Research article

Floodplain Mapping Using HEC-RAS and GIS in Nam Phong River Basin, Thailand

NARETH NUT*
Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia
Email: nnareth@rua.edu.kh

VICHIAN PLERMKAMON
Department of Agricultural Engineering, Khon Kaen University, Khon Kaen, Thailand

Received 15 December 2014 Accepted 31 May 2015 (*Corresponding Author)

Abstract Floodplain management and mapping is a new and applied method for the river engineering and is essential for prediction of flood hazards. The lower Phong Basin area regularly goes more or less under flooding every year in the monsoon season due to lack of flood protection and limited resources. Most of the flood protection works are carried out at the local level without preplanning and considering the problems at the river basin scale. Traditionally, individuals or communities have been trying to develop their own strategies for minimizing the effects of floods. However, due to limitation of resources and knowledge, many householders are unable to protect their properties or possessions from floods. A methodology was applied to integrate hydraulic simulation model, HEC-RAS and GIS analysis for delineation of flood extents and depths within a Nam Phong River in northeast of Thailand. It is necessary to simulate complicated hydraulic behaviour of the river in a more simple way for the purpose of managing and performing all river training works. In this research, the steady flow was used to simulate flood along 148 km end of Nam Phong River starting at upstream from Ubolratana Dam to Chi River in Northeast of Thailand. Floodplain mappings were derived using integrating of HEC-RAS and GIS analysis. Delineation of flood extents and depths within the floodplain were conducted in different return periods. Critical flooding area along the river was distinguished based on the grid layer of flood depths. The results indicated that hydraulic simulation by integrating with GIS analysis could be effective for various kinds of floodplain management and mapping and give as different scenarios for river training works and flood mitigation planning.

Keywords Nam Phong river, floodplain mapping, GIS, HEC-RAS model, Thailand

INTRODUCTION

The Nam Phong Watershed is the largest basin in the northeast of Thailand which provides an important water resources for agriculture, electricity generation, aquaculture, domestic uses, industrial and recreational purposes (KKU, 2003). In Nam Phong flood prone areas, flood causes severe economic and social disruptions to many living households. Nevertheless, floodplain in Lower Phong Basin is still in a very rudimentary stage and no serious concern on comprehensive flood damages. In this area, most of the flood protection works are carried out at the local level without preplanning and considering the problems at the river basin scale. Traditionally, individuals or communities have been trying to develop their own strategies for minimizing the effects of floods. However, due to limitation of resources and knowledge, many householders are unable to protect their properties or possessions from floods.

The most important factors affecting the intensity and flood return period in each region are: volume and time of upstream surface runoff and river or flood conditions, physical characteristics of watershed (area, morphology), hydrological characteristics of the watershed (rainfall, storage, evapotranspiration), and human activities (Noori, 2001). Flooding is a hazard with serious socioeconomic consequences for all activities and infrastructure within an affected floodplain. Thus, accurate delineation of flood extents and depths within the floodplain is essential for flood management officials to make sensible and fair decisions regarding construction, insurance and other regulated practices on land and property potentially affected by flooding (Noman et al., 2003).

Computer models play a pivotal role in facilities such as storm drains, culverts, bridges, and water quality as well as quantity-control structures which is an important design component of these facilities involving with hydraulic analysis to determine conveyance capacity. Recently, computer models are developed and used for predicting and preventing natural disasters worldwide (Barbad et al., 2002; Earles et al., 2004; Abdalla et al., 2006; Yang et al., 2006).

Barbad et al. (2002) made flood zoning maps of the Sepid Rood River in Gilan Province, Iran, using Iranian cartographical maps of 1: 25000, cross sections measured by Iran Rasad Consulting Engineers, and ArcView, HEC-RAS and HEC-GeoRAS software. They concluded that a combination of GIS and the HEC software is feasible and makes the calculations easily. Earles et al. (2004) demonstrated the utility of the HEC-GeoRAS model for floodplain delineation and determination of key hydraulic parameters and also, HEC-RAS capability of producing hydraulic results in Los Alamos, New Mexico, USA. Abdalla et al. (2006) introduced hybrid approach for flood risk assessment through GIS. The results indicated that the developed methodology was efficient in modeling and visualizing the spatial extent of different flood scenarios and in determining flooded areas at risk. Yang et al. (2006) developed a direct-processing approach to river system floodplain delineation by using GIS and HEC-RAS. Due to the efficiencies of the mentioned methods, the purpose of this research was to identify the flood frequency analysis and flooded area and further created floodplain mappings based on the change of return periods or flood events in Lower Phong Basin using HEC-RAS and GIS.

