AN APPLICATION OF HEC-RAS MODEL AND GEOGRAPHIC INFORMATION SYSTEM ON FLOOD MAPS ANALYSIS: CASE STUDY OF UPPER YOM RIVER

Sutthipat Wannapoch* (1), Sarintip Tantanee (1), Sombat Chuenchooklin (1), Kamonchat Seejata (1), Weerayuth Pratoomchai (2)

[1] Department of Civil Engineering, Naresuan University, Phitsanulok, Thailand.
[2] Department of Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand.

*Presenting author: Sutthipat Wannapoch; E-mail: sutthipat.wp@gmail.com
Corresponding author: Sarintip Tantanee; E-mail: stantanee@gmail.com

KEYWORDS: HEC-RAS, Geographic Information System, Flood Hazard, Flood Vulnerability, Upper Yom River.

ABSTRACT: Most important disaster in Thailand is the flood, which frequently occurs and causes widespread losses in both properties and lives. Yom river basin is one of the basin in Thailand which is a narrow stream without regulated dam in upstream. Therefore, during rainy season, these area often suffer from flood. Phrae province where locate in a flood-prone area of upper Yom river basin have faced with flood almost every year. To manage the disaster situations, the approaches to assess the flood susceptible areas and the extent of disaster impact are the challenging tasks. This study aimed to develop flood hazard map, flood vulnerability map, and flood risk map along Yom river in Phrae province by using hydrological model of HEC-RAS and a set of procedures of HEC-GeoRAS for processing geospatial data in Geographic Information System (GIS). The model was calibrated using the rainfall observation data during flood seasons from 2007 to 2016. Then, the results of flood hazard map around the mainstream of the river indicated that 45.87%, 29.55%, 13.47%, 9.65% and 1.46% of the studied area are very low, low, moderate, high, and very high flood hazard class, respectively. The result of flood vulnerability map indicated that 11.35%, 2.37%, 27.97%, 25.69% and 32.62% of the studied area are very low, low, moderate, high, and very high flood vulnerability class, respectively. Then, the obtained flood risk map around the mainstream of the river indicated that 1.39%, 44.50%, 30.04%, 13.18% and 10.89% of the studied area are very low, low, moderate, high, and very high flood risk class, respectively over the studied area.

1. INTRODUCTION

The most serious and frequent disaster in Thailand is flooding during the monsoon season. Main cause of flooding in Thailand is heavy rain in monsoon season, overloaded capacity of dam and river. Geographical characteristics of Northern Thailand is mountainous area, when there is heavy rain the water flow from northern river such as Ping, Wang, Yom, Nan to Chaopraya river, flood-plain area which is central area (flood care Thailand, 2011).

Instance of floods in 2011 by heavy rain from monsoons in July, it impacted a total of 4,039,459 households and 13,425,869 people; 2,329 houses were destroyed; 96,833 houses were partially damaged; around 657 people died;

and 3 were reported missing. According to the Word Bank damage worth of around THB 1,440 billion were estimated (Thai Water, 2012).

Flooding in Yom river is the most natural hazard in northern Thailand. Due to the geographical location is a narrowed path in the upper part, the Yom River receives a large of rainfall during flood season. This causes flooding almost every year in the Phrae flood plain, which is located near the mainstream of the upper Yom river. Thus, the large amount of water directly flows into the Phrae province that causes an overflow from the riverbanks and severe flooding.

Accordingly, this research aims to develop flood hazard map, flood vulnerability map, and flood risk map along the mainstream of Yom river in Phrae province by using HEC-RAS model Geographic Information System (GIS). The obtained flood risk assessment will support the decision makers on the flood preparedness process.

2. STUDY AREA

Yom river basin is one of the basin in Northern Thailand which is a narrow stream without regulated dam in upstream. Therefore, during rainy season, these area often suffer from flood. Phrae province is one of provinces in upper Yom river area, where is affected by floods every year because the area is flat and close to the Yom river. This study focuses on the area in Muang district and along the Yom river in Phrae Province.

