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AN ASSESSMENT OF FLOOD HAZARD AND RISK ZONING IN THE LOWER NAM PHONG RIVER BASIN, THAILAND

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ABSTRACT

Rapid socio-economic development along with exceptional rainfall can potentially exacerbate risk of flood damage to life and property in the lower Nam Phong River Basin. In relation to this, the non-structural measures including risk-based zoning could be considered as an effective solution in mitigating the flood threat in the future. Thus, a coupling of the hydrological model HEC–HMS and hydrodynamic model HEC–RAS, which increases the robustness and predictability to the overall findings, was applied to assess flood hazard in this study. The outcomes highlighted that the applications of the HEC–HMS and HEC–RAS models are suitable for the study area with the Nash-Sutcliffe Efficiency (E_{NS}) varied between 0.75 to 0.87 and the coefficient of determination (R^2) ranged between 0.81 to 0.92. Moreover, the flood zone mapping was also carried out based on the Flood Hazard Rating (FHR) analysis. As a result, the flood hazard areas were determined which covers about 16.5% of the total river basin areas, and it was classified into four zones, i.e. extreme (18.79% of inundated area), high (46.33% of inundated area), moderate (18.24% of inundated area), and low (16.64% of inundated area), respectively. The obtained findings can be useful as the adaptation guideline for water resources planning and flood management in the lower Nam Phong River Basin and other parts of Thailand.

Keywords: Flood hazard; Flood Hazard Rating; HEC-HMS; HEC-RAS; Vulnerability

1. INTRODUCTION

Flood is generally considered to be the most common natural disaster worldwide (Stefanidis & Stathis, 2013), which causes significant economic damage and loss of human life. In recent years, the flood occurrence has increased due to extreme rainfall events in the Central and Northeastern parts of Thailand. According to the World Bank, one of the worst floods in the country's history in 2011 presented an estimated of US$45.7 billion in damages and economic losses and affected 65 of the 77 provinces. In addition, the flood-related damage to agriculture and other related activities resulted in country economy and development (Jothityangkoon et al., 2015). Therefore, defining optimal strategies for appropriate flood management is very important and necessary (Ballesteros-Cánovas et al., 2013). In line with the above concerns, flood risk zone mapping and flood damage assessment are considered to be a supporting component and are essential for comprehensive flood loss prevention and management strategy (Tingsanchali & Karim, 2010). Flood vulnerability mapping and risk area delineation is vital to

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the guidance of local planning, flood risk assessment, and emergency planning (Zhang et al., 2015). Within this context, the spatial variations of different levels of risk and extent of flood damage resulting from catastrophic flood events were identified in this study. To carry out a reasonable investigation, the hydrological model HEC–HMS and hydrodynamic model HEC–RAS in association with the ArcGIS were employed to identify and mapping areas in the lower Nam Phong River Basin, which are susceptible to flood hazard. The main findings from this study can provide insight information to enable a tailor-made approach for flood management in the lower Nam Phong River Basin.

2. METHODOLOGY

2.1. Study Area

The study focused on the lower Nam Phong River Basin, which is located in the Northeastern region of Thailand. Geographically, the river basin has a total area of approximately 2,386 km^2 with an average terrain height ranging from 150 m to 500 m above mean sea level (m+MSL) as illustrated in Figure 1. The Nam Phong River is known to be the main river in the area with its length estimated about 136 km, which connects Ubol Ratana Dam from the upstream to the confluence of the Chi and Phong Rivers located at the downstream outlet of the river basin. The climate in the river basin is typically dominated by monsoon winds. The dry season lasts from February to April, and the wet season goes from May to October, with the annual average temperature ranges between 23^{o}C to 32^{o}C. The estimated mean annual rainfall of the lower Nam Phong River Basin is about 1,238 mm/year, with a heavy rainfall occurs in September and the mean annual streamflow is estimated approximately 669 mm/year.