METHODOLOGY

Study area: This research was conducted in Lower Phong Basin located in the northeast of Thailand bordering to Udon Thani, Mahasarakham, Chaiyaphum and Nong Bua Lamphu provinces. The length of river is approximately 148 km that flows northwestward to southeastward to join Chi River and ultimately draining into the Mekong River. The area of study was approximately 2993.95 km^2 (Fig. 1). The lower part of the watershed consists mainly of paddy fields, agricultural land, and factories and is heavily populated. The land surface in the watershed is generally undulating and sloping towards the east and southeast. The elevation of the relatively flat area around the Ubolratana reservoir is about 190 m. The western watershed consists of many mountain ranges with an average elevation of 900 m, and up to 1,300 m (FAO, 1985). Geographic location of the study area is in between Latitude N 16^0 23’ 39” to N 16^0 46’ 37” and Longitude E 102^0 36’ 22” to E 102^0 57’ 51”.

Datasets: The analyses of this research relied on two types of data; annual peak flow and GIS data including cross-sections, elevation points and topographic map. Peak flow data of Nam Phong basin was simulated from SWAT model with 12-year rainfall records from 2000-2012 water year, and with the daily model calibration from 2004-2007 (R^2=0.93). After evaluation of the accuracy of the data, Gumbel Distribution Method was employed for flood frequency analysis (only 14 major sub-basins were calculated, whereas the small sub-basins were ignored). The analyzed data used as input for the hydraulic simulation of the river reaches which divide into upper reach from Ubolratana Dam to Nong Wai Weir and lower reach from Nong Wai Weir to Chi River.

Calibration for roughness coefficient: The roughness coefficients, which represent the surface’s resistance to flow and are integral parameters for calculating water depth, were initially estimated using the Chow classification by Chow (1959). The Manning’s coefficients used for different zones of the Nam Phong River varies between 0.025 and 0.075. Flood inundation results are derived separately for each cross section in the main channel. Model parameters can largely be divided into two categories (Gilard, 1996): (i) parameters that can be directly inferred from observation, such as area, extent, depth, volume etc., and (ii) parameters that cannot be directly observed at the model scale and will need to be estimated, such as roughness. Manning roughness coefficient *n*, together with the channel geometry is considered to have the most important impact on predicting inundation extent and flow characteristics. Most of the methods from literature for estimating roughness values are useful in establishing the range of roughness values for a river reach. Calibrated roughness values are, however, effective at the reach scale (Beven and Carling, 1992). Calibration is an inverse problem associated with identification, and is used to determine unknown constants or parameters in a model. Calibrating the Nam Phong River model roughness values involved running the hydraulic model several times and changing the Manning roughness coefficients, first estimated from Chow tables, until the best fit between the simulated and observed water level and water extend is found.

Floodplain mapping: For the floodplain delineation, the ArcView GIS software package, developed by the Environmental Systems Research Institute, was used as the computer development environment for this research. Topographic map of the study area with scale of 1:50,000 were applied for based map using 3D analyst capability of ArcView GIS. DEM is used for preparation required data for hydraulic simulation in HEC-RAS, whereas the 113 surveyed cross-sections of the Nam Phong River have relative elevation which GPS have been used for determining absolute and correct positioning of all cross-sections and elevation points. The HEC-GeoRAS extension is used in conjunction with 3D analyst for interpolation of digital terrain data and Spatial Analyst for proper display of the output flow depth grids and velocity grids. HEC-GeoRAS had been used to import RAS geometry form HEC-RAS which represents stream floodplains as a computed water surface elevation at each cross-section. During the data import step, these elevations, along with the distance from the stream centerline to the left and right floodplain boundaries, are brought into ArcView GIS and stored in the cross-section parameter table. As inputs, the script requires the cross-section line theme and the cross-section parameter table. The output is a line theme that is identical to the cross-section theme in location and orientation. Using the water surface profile at each cross-section, DEM with resolution 5 m obtained from Water Resources and Environmental Institute (WREI, 2012) was represented the entire floodwater surface. The water surface lines were used as break-lines, and the cross-section bounding polygon was used to bind the aerial extent of the water surface. When they were viewed in conjunction with the terrain DEM or TIN, flooded areas can be seen. The three-dimensional floodplain view is quite useful for floodplain visualization.