Phrae Province is one of the most ancient cities of Northern Thailand with the total area about 6538.6 km^2. The surrounding area of Phrae is mountainous area with the flat plain in the middle part, as shown in Figure 1. (Phrae Provincial Office, 2018). Muang district location is 18°8’44”N 100°8’29”E with the total total area of 756.1 km^2.

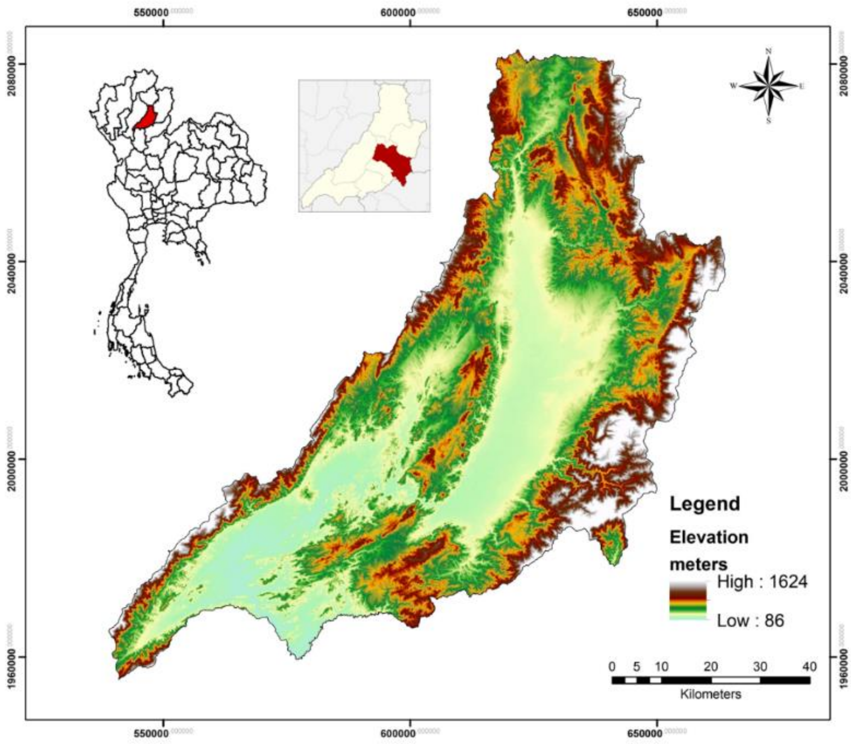

Figure 1 Phrae Province, Thailand.

3. GEOSPATIAL DATA AND METHODOLOGY

Figure 2 shows the framework of the study.