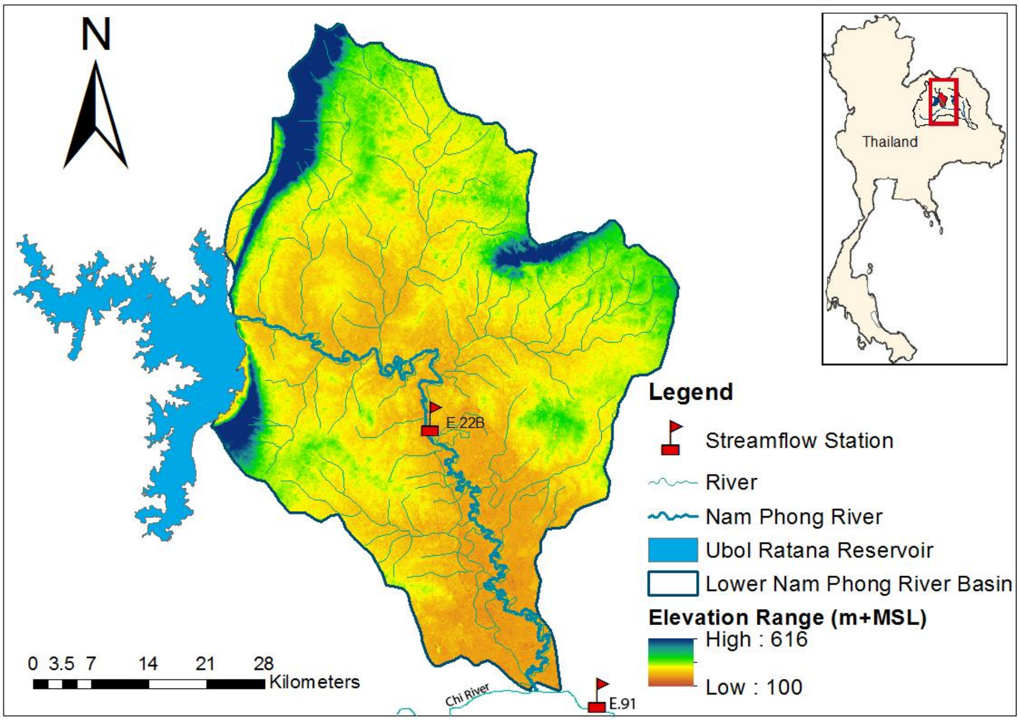

Figure 1 The lower Nam Phong River Basin, Thailand

2.2. Data Collection

The data collection is very important task as it lays the foundation of modeling and simulations of flood situations in the lower Nam Phong River Basin. The data used include daily rainfall obtained from the Thai Meteorological Department during 1956 to 2013 from eight gauging stations (e.g. Kranuan, Ubol Ratana, Khon Kaen, Non Sang, Chiang Yuen, Tha Khantho and Nam Phong). The missing rainfall was estimated from the Multiple Linear Regression method, whilst the Thiessen polygon method was used to transform pointed-based rain gauge data to areal rainfall for each sub-basin. The discharge and water level data from 2004 to 2013 and the survey cross sections were collected from the Royal Irrigation Department (RID). A high resolution of Digital Elevation Model (DEM) with a 5×5 m cell size, land use, and soil types in 2010 were taken from the Land Development Department (LDD).

2.3. The HEC-HMS Model for Rainfall-runoff Simulation

In quantifying essential components of the hydrological conditions of the river basin, the Hydrologic Engineering Center–Hydrologic Modeling System (HEC–HMS) model developed by the U.S. Army Corps of Engineer was set up. In brief, the HEC–HMS model is designed to simulate the rainfall-runoff processes in the river basin based on four major components, including runoff volume, direct runoff, baseflow, and channel flow. In this study, the Soil Conservation Service–Curve Number (SCS–CN) method was applied for the event-based simulation due to its simplicity manner and efficiently in determining the amount of runoff in a particular area. Direct runoff was performed by using the Snyder Unit Hydrograph method, and the recession baseflow and Muskingum routing methods were also selected in the HEC–HMS model simulations. Furthermore, the E.22B gauging station was selected to perform the calibration and validation processes in the hydrological simulations. Accordingly, the period from 2004 to 2010 was used for calibration and the period of 2011 to 2013 was used for validation.

