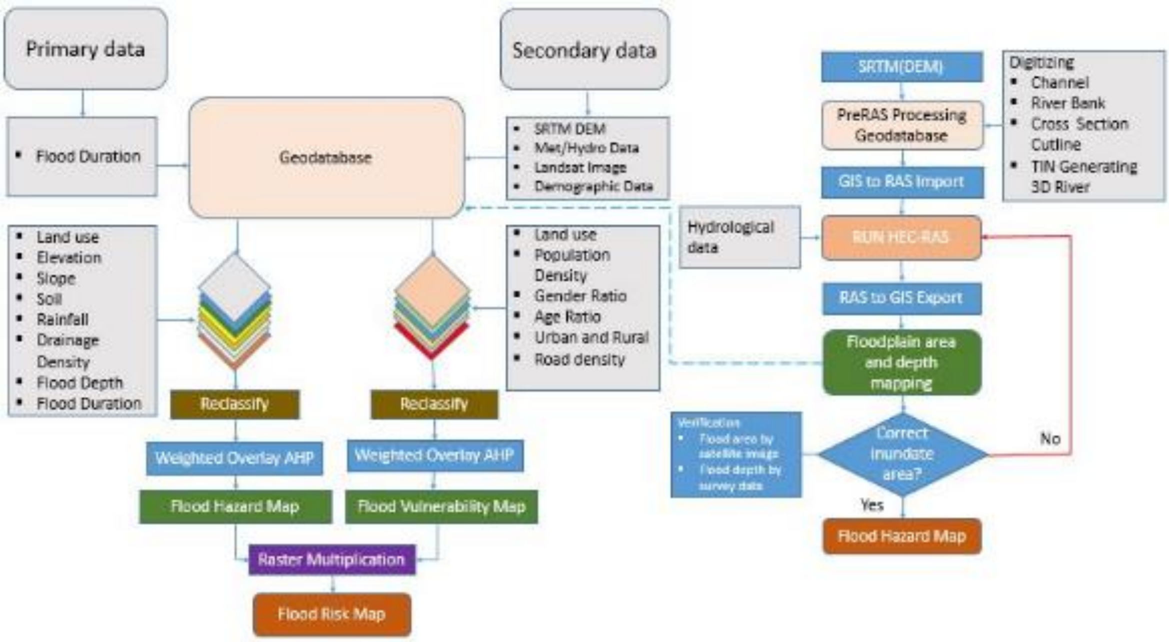


Fig. 2. Flow chart of the methodology of this study.

4.2.2 Elevation and slope map

Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with 30 m resolution data was used to generate the elevation and slope map. The higher the elevation is, the lower the hazard of flood disasters cause [27]. The slope is an important factor that affects water velocity. The flatter the slope, the higher is the probability of the area will be flooded.

The elevation and slope were classified into five categories by using Natural Breaks (Jenks) classification method. Then, final maps were reclassified into five classes: very low, low, moderate, high and very high (Fig.3b and 3c).

4.2.3 Rainfall map

The amount of rainfall can directly affect the water levels of the river and the amount of flow accumulation [19]. The 13 meteorological stations in and around the Nyaung-U Township of annual rainfall data were used to interpolate for the rainfall layer. The interpolation method was performed using the Inverse Distance Weighted (IDW) method in ArcGIS. Rainfall data were classified into five classes using standard classification schemes namely equal intervals. Finally, the rainfall map was reclassified into different five classes: very low, low, moderate, high and very high. (Fg.3d).

4.2.4 Soil Map

Food and Agriculture Organization (FAO) global soil data was used to generate the soil map. Based on the water infiltration capacity, the soil layer was classified into two classes namely clay loam and sandy clay loam (Fig. 3e).

4.2.5 Flood Duration Map

The flood duration map was developed using field survey data of the year 2015, 2016 and 2017. Based on the information from the field survey, the Inverse Distance Weighted (IDW) method was used to create the flood duration map. Then the flood duration map was classified into five categories using Natural Breaks (Jenks) classification method. The final map was reclassified into five classes namely very low, low, moderate, high and very high using standard classification (Fig.3f).