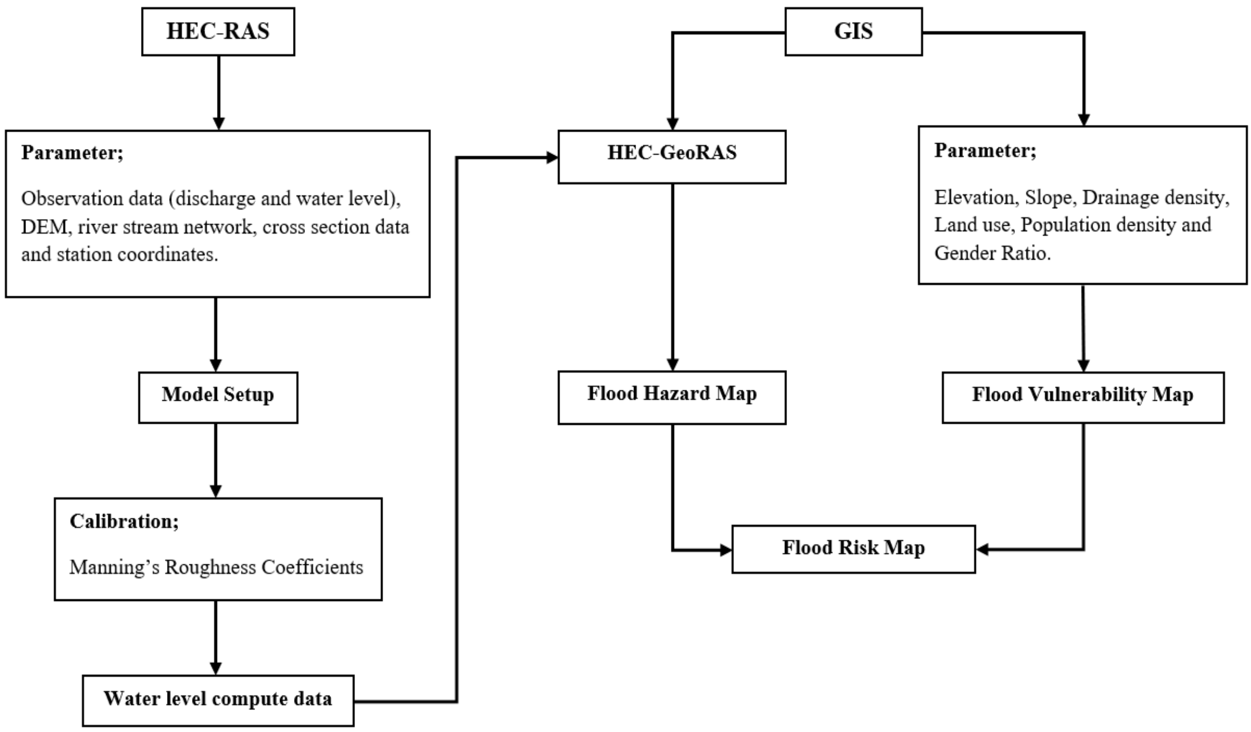

Figure 2 Schematic diagram of research framework.

3.1 Geospatial data

In order to assess flood vulnerability, six conditioning parameters were selected and prepared based on literature reviews and data availability. Each conditional parameter was analyzed in the GIS environment. The parameters include elevation, slope, drainage density, land use, population density and gender ratio. The cell size of the raster for these parameters were 30 meters which were divided into classes using the natural breaks (Jenks) classification method. Figure 3 shows the spatial distribution of each parameter.