2.4. The HEC-RAS Model for Flood Simulation

For determining flood prone areas and detailed hydraulic analysis of flood behavior, the Hydrologic Engineering Center–River Analysis System (HEC–RAS) model developed by the U.S. Army Corps of Engineers was executed. The model contains four one-dimensional river analysis components, i.e. sediment transport computations, water quality analysis, steady flow water surface profile computations, and unsteady flow simulation. In this assessment, the unsteady flow analysis was applied in HEC–RAS model simulations. The calculated discharges obtained from HEC–HMS model were input as the upstream boundary condition, and the stages observed at the E.91 gauging station were used as the downstream boundary condition (note: the E.91 gauging station was selected because its location is very close to the confluence of the Chi and Phong Rivers by approximately 2 km as presented in Figure 1). Moreover, the E.22B gauging station was chosen to evaluate the performance of the HEC–RAS model that best represents flood risk in the lower Nam Phong River Basin. The stage time-series from 2006 to 2010 was used for calibration and from 2011 to 2013 was used for validation.

2.5. Accuracy of Flood Inundation Maps

The goodness of fit between the satellite imagery and the simulated inundation mapping was assessed using the relative error (RE) and F-statistics (F_S) as indicated in Equations 1 and 2, respectively. Relative Error (RE) uses to compare the similarity of simulated flood inundation area and extracted satellite image whereas (F_S) applies to compare the geospatial similarity for the overlapping portion area. It is important to note that lower RE and higher F_S values indicate the goodness of fit between observations and simulations.

$$RE = \frac{|X_o - X_p|}{X_o} \quad (1)$$

$$F_s = \left(\frac{X_{op}}{X_o + X_p - X_{op}}\right) \times 100 \quad (2)$$

where X_o is the inundation area extracted from satellite images, X_p is the simulated flood inundation area, X_{op} is the intersection of X_o and X_p.

2.6. Classification of Flood Zones

A clear description of areas at different degrees of risk from fluvial flooding can be presented in the form of flood risk inundation mapping created in a Geographic Information System (GIS) environment. Traditionally, the designated flood zones can be classified based on the flood return periods (Nareth & Plermkamon, 2013), however, when taking a closer look, it reveals that the designation of flood hazard zones is very data intensive and depends largely on a very high resolution terrain dataset (Forkuo, 2011). In this context, the inundation extent was spatially delineated through the interpolation of flood depth values between cross sections and DEM for the period from 2011 to 2013. Correspondingly, a satellite image of the flood, which was taken on October 15, 2011, derived from the Thailand Flood Monitoring System (TFMS) was employed to compare with simulated flood inundation extent. Furthermore, the Flood Hazard Rating (FHR) analysis was also carried out to determine the most vulnerable areas in the river basin as described in Equation 3 (Priest et al., 2008). Additionally, in order to have a clear and easy understandable map, the flood hazard was categorized into four different zones, namely low, moderate, high, and extreme (see Table 1). According to Priest et al. (2008), it is necessary to add an additional depth-velocity threshold as an "extreme" level, i.e. an FHR level greater than 7 m^2/s, to imply that all properties are vulnerable to collapse or serious structural damage if the majority of buildings are in direct contact with floodwater.

$$FHR = d \times (v + 0.5) + DF \quad (3)$$

where d is flood depth (m), ν is velocity (m/s), *DF* is debris factor.

Table 1 Risk to life thresholds based on depth-velocity function (Priest et al., 2008)

Level of FHR (m^2/s)	Hazard level	Description
< 0.75	Low	*Caution* Shallow flood water or deep standing water
0.75 < 1.5	Moderate	*Dangerous to vulnerable groups* Deep or fast flowing water. Fatalities concentrated in vulnerable groups or the result of human behavior.
1.5 < 2.5	High	*Dangerous to the most people* Deep or fast flowing water. Fatalities due mainly to exposure to the hazard.
2.5 < 7.0	Extreme	*Dangerous for all* Extreme danger from deep and fast flowing water (poorly constructed and wooden buildings may collapse). Fatalities due to hazard exposure.
> 7.0	Extreme	*Dangerous for all* Extreme danger from deep and fast flowing water (all properties are vulnerable to collapse). Fatalities due to hazard exposure.