4.2.6 Drainage Density map

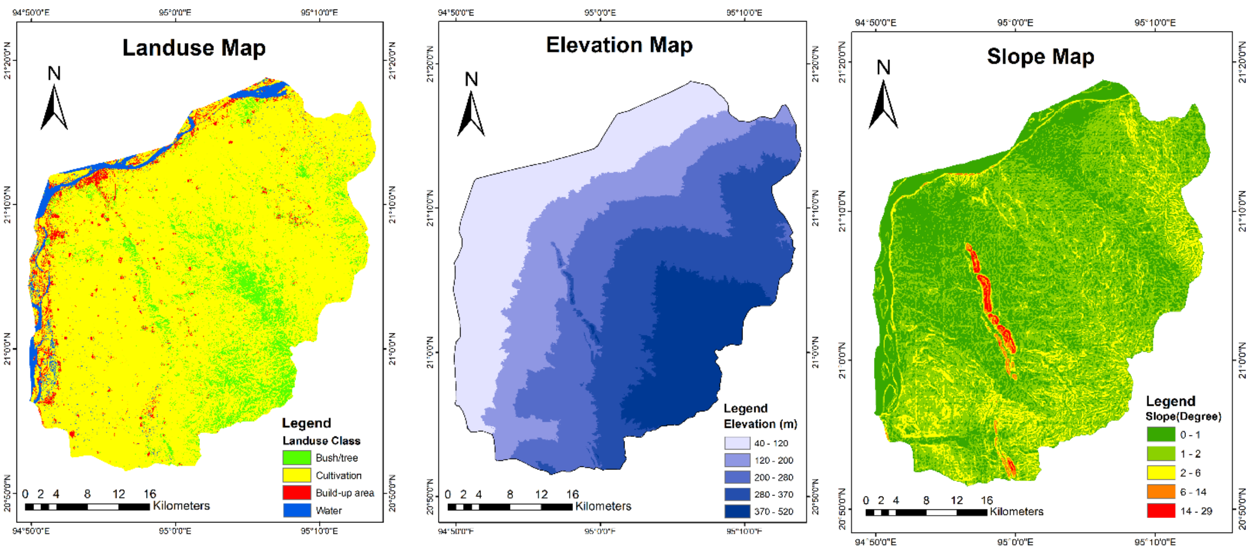
The natural and artificial drainage lines were digitized from the topographic map with a scale of 1:250000. The following formula was used to create the drainage density map in ArcGIS.

$$\text{Drainage Density} = Drainage\ length(km)/Area\ ward(km)^2 \qquad (1)$$

The classification method was Natural Breaks (Jenks). Finally, the drainage density map was reclassified in five classes (Fig.3g).

4.2.7 Flood depth map

HEC-RAS is one of the widely applied hydraulic models in the flood studies [28]. In this study, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with 30 m resolution data was used as input data to generate a watershed and drainage network in HEC-GeoRAS. The river channel, bank stations (left and right), flow paths, and cross-section cutline were prepared in HEC-GeoRAS and exported to the HEC-RAS model. The return periods 10 and 100 year of flood peak were used as an input to the HEC-RAS model to simulate results for each cross-section. Finally, flood inundation area and flood depth were generated in a GIS environment. The hazard level is determined by reclassifying the flood depth into five categories: 0-1, 1-2, 2-3, 3-5 and > 5(Fig.3h and 3i).



(a) (b) (c)