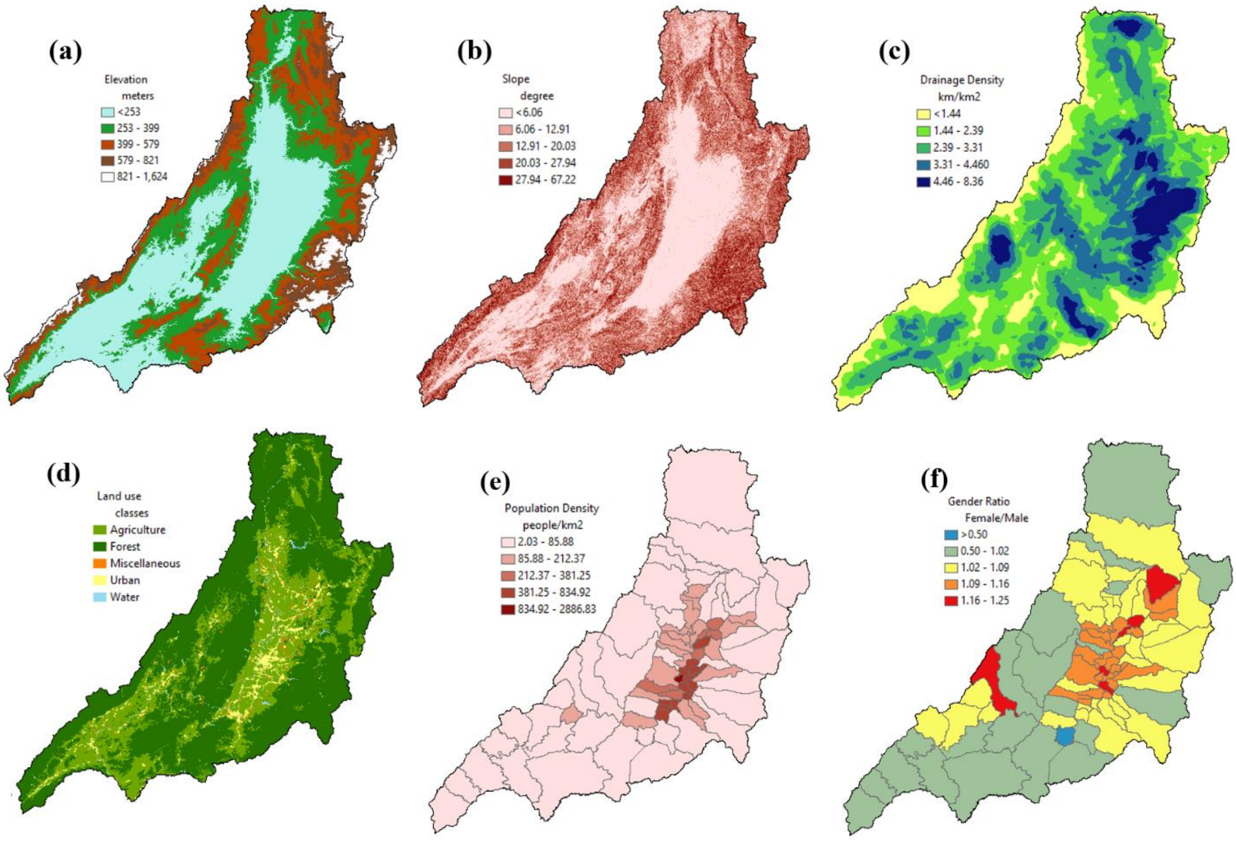

Figure 3 Flood parameters for the study area; (a) elevation, (b) slope, (c) drainage density, (d) land use, (e) population density, (f) gender ratio.

3.2 HEC-RAS Model

HEC-RAS is a hydraulic model that can use to analyze water flow through natural rivers and other channels. The model was developed by the United States Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many researchers since its public release in 1995 (U.S. Army Engineer Hydrologic Engineering Center). HEC-RAS modelling was used to simulate both stage hydrograph and flow hydrograph. The discharge boundary at upstream and water-level boundary at downstream can be assigned in the model. Runoff from sub-catchment was calculated using one dimension analysis of uniform lateral inflow with 2-10 km distance variation between two cross sections generated by DEM. Observed data of station Y.20 (Song district, Phrae) were used as upstream boundary condition and station Y.37 (Wang chin district, Phrae) were used as downstream boundary condition whereas station Y.1C (Mueang Phrae district, Phrae) were used in verification process.

3.3 Geographic Information System (GIS) and HEC-GeoRAS

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data. ArcGIS is a one of GIS application for working with maps and geographic information. GIS was used to create flood vulnerability map and flood risk map. HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface. The interface allows the preparation of geometric data for importing into HEC-RAS and exporting simulation results from HEC-RAS (U.S. Army Engineer Hydrologic Engineering Center).

3.4 Model calibration

The model was calibrated by compared between computed results data and observed data. The computation was done for a period of six months (flood season), starting from June to November. During the calibration process, the main adjustable parameter is Manning's roughness coefficient (n) for each cross-section. Three parameters namely the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Root Mean Square Error (RMSE) were calculated to identify the degree of agreement between computed values and observed values.