3. RESULTS

3.1. The Performance Evaluation of HEC-HMS Model

The evaluation of HEC–HMS model was carried out by comparing the results through both graphical displays and statistical criteria. As indicated in Figure 2, the results demonstrated a good agreement between observed and simulated flows during the calibration and validation processes. Based on the statistical indices, i.e. Nash-Sutcliffe Efficiency (E_{NS}) = 0.81 and coefficient of determination (R^2) = 0.86 for calibration and E_{NS} = 0.87 and R^2 = 0.92 for validation, it can be concluded that HEC–HMS is suitable for modeling the hydrological processes in the lower Nam Phong River Basin.

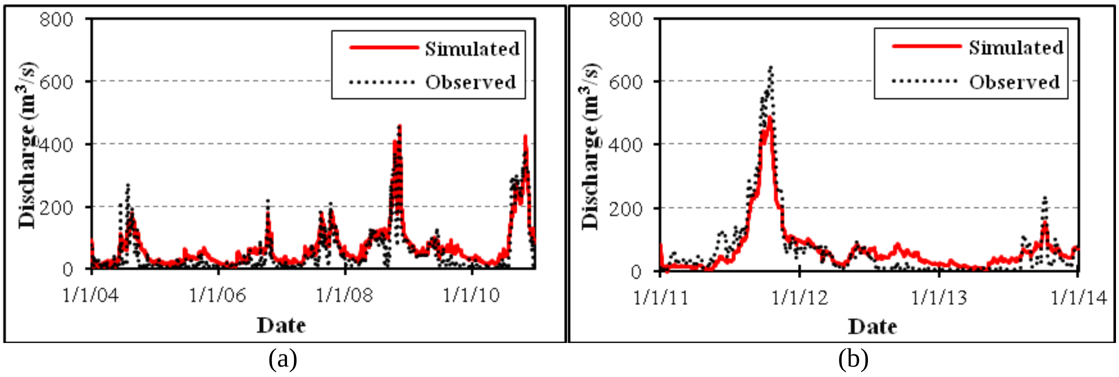

Figure 2 Comparison of HEC–HMS simulated and observed daily discharges during: (a) calibration period; and (b) validation period at the E.22B gauging station

3.2. The Performance Evaluation of HEC-RAS Model

To perform flood analysis and simulation in HEC – RAS model, the Manning's *n* values were adjusted based on the land uses along the Nam Phong River. The results show in Figure 3 indicate the acceptable range for both calibration and validation processes with the E_{NS} = 0.75 and R^2 = 0.81 for calibration, and E_{NS} = 0.75 and R^2 = 0.84 for validation (note: the stage hydrograph between observed and simulated results is not very well matched during the validation period due to the overflow from the Nam Phong River, together with the regulated release flow from Ubol Ratana Dam). Referring to the statistical indices and the trend of observed and simulated stage hydrographs, it can be concluded that the HEC–RAS model is suitable to simulate floodplain inundation and river hydraulics over the lower Nam Phong River Basin.

