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Suan Sunandha Science and Technology Journal

Flood hazard mapping using hydraulic model and GIS: a case study in Mandalay city, Myanmar

Kyu Kyu Sein[1*], Thida Myint[1]

[1]Department of Meteorology and Hydrology, Ministry of Transport
Office No.5, Ministry of Transport, Nay Pyi Taw, Myanmar

Corresponding author E-mail: *sein.dmhmdy@gmail.com

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Abstract: This paper presents the use of flood frequency analysis integrating with 1D Hydraulic model (HEC-RAS) and Geographic Information System (GIS) to prepare flood hazard maps of different return periods in Ayeyarwady River at Mandalay City in Myanmar. Gumbel's distribution was used to calculate the flood peak of different return periods, namely, 10 years, 20 years, 50 years, and 100 years. The flood peak from frequency analysis were input into HEC-RAS model to find the corresponding flood level and extents in the study area. The model results were used in integrating with ArcGIS to generate flood plain maps. Flood depths and extents have been identified through flood plain maps. Analysis of 100 years return period flood plain map indicated that 157.88 km^2 with the percentage of 17.54% is likely to be inundated. The predicted flood depth ranges varies from greater than 0 to 24 m in the flood plains and on the river. The range between 3 to 5 m were identified in the urban area of Chanayetharzan, Patheingyi, and Amarapua Townships. The highest inundated area was 85 km^2 in the Amarapura Township.

Keywords: Flood Frequency, HEC-RAS, Flood Hazard, Return Period, GIS

1. Introduction

Myanmar is one of the vulnerability to climate change impacts in terms of extreme temperature, severe drought, cyclones, floods, heavy rainfall and less precipitation, landslides, earthquakes and tsunami. Flooding is the second largest natural disaster after a fire, which is facing every year in Myanmar (Union of Myanmar, 2009). Flooding is negatively impacting on social economy, loss of lives and properties, health related problems, and ecosystem functions. In Myanmar, there are two types of flood; widespread flood and flash flood which mainly occur in the month of July, August and late September to October in each year (DMH, 2004). The maximum flood peak can be seen in August due to evidence of peak monsoon rains. The main cause of river flooding is the occurrence of intense rainfall during the monsoon season in the northern part and eastern part of Myanmar, which are the upstream of the rivers (DMH, 2010). According to the historical data from DMH, the percentages of occurrence of floods which exceeded the danger level in medium and large rivers of Myanmar are 6% in June, 23% in July, 49% in August, 14% in September and 8% in October (Aye Ko, 2006). The floods of 2015, 2004, 1974, 1997, 1991, 1973, and 1988 (years are arranged with respect to their intensities) verify their devastating nature and destructive impact on infrastructure in Myanmar (Sein, 2012).

In 2015, Myanmar experienced in unexpected big floods affecting the entire country. A total of 69 people have been killed and over 259,000 people, including 88,000 children, 39,474 households were affected, more than 4046.85 km^2 of farmland were inundated, with some 2104.36 km^2 were damaged across 12 of Myanmar's 14 States and Regions since the monsoon onset rains in June (UNOCHA, 2015). Due to this phenomenon, it is necessary to evaluate flood hazard assessment in order to know how much would be inundated and destroyed if a particular hazard occurs.

One of the widely used models of analysis, flood plain delineation is the HEC-RAS hydraulic model developed by the US Army Corps of Engineers. This model results give to determine the extent of inundation, and flood depth (Brunner and Bonner, 2010). The combination with HEC-RAS model and GIS environment allow to analyze and visualize of floodplain management and accessing the changing of water surface profile (Brunner and Bonner, 2010; Shahzad, et al., 2015). Moreover,

Suan Sunandha Science and Technology Journal

GIS environment performs as the effective planning tool to export data result from HEC-RAS model to floodplain management, damage analysis, and flood early warning systems (Tate and Maidment, 1999). The input parameters to HEC-RAS models are river discharge, channel, flood plain geometry, and channel resistance. The objective of this study intends to delineate a flood hazard map in the Ayeyarwady River at Mandalay city in Myanmar by integrating 1D hydraulic model and GIS environment in order to provide decision makers and relevant agencies to protect flood disaster.