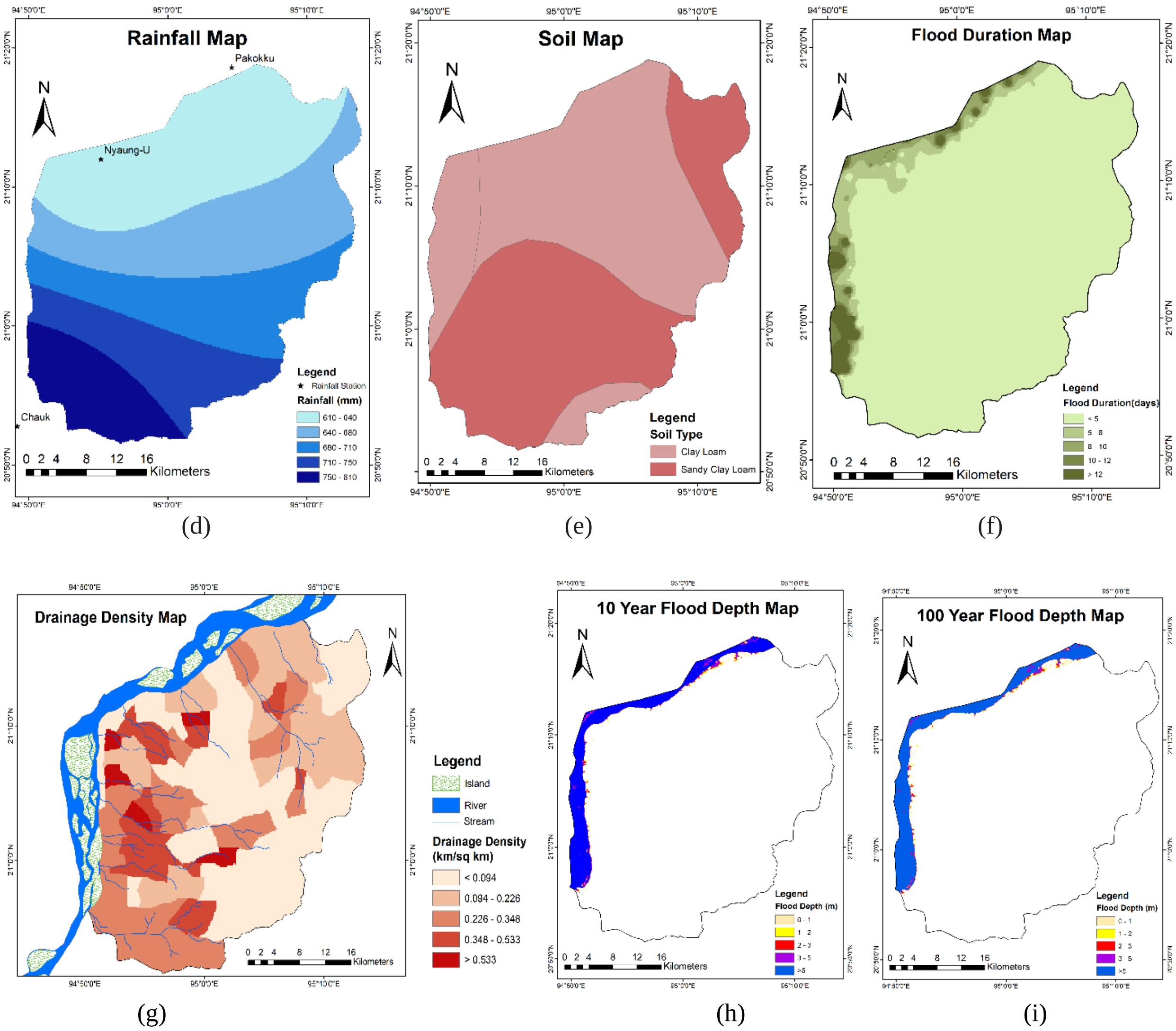


Fig. 3. Flood hazard related factors in the study area: (a) Land use; (b) Elevation; (c)Slope; (d) Rainfall; (e)Soil (f) Flood duration (g) Drainage density(h) 10-year flood depth (i) 100-year flood depth.

4.3 Flood Hazard Weighting Using Analytical Hierarchical Process (AHP)

Analytical hierarchy process (AHP) is a semi-qualitative method, which involves a matrix-based pairwise comparison of the contribution of various factors for flooding. Saaty (1980) developed it. Factor weights for each criterion are determined by a pairwise comparison matrix as described by [29],[30]. Firstly, to get factor weights in AHP, one has to build a pairwise comparison matrix with scores 1 to 9. In a pairwise comparison matrix, each factor objected to every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell.

When the factor on the vertical axis is more important than the factor on the horizontal axis, this value varies between 1 and 9.

In this study, the pairwise comparison matrix was created as 8 x 8 matrix using flood hazard factors namely land use, elevation, slope, soil, rainfall, flood depth, flood duration, and drainage density. Secondly, relative important weights for each factor are calculated. The result of the relative important weights is shown in table (2). Finally, consistency ratio CR need to calculate for the 8 x 8 matrix. In AHP, the consistency used to build a matrix on the number of parameters for an 8 x 8 matrix, the CR must be less than 0.1 to accept the computed weights. In this study, the CR value is 0.032. The weighted flood hazard ranking for the study area is shown in table (3).

Table 2. Relative Weights for Flood Hazard using AHP

Factors	Flood depth	Flood duration	Land use	Soil	Drainage density	Rainfall	Elevation	Slope	Weight
Flood depth	0.28	0.38	0.28	0.26	0.26	0.17	0.27	0.24	0.2706
Flood duration	0.14	0.19	0.28	0.26	0.18	0.25	0.16	0.17	0.2060
Land use	0.14	0.10	0.14	0.18	0.18	0.17	0.16	0.14	0.1504
Soil	0.09	0.06	0.07	0.09	0.18	0.08	0.11	0.10	0.0989
Drainage density	0.09	0.10	0.07	0.04	0.09	0.17	0.11	0.10	0.0970
Rainfall	0.14	0.06	0.07	0.09	0.04	0.08	0.11	0.10	0.0883
Elevation	0.06	0.06	0.05	0.04	0.04	0.04	0.05	0.10	0.0571
Slope	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.03	0.0318
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0000

4.4 Creation of Flood Hazard Map by combining Hazard Weighting in GIS

The flood hazard index map was developed the combination of hazard weight using the following equation

$$\text{FHI} = \sum_{i=1}^{n}(r_i . w_i) \quad (2)$$

where r_i is the rating of the parameter in each point; w_i is the weight value of each factor, n is the number of factors.