3.5 Flood Hazard Map

Flood hazard maps are designed to increase awareness of the likelihood of flooding among the public, local authorities and other organizations. They also encourage people living and working in flood-prone areas to find out more about the local flood risk and to take appropriate action (Environment Agency, 2010). After running the HEC-RAS and model calibration, the output is exported to the GIS. Flood hazard map was classified into five categories of flood depth (meter); very low (0-0.5), low (0.5-1), moderate (1-2.5), high (2.5-5) and very high (>5). (V.Moya, S.Kure, K.Udo and A.Mano, 2015)

3.6 Flood Vulnerability Map

Vulnerability is more widely used in risk analysis. A risk calculation can show the possibilities for vulnerability reduction (local territorial strategies, vulnerability assessment of buildings, temporary relocation and reception capacity) (Ledoux, 1995; IFRC, 1996). In this research flood vulnerability map was created by the Analytic Hierarchy Process (AHP). The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), is an effective tool for dealing with complex decision-making and may aid the decision maker to set priorities and make the best decision. AHP is one of the widely used multi-criteria decision-making tools, because of its simplicity in implementation, interpretation and its capability in handling also poor quality data and efficiency in regional studies (Wang et al. 2011; Chen et al. 2014).

In AHP, the consistency used to build a matrix is checked by a consistency ratio, which depends on the number of factors. The required level of consistency is evaluated using the following index:

$$CR = \frac{CI}{RI} \tag{1}$$

Where CR = Consistency Ratio

CI = Consistency Index

RI = Random Index as shown in Table 1

CI is calculated using this equation

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

Where, λ is the average value of consistency vector and n is the number of factors.

Table 1: Random Index (RI) values (Saaty, 1980)

No. of Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	**0**	**0**	**0.58**	**0.90**	**1.12**	**1.24**	**1.32**	**1.41**	**1.45**	**1.49**

AHP is a semi-qualitative method, which involves a matrix-based pair-wise comparison of the contribution of different factors for flooding. It was developed by Saaty (1980). Factor weights for each criterion are determined by a pairwise comparison matrix as described by Saaty (1990, 1994), and Saaty and Vargas (2001). To get factor weights in AHP, one has to build a pair-wise comparison matrix with scores given in Table 2. In the construction of a pairwise comparison matrix, each factor is rated against 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.

Table 2: Scale of preference between two parameters in AHP (Saaty, 2000)

Scales	Degree of preferences	Explanation
1	Equally	Two activities contribute equally to the objective.
3	moderately	Experience and judgment slightly to moderately favor one activity over another.
5	Strongly	Experience and judgment strongly or essentially moderately favor one activity over another.
7	Very strongly	An activity is strongly favored over another and its dominance is shown in practice.
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation.
2,4,6,8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9.
Reciprocals	Opposites	Used for inverse comparison.

Priority weighting of pairwise comparison matrix is shown in table 3 using 6 x 6 matrix, where diagonal elements are equal to 1. The values of each row are compared with each column to define the relative importance to obtain the rating score. The relative importance of each factors considered for flood vulnerability index was assigned by the referencing literatures and the information obtained from experts. The result of the Relative Importance Weights is shown in table 4.

Table 3: Pairwise comparison matrix using flood vulnerability parameter in AHP

Factors	Elevation	Slope	Drainage density	Land use	Population density	Gender Ratio
Elevation	1.00	4.00	5.00	3.00	3.00	3.00
Slope	0.25	1.00	2.00	3.00	3.00	3.00
Drainage density	0.20	0.50	1.00	3.00	2.00	2.00

Land use	0.33	0.33	0.33	1.00	1.00	1.00
Population density	0.33	0.33	0.50	1.00	1.00	1.00
Gender Ratio	0.33	0.33	0.50	1.00	1.00	1.00
Total	2.44	6.49	9.33	12.00	11.00	11.00

Table 4: Relative weights for flood vulnerability by using AHP

Factors	Elevation	Slope	Drainage density	Land use	Population density	Gender Ratio	Weight
Elevation	0.41	0.62	0.54	0.25	0.27	0.27	0.39
Slope	0.10	0.15	0.21	0.25	0.27	0.27	0.21
Drainage density	0.08	0.08	0.11	0.25	0.18	0.18	0.15
Land use	0.14	0.05	0.04	0.08	0.09	0.09	0.08
Population density	0.14	0.05	0.05	0.08	0.09	0.09	0.08
Gender Ratio	0.14	0.05	0.05	0.08	0.09	0.09	0.08
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The calculated value of the Consistency Index (CI) was 0.104 and the Consistency ratio (CR) was 0.084.