2. Reviews of past flood in Mandalay city

In 2004, the flood has occurred a result of intense rainfall in the upper portion of the Ayeyarwwady River. The highest recorded water level of Ayeyarwady River was 1382 cm during the study period 1968-2010 and it exceeded 122 cm above danger level. The people living, in near the river have been moving out of their homes and staying in refugee camps located on higher place. The agricultural areas of 122.68 km^2 were damaged out of 329.90 km^2 were inundated (DMH, 2004).

In 2006, flooding was facing two times. In September it was tropical cyclone in the South China Sea and low pressure in the Bay of Bengal that caused heavy continuous rains in the study area. Heavy rains continued throughout 2nd September to 30th September and accumulated 450 mm of rainfall which was the half of the normal annual rainfall recorded in the past 60 years. Therefore, the local drainage system cannot control the excess amount of higher surface runoff and overflow to the surrounding area. As the result, at least 20 people were killed and 4000 people left their home. The second flooding in October was due to the overflowing of Myitnge River. The highest recorded water level of Myitnge River was 1048 cm during the study period and it exceeded 178 cm above danger level (DMH, 2006).

In 2010 and 2011 flood were not totally related with River flooding. The urban area such as Aungpinlay, Aungtharyar, Thamankhone, Kywesakan, Nyaung Kawe and Patheingyi area were flooded caused by torrential rain during the month of October. These floods destroyed thousands of homes, 3,000 people had to leave their homes, and 10 people including 7 children were killed, and almost 2,000 people got injuries (DMH, 2010 and 2011).

3. Materials and Method

3.1 Study area

Mandalay city is situated in the Mandalay region of the central component of Myanmar latitude of 21º 45'- 22º 10' N and longitude of 96º 00'- 96º 21' E. It lies on the eastern bank of the Ayeyarwady River. The study area covers an area of about 900 km^2 with 7 townships namely Aungmyaetharzan, Chanayetharzan, Chanmya-tharzi, Mahaaungmyae, Pyigyitagon, Amarapura and Patheingyi (Figure 1).

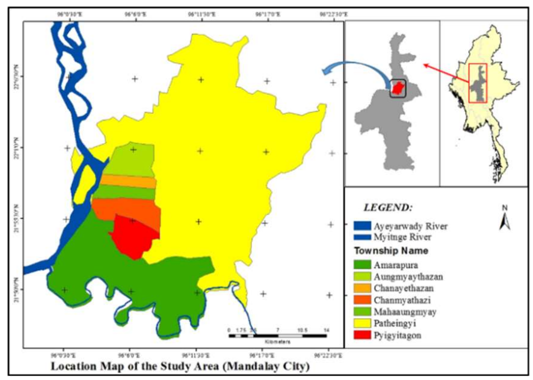

Figure 1. Location map of Mandalay city

Among the 7 townships, most part of the area of Amarapura and Patheingyi or rural area which has more than 4.04 km^2 of farmland and the remaining 5 townships are urban area. The lowest elevation range can be seen in and around Ayeyarwady River, western part of the city and the highest elevation is the eastern part of the city which has mountains. As Mandalay is the second largest city as same as the population. The climate in the study area is normally hot and dry climate and annual rainfall of 500 mm to 1500 mm. The normal rainfall is 811 mm. The pattern of rainfall distribution throughout the year is two peaks, once in May and the other in September due to the influence of monsoon onset and withdraw. The Ayeyarwady River and one of its tributaries, Myitnge River is passing through in the study area. The original of the Ayeyarwady River is Tibetan Plateau and the total catchment area is 2,445,434 km^2 and its length is about 1600 km from origin to its river mouth (DMH, 2004). The catchment area of Ayeyarwady River in Mandalay is 120,190 km^2 with