Using the FHI, the study area was finally classified into five hazard categories ranging from very low to very high. (Fig.5a and 5b).

4.5 Flood Vulnerability Analysis

For the Vulnerability analysis, six factors of population density, land use, gender ratio, age ratio, urban and rural and road density factors were considered. Firstly, these six factors were used for input in GIS to create the map and reclassify into five classes. Finally, the Analytical Hierarchical Process (AHP) was used to calculate flood vulnerability weight and index for six factors.

4.5.1 Population Density map

The demographic data were used to calculate the population density of each ward. The population density was classified into five classes using a natural break (Jenks) method in GIS. The final map was reclassified into different five classes, which are very low, low, moderate, high and very high (Fig.4a).

4.5.2 Land use map

Landsat 8 OLI satellite image of December 2018 was used to classify the land use layer using a supervised classification method in ArcGIS. The image was at a spatial resolution of 30 m. The four land use classes were classified; cultivation, water body, buildup area and bush/tree. The reclassification method of land use for the vulnerability was determined to be affected in terms of economic and infrastructure loss. Base on the vulnerability range the final map was reclassified into five classes namely very low, low, moderate, high and very high Fig.4b.

4.5.3 Gender ratio and Age ratio map

The gender ratio and age ratio of each ward is considered based on the classification of vulnerability. The gender ratio is the ratio of total female to the total male of each ward. Women are generally more vulnerability to natural hazards than men [31]. The young and elderly people are vulnerable to natural hazards. Gender ratio and age ratio was classified into five classes using a natural break (Jenks) method in GIS. The final map was reclassified into different five classes, which namely very low, low, moderate, high and very high (Fig.4c and 4d).

4.5.4 Urban and rural map and road density map

Each urban and rural and road were digitized from topographic map. The urban and rural was classified into two classes. Urban is more vulnerability than rural area as the population growth and lack of drainage in an urban area, etc. Thus the vulnerability score in urban was higher than rural. Then, the vulnerability classes were divided into 5 classes for road density using natural break (jenk) classification method (Fig.4e and 4f). The lower road density the more vulnerability will be in the study area.

4.6 Flood Vulnerability Weighting using Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) method was used to calculate the weight value for each flood vulnerability factors which namely land use, population density, gender ratio, age ratio, road density and, urban and rural. Table (4) indicates the result of the Relative Importance Weights (RIW). CR value is 0.026. The weighted flood vulnerability ranking for the study area is shown in table (5).

Table 3. Weighting and rating value of each parameter for the flood hazard map

Factor	Weight	Hazard Rating Value	
		Description	Rating
1.Flood depth(m)	0.2706	> 5	Very High (5)
		3 - 5	High (4)
		2 - 3	Moderate (3)
		1 - 2	Low (2)
		0 - 1	Very Low (1)
2.Flood duration(Day)	0.2060	>12	Very High (5)
		10 - 12	High (4)
		8 - 10	Moderate (3)
		5 - 8	Low (2)
		< 5	Very Low (1)
3.Landuse	0.1504	Water	High (4)
		Build-up area	Moderate (3)
		Cultivation	Low (2)
		Brush/tree	Very Low (1)
4.Soil	0.0989	Sandy Clay Lom	High (2)
		Clay Lom	Low (1)
5.Drainage density(km/ km^2)	0.0970	> 0.533	Very High (5)
		0.348 - 0.533	High (4)
		0.226 - 0.348	Moderate (3)
		0.094 – 0.226	Low (2)
		< 0.094	Very Low (1)
6.Rainfall(mm)	0.0883	> 750	Very High (5)
		710 - 750	High (4)
		680 - 710	Moderate (3)
		640 - 680	Low (2)
		< 640	Very Low (1)
7.Elevation(m)	0.0571	40 - 120	Very High (5)
		120 - 200	High (4)
		200 - 280	Moderate (3)
		280 - 370	Low (2)
		370 - 520	Very Low (1)
8.Slope(Degree)	0.0318	0 - 1	Very High (5)
		1 - 2	High (4)
		2 - 6	Moderate (3)
		6 - 14	Low (2)
		14 - 29	Very Low (1)