3.7 Flood Risk Map

Flood risk is the probability of loss and depends on three elements, hazard, vulnerability, and exposure (Kron 2005; Winsemius et al. 2013; WMO 2013; Budiyono et al. 2014). A flood risk map is a result of the combination of two components: Hazard and vulnerability (Ouma and Tateishi, 2014; Yagoub, 2015).

$$\text{Flood Risk Map} = \text{Flood Hazard Map} * \text{Flood Vulnerability Map} \quad (3)$$

Flood risk map was created by raster calculator method in ArcGIS. Finally, the risk map was identified in 5 levels; Very low, Low, Moderate, High and Very High.

4. RESULT AND DISCUSSION

4.1 Model calibration

Manning's roughness coefficient (n) was adjusted by trial and error and determined to be in the range of 0.025 to 0.040. Three parameters namely the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Root Mean Square Error (RMSE) were calculated to identify the degree of agreement between computed values and observed values. The results of comparison between computed and measured data as shown in Figure 4 are R^2 = 0.914, NSE = 0.863 and RMSE = 0.756 at Station Y.1C (2011). Normally, a value of R^2 and NSE close to 1 indicates good agreement between computed and observed data, but a value of RMSE close to zero indicates good results. Both obtained R^2 and NSE show the good agreement, however, the value of RMSE is high. Thus, further study should be done by modifying the model parameters to decrease these error.

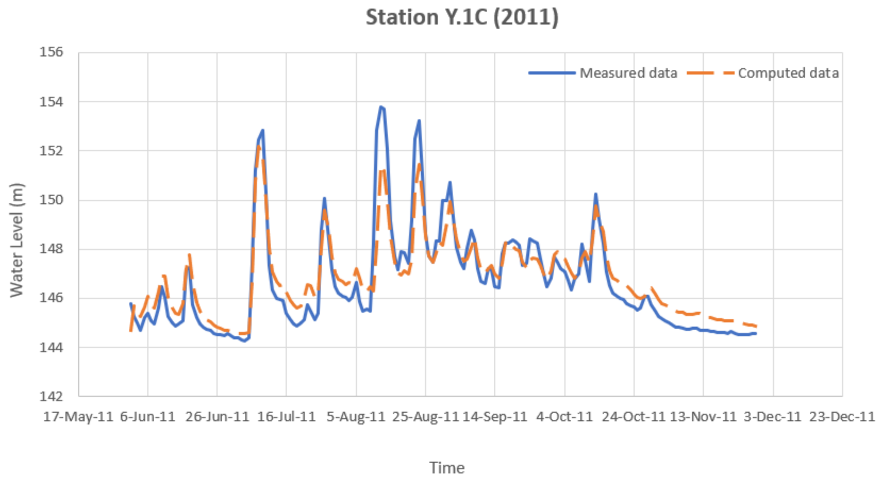

Figure 4 Comparison computed data and measured data water level at station Y.1C (2011 flood).

4.2 Flood hazard map

Flood hazard map was created from ArcGIS by using imported water level by HEC-GeoRAS. The results of flood area around the mainstream indicated that 45.87%, 29.55%, 13.47%, 9.65% and 1.46% of the studied area are very low, low, moderate, high, and very high flood hazard class, respectively as shown in Figure 5.