RESULTS AND DISCUSSION

In the present finding, flood frequency analyses were carried out with peak discharge data for 12 years (2000–2012) by the Gumbel's Distribution method which it is a suitable method in the condition like Thailand. The maximum annual water discharge from sub-watershed was calculated for flooding occurrences for 5-year, 10-year, 25-year, 50-year and 100-year return periods (Table 1). Flood frequency analysis was used as the steady flow data for simulation in order to further analysis the floodplain area at the Nam Phong watershed. Critical depth for upstream and critical depth for downstream was considered as boundary conditions for this analysis. Other inputs such as Manning's n value, river system schematic, contraction and expansion coefficients, flow regime entered to model and HEC-RAS model has run for steady flow regime. The result indicated only three-major rivers: Huai Sai Bat, Huai Suea Ten, Huai Khum Mum could reach to the big discharges based on changing of return period of flooding, whereas the other small sub-basins could produce less discharge which would be caused less effect to the floodplain area. Fig. 2 show floodplain mapping of the affected area and depth for the 10 and 100 years flooding events. Critical flooding area along the river could be distinguished basing on the grid layer of flood depths, and the flooding occurred mainly at the downstream of the basin which it is more populated, economical and industrious areas.

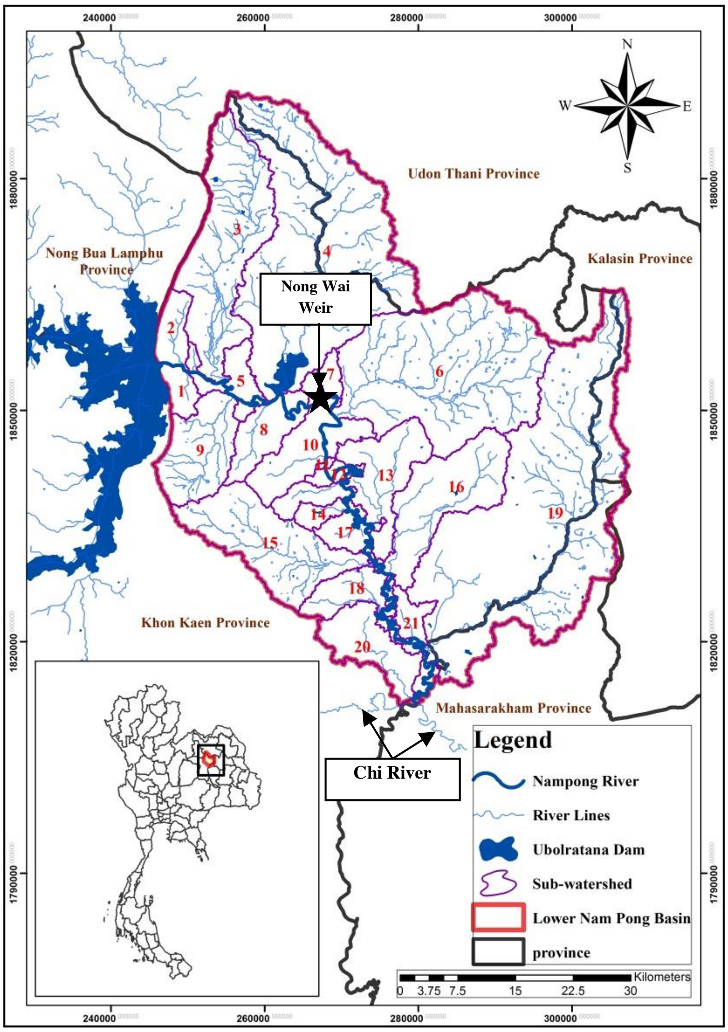
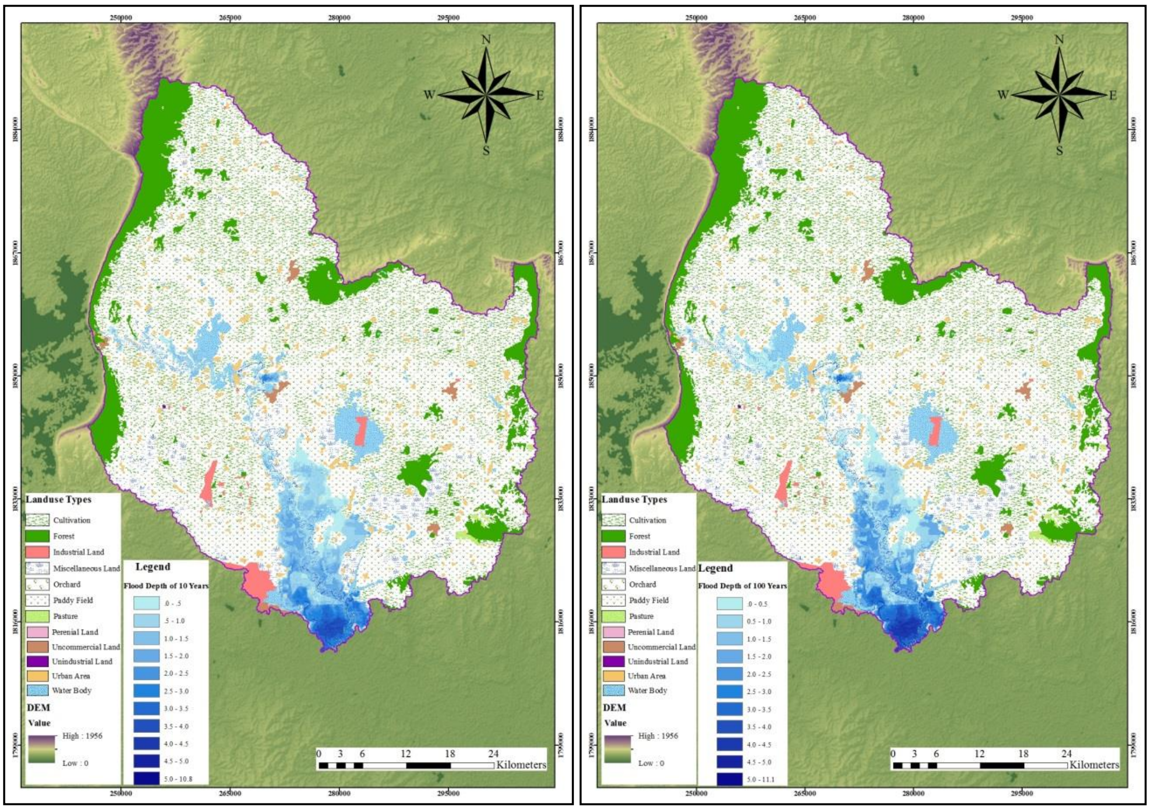


Fig. 1 Location of the study area

Table 1 Maximum discharge (m^3/s) of 14 sub-basins from the SWAT model based on return periods (2000-2012)

Nam Phong River	Tributary Name	Sub-basin Name	Peak Flow (m^3/s)	β	u	Return Periods of Flood Frequency Analysis				
						5 YR	10 YR	25 YR	50 YR	100 YR
Upper Reach	Huai Chot	Sub-basin 08	27.26	5.37	8.19	16.24	20.27	25.36	29.14	32.88
	Huai Khum Mum	Sub-basin 03	189.90	39.25	54.28	113.15	142.61	179.83	207.44	234.84
	Huai Sai	Sub-basin 02	565.10	6.31	8.94	18.41	23.15	29.13	33.58	37.98
	Huai Suea Ten	Sub-basin 04	169.70	17.76	113.91	140.54	153.86	170.70	183.19	195.59
	Huai Yang 1	Sub-basin 09	84.67	16.30	27.37	51.82	64.05	79.51	90.97	102.35
Lower Reach	Huai Hin Lat	Sub-basin 12	9.09	0.87	6.29	7.59	8.24	9.06	9.67	10.27
	Huai Kao Khot	Sub-basin 13	48.03	1.40	42.98	45.08	46.13	47.45	48.44	49.41
	Huai Nong Pla	Sub-basin 16	68.36	6.81	43.15	53.37	58.48	64.94	69.73	74.48
	Huai Pha Khue	Sub-basin 20	40.37	3.82	26.49	32.22	35.09	38.71	41.40	44.07
	Huai Plalai	Sub-basin 18	36.26	2.53	27.11	30.90	32.79	35.19	36.96	38.73
	Huai Sai Bat	Sub-basin 19	478.00	73.72	155.74	266.31	321.63	391.53	443.38	494.85
	Huai Siao	Sub-basin 06	185.80	33.37	91.46	141.51	166.55	198.19	221.66	244.96
	Huai Yai	Sub-basin 15	95.75	12.62	46.44	65.37	74.84	86.81	95.68	104.49
	Huai Yang 2	Sub-basin 10	22.52	2.72	13.07	17.16	19.20	21.78	23.70	25.60