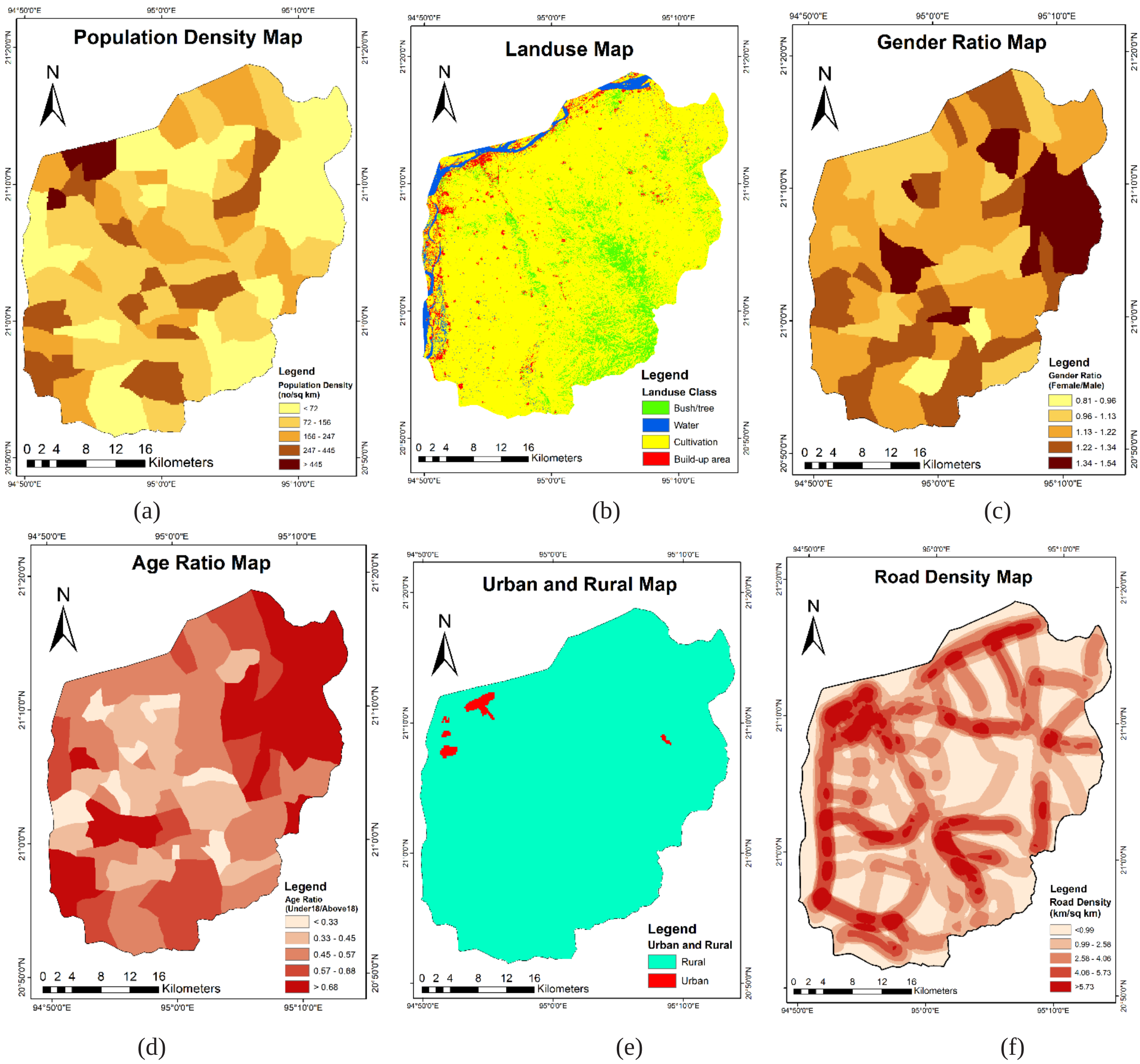


Fig. 4. Flood vulnerability related factors in the study area: (a)Population Density; (b) Land use; (c) Gender Ratio; (d) Age Ratio; (e)Urban and Rural; (f)Road Density