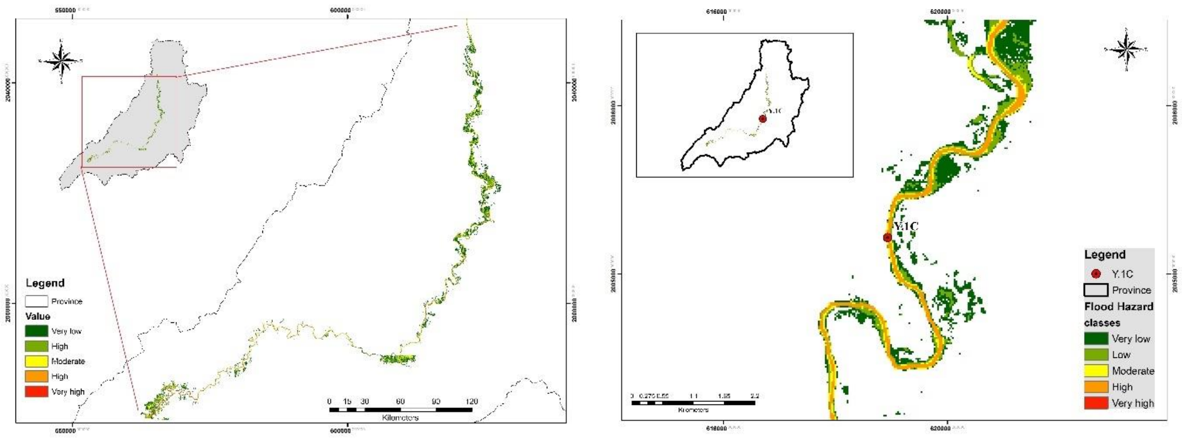

Figure 5 Flood hazard map in Phrae, Thailand (2011 flood).

4.3 Flood vulnerability map

Flood vulnerability map was created from ArcGIS by using AHP Method. The results of flood vulnerability map indicated that 11.35%, 2.37%, 27.97%, 25.69% and 32.62% of the studied area are very low, low, moderate, high, and very high flood vulnerability class, respectively, as shown in Figure 6. The high vulnerability areas are close to the river where is flat area of both urban and agricultural area.

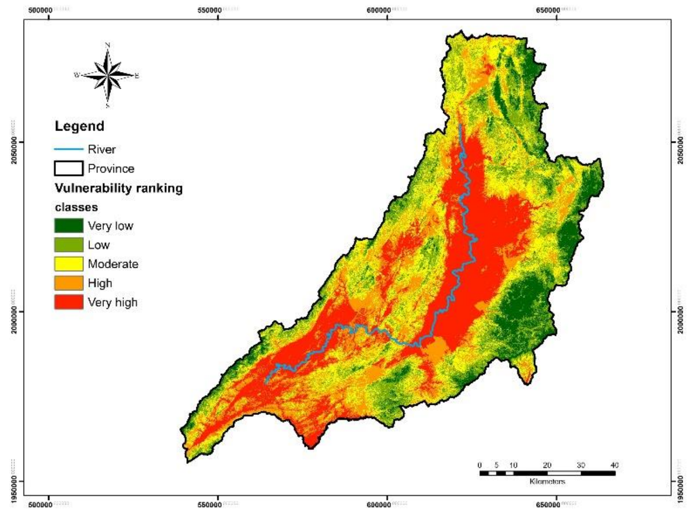

Figure 6 Flood vulnerability map in Phrae, Thailand (2011 flood).

4.4 Flood Risk Map

Flood risk map was created from ArcGIS by coupling flood hazard map and vulnerability map. The flood risk map around the Yom river in Phrae indicated that 1.39%, 44.50%, 30.04%, 13.18% and 10.89% of the studied area are very low, low, moderate, high, and very high flood hazard class, respectively as shown in Figure 7.