Suan Sunandha Science and Technology Journal

maximum discharge 30216 m^3/sec while Myitnge River in Mandalay is 27,904 km^2 with maximum discharge 665 m^3/sec. During the study period 1968-2010, the flood was observed in 12 years in the Ayeyarwady River with maximum peak in August and 36 years in Myitnge River with maximum peak in July (Aye Ko, 2006). The comparison between monthly mean rainfall and water level of the two rivers are shown in figure (Figure 2). Rainfall peak and water level peak are different since local rain is not affected in the study area. Most of the flood in the study area is mainly related to upstream rain effects.

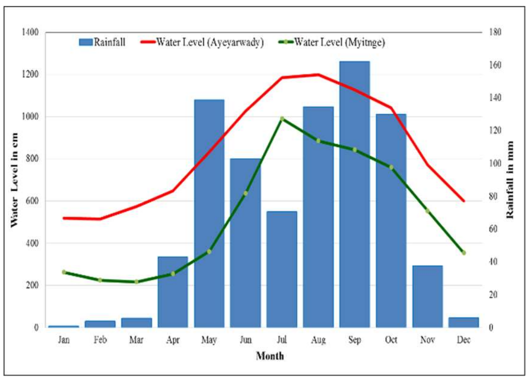

Figure 2. Monthly highest water level of two rivers compared with monthly maximum rainfall in the study area

3.2 Data

Annual maximum water level and peak discharge data of 1968 – 2010 were collected from the Department of Meteorology and Hydrology to calculate the different return periods of 10 years, 20 years, 50 years, and 100 years. The 30 m resolution of Advanced Space borne Thermal Emission and Radiometer (ASTER) Digital Elevation Model (DEM) (Figure 3) was freely downloaded from the website gdem.ersdac.jspacesystem.or.jp in order to extracts basin geometry, stream networks, river geometry, Triangular Irregular Network (TIN), and flow direction. The UTM 50,000 scale topographic maps were collected from the Mandalay City Development Committee to digitize the study area and drainage system.

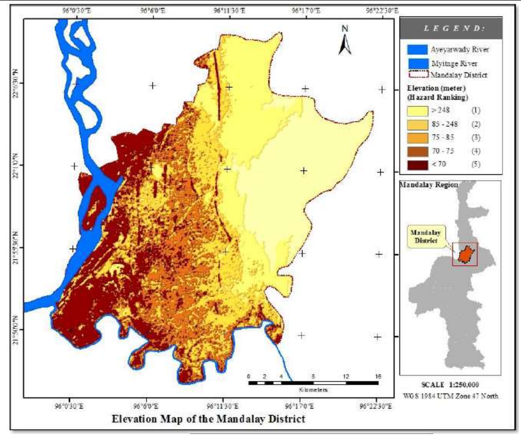

Figure 3. Elevation range in the study area

3.3 Method

3.3.1 Flood frequency analysis

The Gumbel's distribution method was used to analyze the extreme values of different return periods of 10 years, 20 years, 50 years and 100 years using observed discharge data. In this method the variate X (maximum rainfall or flood peak discharge) with a recurrence interval T is given by (Subramanya, 1994);

$$x_T = \bar{x} + K\sigma_{n-1} \quad (1)$$

Where, x_T = maximum rainfall or flood peak discharge or water level

$\bar{x}$ = average value of x

σ_{n-1} = standard deviation of sample size N

$$\sigma_{n-1} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}} \quad (2)$$

K = frequency factor expressed as

$$K = \frac{y_T - \bar{y}_n}{S_n} \quad (3)$$

y_T = reduced variate, a function of T and is given by

$$y_T = -\left[\ln . \ln \frac{T}{T-1}\right] \quad (4)$$

$\bar{y}_n$ = reduce mean, a function of sample size N

S_n = reduce standard deviation, a function of sample size N

3.3.2 Flood plain analysis using HEC-RAS and GIS

Suan Sunandha Science and Technology Journal

ASTER DEM was used as input data to generate watershed and drainage network in HEC-GeoRAS. The channel, bank stations, flow direction and cross section cutlines were prepared in HEC-GeoRAS and exported to HEC-RAS model. Upstream (Thabeikkyin) and Downstream (Sagaing) stations of Mandalay were selected for flow input data. The different return periods of flood peak were obtained from Gumbel's and used as an input to HEC-RAS model in order to simulate results for each cross section.