Table 4. The outputs of the Relative Importance Weights (RIW) using AHP model

Factors	Land use	Population density	Gender ratio	Age ratio	Road density	Urban and rural	Weights
Land use	0.34	0.43	0.38	0.29	0.32	0.23	0.3305
Population density	0.17	0.21	0.25	0.29	0.24	0.23	0.2320
Gender ratio	0.11	0.11	0.13	0.14	0.16	0.15	0.1339
Age ratio	0.17	0.11	0.13	0.14	0.16	0.15	0.1434
Road density	0.09	0.07	0.06	0.07	0.08	0.15	0.0875
Urban and rural	0.11	0.07	0.06	0.07	0.04	0.08	0.0728
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.0000

Table 5. Weighting and rating value of each parameter for flood vulnerability map

Factor	Weight	Vulnerability Rating Value	
		Description	**Rating**
1.Landuse	0.3305	Build-up area	High (4)
		Cultivation	Moderate (3)
		Water	Low (2)
		Brush/tree	Very Low (1)
2.Population Density(no./km^2)	0.2320	> 445	Very High (5)
		247 - 445	High (4)
		156 - 247	Moderate (3)
		72 - 156	Low (2)
		< 72	Very Low (1)
3.Gender ratio (Female/Male)	0.1339	> 1.34	Very High (5)
		1.22 - 1.34	High (4)
		1.13 - 1.22	Moderate (3)
		0.96 - 1.13	Low (2)
		< 0.96	Very Low (1)
4.Age ratio (Under18/Above18)	0.1434	> 0.68	Very High (5)
		0.57 - 0.68	High (4)
		0.45 - 0.57	Moderate (3)
		0.33 - 0.45	Low (2)
		< 0.33	Very Low (1)
5.Road Density (km/km^2)	0.0875	< 0.99	Very High (5)
		0.99 - 2.58	High (4)
		2.58 - 4.06	Moderate (3)
		4.06 - 5.73	Low (2)
		> 5.73	Very Low (1)
6.Urban and rural	0.0728	Urban	High (2)
		Rural	Low (1)

4.6 Flood Vulnerability Weighting using Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) method was used to calculate the weight value for each flood vulnerability factors which namely land use, population density, gender ratio, age ratio, road density and, urban and rural. Table (4) indicates the result of the Relative Importance Weights (RIW). CR value is 0.026. The weighted flood vulnerability ranking for the study area is shown in table (5).

4.7 Creation of Flood Vulnerability Map by combining Vulnerability Weighting in GIS

The flood vulnerability index map was produced the combination of vulnerability weight using the following equation

$$\text{FVI} = \sum_{i=1}^{n} (r_i \cdot w_i) \quad (3)$$

where r_i is the rating of the parameter in each point, w_i is the weight value of each parameter and n is the number of the factors.

Using the FVI, the study area was finally classified into five hazard categories ranging from very low to very high. (Fig.6).

4.8 Flood Risk Mapping

Flood risk is a function of flood hazard and flood vulnerability. To create the flood risk map of the study area the function of flood hazard and flood vulnerability were done by multiplying in ArcGIS. The following equation was used to generate the flood risk map of Nyaung-U Township in the raster calculator of ArcGIS.

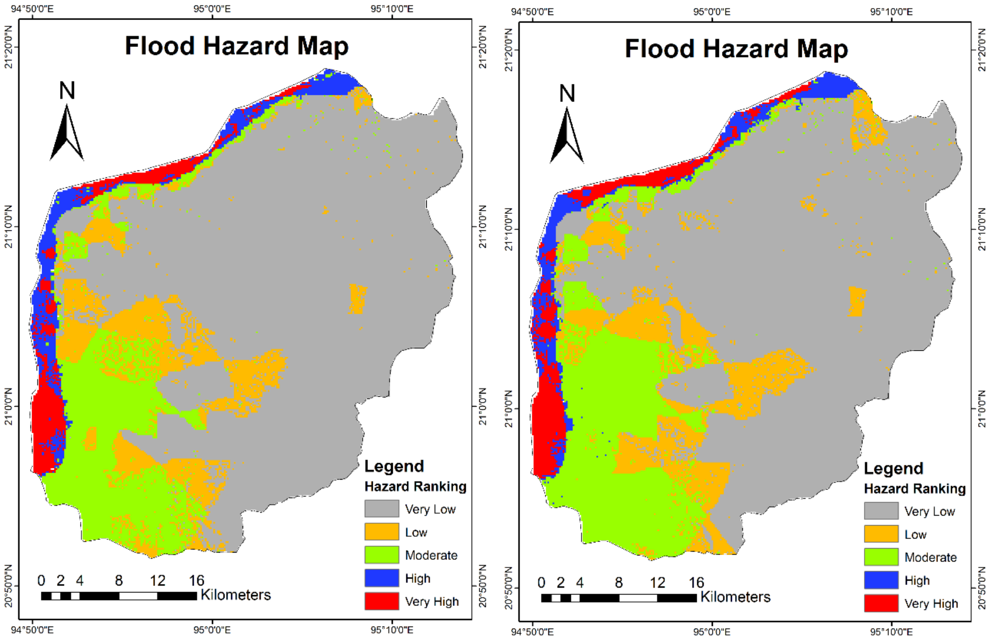
$$\text{Risk Map} = \text{Hazard Map} \times \text{Vulnerability Map} \quad (4)$$

Finally, the risk map was classified into five levels: very low, low, moderate, high and very high (Fig.7a and 7b).