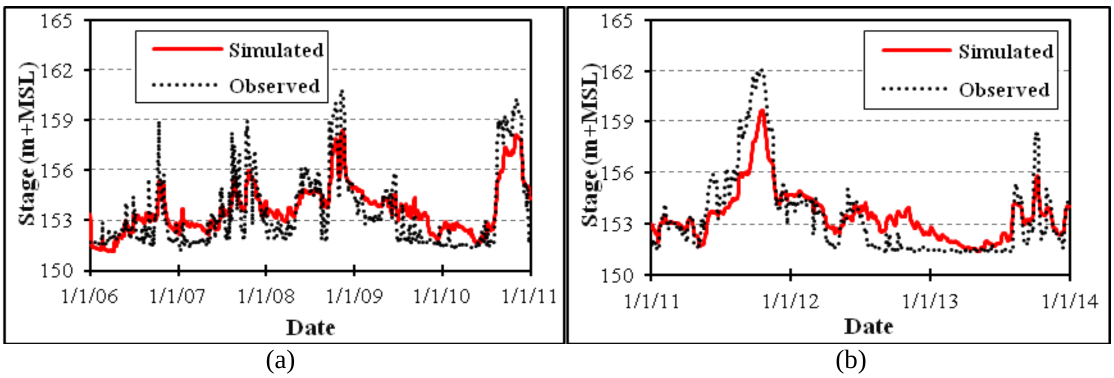

Figure 3 Comparison of HEC–RAS simulated and observed daily stages during: (a) calibration period; and (b) validation period at the E.22B gauging station

3.3. Flood Zone Mapping

The goodness of fit analysis was applied to compare the similarity between simulated flood inundation areas and satellite image for the event on October 15th, 2011. Based on the topography of the Nam Phong River Basin, the "medium flood level" that greater than 2.5 m (measured at the middle of the channel from the cross section at E.22B), was selected for this comparison. The results showed that a total of 147.46 km^2 of the simulated flood area is nearly with 130.54 km^2 from the satellite image. The RE value given as approximately 13%, and the F_s value also obtained about 188.9, which indicates a satisfactory goodness of fit for the two mappings. As summarized in Table 2, the areas with high FHR values ranging from 2.5 m^2/s to 7.0 m^2/s are grouped as "extreme" zone (18.79% of inundated area). The exceptional FHR values that greater than 7 m^2/s are also considered as "extreme" zone, where all buildings are directly vulnerable to floods. In detail, the flood hazard level that ranges from 7 m to 10.8 m associated with the velocity from 0.7 m/s to 0.96 m/s, and the vulnerability level of population, were considered to be the most vulnerable areas in the river basin. The FHR values vary from 1.5 m^2/s to 2.5 m^2/s are defined as the emergency level for the "high" zone (46.33% of inundated area). The "moderate" zone (18.24% of inundated area) is also introduced when the FHR values fall between 0.75 m^2/s and 1.5 m^2/s, and the remaining values less than 0.75 m^2/s is called "low" zone (16.64% of inundated area).

Table 2 Flood hazard areas in the lower Nam Phong River Basin

Flood zone	FHR (m^2/s)	Area (km^2)	Percentage (%)
Low	< 0.75	65.36	16.64
Moderate	0.75-1.5	71.70	18.24
High	1.5-2.5	182.13	46.33
Extreme	> 2.5	73.86	18.79

4. DISCUSSION

The lower Nam Phong River Basin was modeled using HEC-HMS and HEC-RAS models in order to assess flood hazard. Both models were calibrated and validated for historical flow events (2004–2013). From visual observation and statistical performances (E_{NS} and R^2 greater than 0.70), there is an improvement of simulated hydrographs in terms of peak runoff and time to peak as a result of changing calibration parameters, which confirms that both models are useable for flood hazard assessment. Moreover, a satisfactory goodness of fit between satellite-based (130.54 km^2) and HEC-RAS simulated flood inundation extents (147.46 km^2) was also found based on a low Relative Error (RE) of 13% and a high F-statistics (F_S) of 188.9. Based on the Flood Hazard Rating (FHR) analysis, the downstream of the lower Nam Phong River Basin is likely to be more vulnerable than the other parts of the river basin, where the high zone covers about 46.33% of the total inundated area and extreme zone occupies about 18.79% as illustrated in Table 2 and Figure 4. The aforementioned vulnerable downstream area of the lower Nam Phong River Basin is corresponding to the high risk flood prone area identified by Department of Water Resources (2006). In addition, it can be recognized that the areas close to the main Phong River will significantly be affected by the higher flow velocity. The results also showed that flood depths vary from 0 m to 10.8 m, whereas the flow velocity is calculated to be from 0 m/s to 0.96 m/s. The obtained information from this study will be very useful for prioritizing the flood prone areas in terms of the importance of the assets at risk, as well as selecting the mitigation measures.