At the same time, water surface profiles were running in the model for 10, 20, 50 and 100 years flood. After running input data in HEC-RAS model, the result outputs were exported to ArcGIS in the format of RAS GIS Export file. The RAS GIS Export File was imported into ArcGIS after generating water surface and flood plain delineation. ArcGIS was used to generate flood depth and inundation mapping for different return periods. The overall methodology flow chart is shown in (Figure 4).

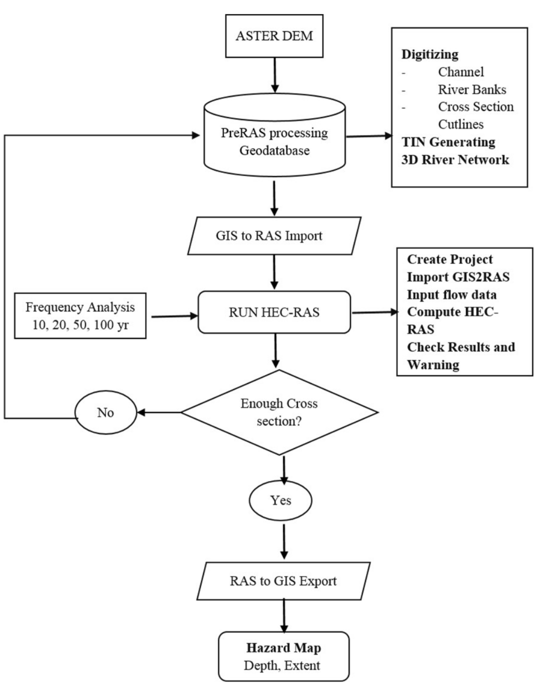

Figure 4. Methodology flow chart for flood hazard mapping

4. Results and Discussion

Flood hazard maps for the different return periods of 10, 20, 50, 100 years were conducted using the annual peak flow of 43 years from 1968 to 2010. The maximum discharges at upstream and downstream for different periods were obtained using Gumbel's distributions (Table 1).

Table 1. Peak Discharge Data of Upstream and Downstream

Return Periods (Years)	Upstream		Downstream	
	Flow (m^3/s)	Water Level (m)	Flow (m^3/s)	Water Level (m)
10	25194	82.39	31037	69.94
20	27008	83.06	33390	70.34
50	29356	83.87	36309	70.76
100	31116	84.43	38495	71.14

Although the different return periods, namely 10, 20, 50, and 100 years flood plain maps were generated, but only the 100 years flood plain maps are presented for Mandalay city (Figure 5). Since peak flow of 100 years recurrent interval is much higher and more reliable than the other recurrent interval. The model results showed that 17.54% area is predicted to be inundated under 100 years return period (Table 2) under different flood depths. The depths range in 100 years flood varies from greater than 0 to 24 m in the flood plains and on the river. The affected area under various flood depths is shown in (Figure 6). The total inundated area in Mandalay is 157.88 km^2.