5. RESULTS AND DISCUSSION

5.1 Flood Hazard

Flood hazard maps were generated for Nyaung-U Township. Flood-prone areas were evaluated based on the 8 related hazard factors namely land use, elevation, slope, rainfall, soil, flood duration, drainage density and flood depth. Then, the hazard ranking was assigned into five classes from very low to very high class. The 10-year flood hazard result showed that the high and very high flood hazard areas located along the river with the area of 55.78km^2 and 48.89km^2 respectively. While the moderate and low flood hazard areas located along the river and southern part of the study area with the areas of 210.62km^2 and 169.68km^2 respectively. The very low area was distributed central part, the northern and eastern part of the study area with the area of 974.03km^2. The 100-year flood hazard result shows that high and very high regions were concentrated along the river and both areas were 51.76 km^2 and 59.60 km^2 respectively of the total area while moderate area was along the river and southern part of the study area with the area of 260.65 km^2. The low area was along the river, southern and northern part of the study area and that area was accounting for 182.94 km^2. The very low area was located mostly central part, northern and eastern part of the study area.



(a) (b)

Fig. 5. (a) 10 year return period flood hazard map,(b) 100 year return period flood hazard map of Nyaung-U Township.

5.2 Flood Vulnerability

Flood vulnerability map was generated for Nyaung-U Township based on the six factors; land use, population density, gender ratio, age ratio, urban or rural and road density. Then, the vulnerability ranking was assigned into 5 classes from very low to very high class. The flood vulnerability result showed that the very high flood vulnerability areas located mostly along the river, northeastern and southern part of the study area with the area of 173.67km^2. High vulnerability regions were distributed mostly southern, northern and northeastern part of the study area with the area of 477.19km^2. Moderate, low and very low flood vulnerability zones were 377.07, 335.02 and 95.05 km^2 of the total area of the Nyaung-U Township.

5.3 Flood Risk Assessment

The result of flood risk map by the 10-year return period indicates that Nyaung-U, Kya Oh, Mee Laung Pyar, Sint Ku and Let Pan Chay Paw were the very high flood risk zone with the area of 14.21 km^2. The very high flood risk zones were located along the river and near riverbanks. The high flood risk zones were located along the river and near riverbanks with the areas of 21.98 km^2. The moderate risk regions were mostly along the river with the areas of 63.71 km^2. The region with the low risk was mostly near the river and southern part of the area accounting for 229.89 km^2 and expect near riverbanks and southern part other regions were very low risk, accounting for 1129.21 km^2.

The very high and high-risk regions in the 100-year return period were concentrated near, or along the river of the study area and the two areas account for 16.26 km^2 and 24.70 km^2 respectively. The area of moderate risk was 69.86 km^2 and distributed near, or along the river. The low-risk regions were concentrated the whole area of the Nyaung-U township expect the central part, eastern and northeastern region. The area accounts for 406.15 km^2 of the study area. The very low-risk area distributed mostly in the central and eastern parts of the study area, accounting for 942.04 km^2. In the 100-year return period, the areas of high and very high risk were more increase to 2.72 km^2 and 2.04 km^2 than the 10 year return period.

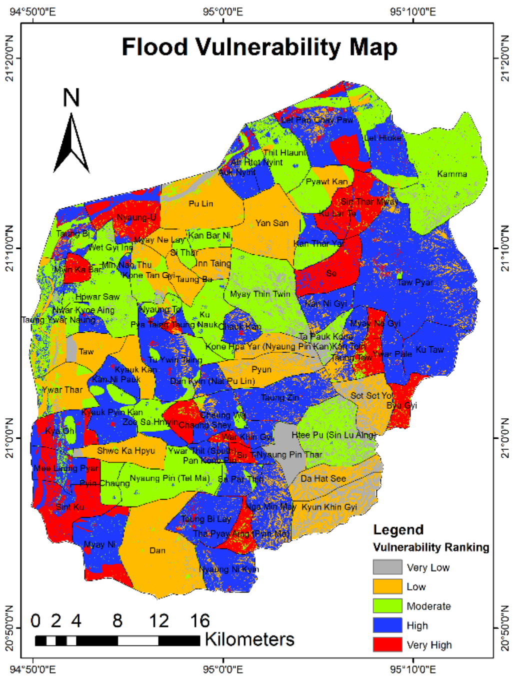


Fig. 6. Flood Vulnerability map of Nyaung-U Township.