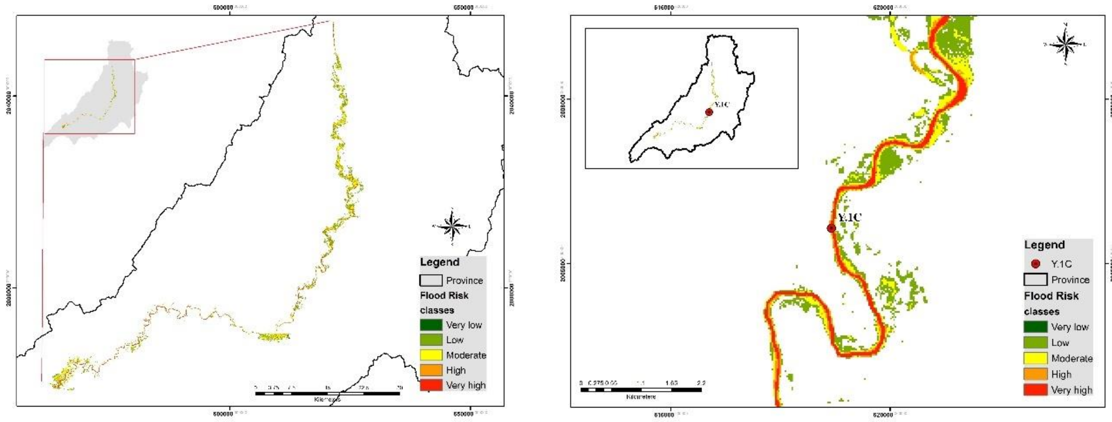

Figure 7 Flood risk map in Phrae, Thailand (2011 flood).

5. CONCLUSION

The main objective of this study is to assess flood risk of the upper Yom river by coupling flood hazard map and vulnerability map. The study process has been done by using hydrological model of HEC-RAS and a set of procedures of HEC-GeoRAS for processing geospatial data in Geographic Information System (GIS). The area along upper Yom river in Phrae province was selected as the studied area since it faces the severe flood almost every year. The obtained flood hazard map which includes both hazard and vulnerability can support the decision makers in flood preparedness process.

Further study can be done by taking more factors into account as well as improving the accuracy of the hazard map with the satellite images.

6. ACKNOWLEDGEMENTS

This research was supported by "Advancing Co-design of Integrated Strategies with Adaptation to Climate Change in Thailand (ADAP-T)" (Grant Number: JPMJSA1502) supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS), JST-JICA. Including thanks to the Thai Meteorological Department, Thai Royal Irrigation Department (RID), Land Develop Department (LDD), for providing various datasets for this research.

7. REFERENCE

Land Development Department, (2015). Soil resource survey report, Phrae province.

Ledoux, B. (1995) Bilan de la mise en œuvre des méthodologies d'élaboration des études de vulnérabilité dans le cadre des PER entre 1984 et 1994, Paris, Ministère de l'Environnement, DPPR, SDPRM, 160 p.

Phrae Provincial Office, (2018). General Information of Phrae province. Retrieved from phrae.go.th/

Royal Irrigation Department, (2009). Chapter 3 Water management for flood mitigation. Retrieved from http://irrigation.rid.go/rid4/jone_water/data/2552/pland/25-06-52/ES03.doc.

Saaty, T., 1980. The Analytic Hierachy Process. McGraw-Hill. 1980.

ThaiWater. (2012). 2011 Thailand Flood Executive Summary. Retrieved from http://www.thaiwater.net/index.php/ourworks2554/379-2011flood- %20summary.html

Upper Northern Region Irrigation Hydrology Center, (2016). Run off data report, Phrae province.

US Army Corps of Engineering, (1775). The documentation for HEC-RAS. Retrieved from hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Users%20Manual.pdf

Wolfgang, K. (2005). Flood Risk= Hazard. Values. Vulnerability. Water International, 30(1), 58-68.

Yagoub, M.M. 2015. Spatio-temporal and hazard mapping of Earthquake in UAE (1984–2012): Remote sensing and GIS application. Geoenvironmental Disasters 2(1): 1–14.