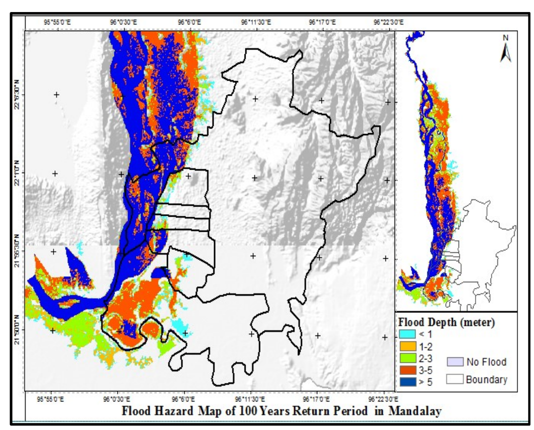

Figure 5. 100 years flood hazard map I Mandalay City

Table 2. Percentage flood affected area for 100 years return period flood

	100 years

Suan Sunandha Science and Technology Journal

Water Depth (m)	Flood Area (km^2)	% of flood effected Area
< 1	14.30	1.59
1-2	9.92	1.10
2-3	10.52	1.17
3-5	53.64	5.96
> 5	69.50	7.72
Total	157.88	17.54

The maximum area was inundated from a flood depth of greater than 5 m follow by 3 to 5 m (Figure 7). Flood at a depth of greater than 3 m is sufficient to cause a maximum damage to any households if it stays for a longer period. It is also can be seen that Amarapura township is mostly affected with an area of inundation of 85 km^2, followed by Patheingyi with 52 km^2, Pyigyitagon with 7 km^2, Aungmyae-tharzan with 6 km^2, Chanmyatharzi and Mahaaungmyae with 4 km^2, and Chanayetharzan with 1 km^2. Furthermore, the flood depths between 3 to 5 m were observed in Chanayetharzan, Patheingyi, and Amarapua while more than 5 m were seen in and around the river. The rest townships were inundated with the depth of 1 to 3 m respectively.

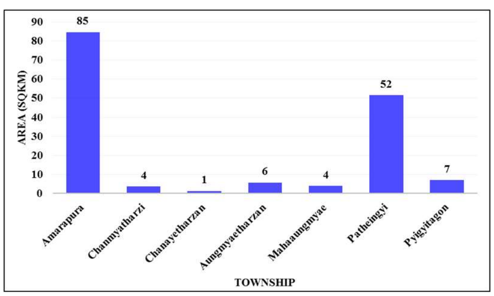

Figure 6. Flooded area in each Township

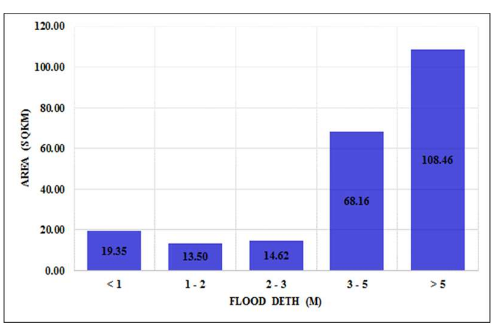

Figure 7. Depth of flooded area

5. Conclusion

The HEC-RAS hydraulic model allowed to simulate the flood hazard mapping at the Ayeyarwady River at Mandalay city. HEC-GeoRAS environment is a useful tool as pre-processing for the visualization of the hydraulic model. Integrating flood frequency analysis, HEC-RAS, and GIS outputs allow to generate flood depth and inundated area of a given catchment. The advantage of HEC-RAS software is available to freely download at HEC-RAS website. However, the efficiency of the model using the ASTER DEM were not as good as the very high resolution for the reason of coarser resolution. Moreover, this study has limitation in accuracy assessment due to lack of field data. It is important and necessary to use field data to validate the model in order to define the accuracy of results. The model output indicated 100 years return periods flood depth varies greater than 0 to 24 m and the total inundated area is 157.88 km^2 with the maximum area under flood was 3 to 5 m in Mandalay. Amarapura is the highest affected area with an inundation of 85 km^2 followed by Patheingyi, Pyigyitagon, Aungmyaetharzan, Chan-myatharzi, Mahaaung-myae, and Chanayethar-zan township. Results from the flood hazard map will be useful in flood management, flood disaster preparedness and mitigation planning.

6. Acknowledgements

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