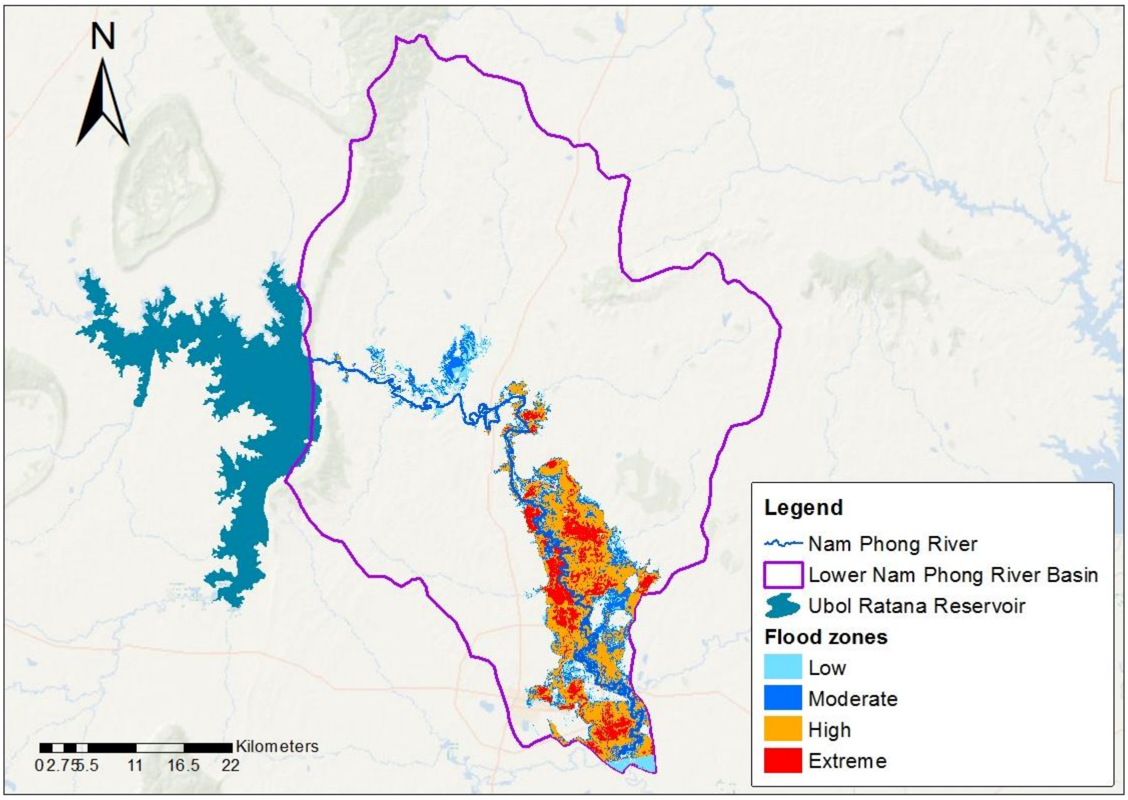

Figure 4 Flood zone mapping in the lower Nam Phong River Basin

5. CONCLUSION

An assessment of flood hazard and risk-based zoning in the lower Nam Phong River Basin was carried out in this study. The results proved that the application of the hydrological model HEC–HMS and hydrodynamic model HEC–RAS are suitable for the river basin with relatively high values of both statistical indices (i.e. E_{NS} varied between 0.75 to 0.87 and R^2 ranged between 0.81 to 0.92). In addition, the flood zone mapping was also prepared to cope with the flood problems based on the FHR analysis. The zoning areas can be classified as extreme (FHR > 2.5 m^2/s, 18.79% of the entire inundated area), high (FHR = 1.5 m^2/s to 2.5 m^2/s, 46.33% of the entire inundated area), moderate (FHR = 0.75 m^2/s to 1.5 m^2/s, 18.24% of the entire inundated area), and low (FHR < 0.75 m^2/s, 16.64% of the entire inundated area). In line with above discussion, it can be said that flood zone mapping plays the important role in identifying the most vulnerable areas, which will be very useful for decision makers to overcome future flood disasters in the lower Nam Phong River Basin.

6. ACKNOWLEDGEMENT

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