6. CONCLUSION

In this study, the analytical hierarchy process (AHP), GIS and HEC-RAS model were applied to develop flood hazard, vulnerability and risk map for the Nyaung-U Township in the central Myanmar. To focus this objective, eight inducing flood hazard factors of land use, elevation, slope, rainfall, soil, flood duration, drainage density and flood depth, and six inducing flood vulnerability factors of land use, population density, gender ratio, age ratio, urban or rural and road density, were taking into consideration. The results of flood hazard map in 10 and 100-year return period illustrate that the high and very high hazard zone were located near and along the river, while the moderate hazard zone was located along the river and southern and southwestern part of the study area. The low and very low regions were located mostly in the central part, southeastern, the eastern and northern parts of the study area.

The flood vulnerability result showed that the very high flood vulnerability areas located mostly along the river, northeastern and southern part of the study area with the area of 173.67 km2. The results of the final risk map in the 10 and 100-year return period showed that the areas of high and very high-risk zones were located at near and along the river in the western part of the study area. The results in this study can provide valuable information to the decision-maker for the flood hazard and risk management in Nyaung-U Township. The satellite image with high resolution 1 m or 5 m should be used to improve the results for the future work. The more factors also may be considered if the required data are available for the flood risk assessment. Moreover, the techniques applied in this study can used to other areas.

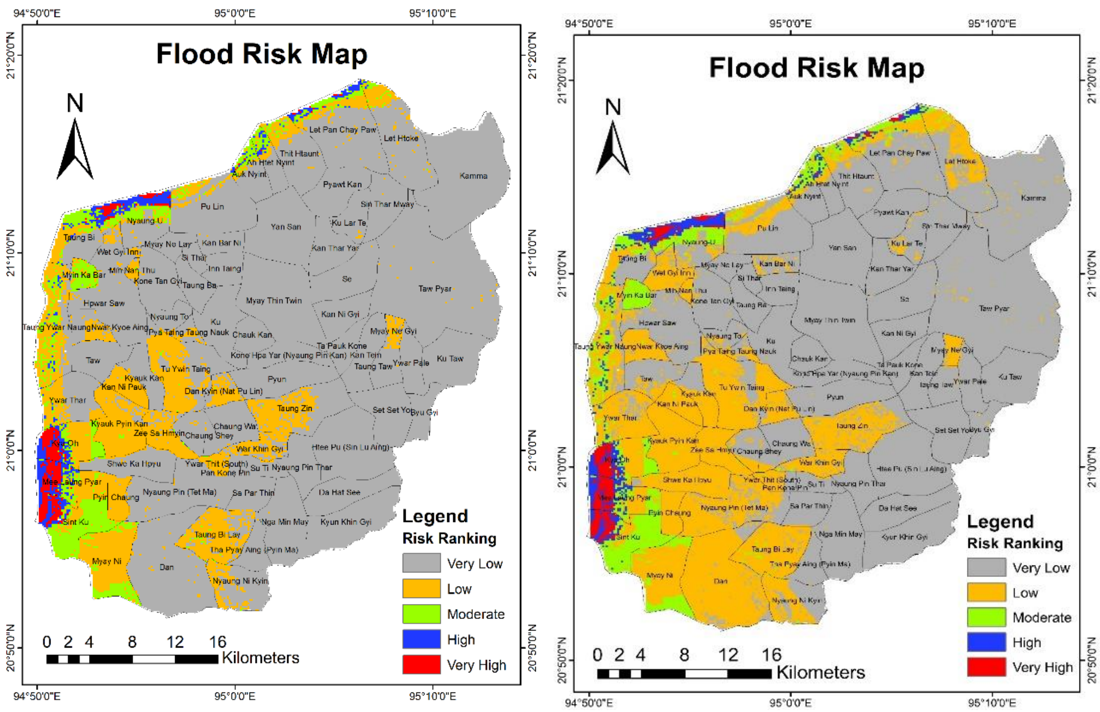


Fig.: 7. (a) 10-year return period flood risk map, (b) 100-year return period flood risk map of Nyaung-U Township.

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