a) **10-year-flood event** b) **100-year-flood event**

Fig. 2 Flood-affected area of 10 and 100 years flood event

Table 2 shows the analysis of the flooded areas revealed that a larger percentage more than 76% and 17% of paddy field and miscellaneous land lied in a floodplain area followed by urban, cultivation and forest area comprising 2%, 1.35% and 1.15%, respectively in accordance with the flooded areas of 5-year, 10-year, 25-year, 50-year and 100-year return periods. Anyways, there was not much (almost no flood) affected by the flood to the industrial land based on these various return periods it was because the topography of this area was too high to be effected by the flooding. It also illustrated that 2.56 km^2, 2.85 km^2, 0.10 km^2, 36.87 km^2, 154.89 km^2, 1.93 km^2, 3.59 km^2 of cultivation area, forest, industrial land, miscellaneous land, paddy field, uncommercial land and urban are respectively inundated by 5-year flood. Similarly, 3.59 km^2, 3.08 km^2, 0.21 km^2, 43.33 km^2, 192.18 km^2, 2.60 km^2, 5.01 km^2 of cultivation, forest, industrial land, miscellaneous land, paddy field, uncommercial land and urban are respectively inundated by 100-year flood, which it is showed that the flooded area increased with flooding intensity, mostly paddy field was moderately inundated (0.49 % changes) by different year flooding from 5 - 100 years, and slightly followed by urban area, and cultivation, whereas the uncommercial and industrial are the least effected.

Table 2 Flooded areas (%) according to the landuse types based on return periods

Landuse Types	Total flood damage area (km^2)									
	5 years Flood		10 years Flood		25 years Flood		50 years Flood		100 years Flood	
	Area	%	Area	%	Area	%	Area	%	Area	%
Cultivation	2.56	1.26	3.44	1.45	3.47	1.44	3.50	1.44	3.59	1.43
Forest	2.85	1.41	3.05	1.28	3.07	1.28	3.08	1.27	3.08	1.23
Industrial land	0.10	0.05	0.21	0.09	0.21	0.09	0.21	0.09	0.21	0.08
Miscellaneous land	36.87	18.18	41.13	17.27	41.65	17.33	42.24	17.40	43.33	17.33
Paddy Field	154.89	76.38	182.76	76.76	184.36	76.72	186.16	76.69	192.18	76.87
Uncommercial land	1.93	0.95	2.60	1.09	2.60	1.08	2.60	1.07	2.60	1.04
Urban Area	3.59	1.77	4.91	2.06	4.93	2.05	4.96	2.04	5.01	2.00
Total	202.78	100.00	238.10	100.00	240.28	100.00	242.75	100.00	250.01	100.00

CONCLUSION

This study focused on a systematic approach in the preparation of floodplain modeling integrating of hydraulic simulation with GIS analysis. The major tools/models used in this method were one-dimensional numerical model HEC-RAS and ArcView GIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and ArcView GIS. Results of this study can separate high-hazard from low-hazard areas in the floodplain to minimize future flood losses. Hydraulics simulation for floodplain mapping could be beneficiary in several aspects for land and water resources management and also engineering purposes. It can be applied to prevent unwise land use in flood prone areas and flood insurance studies, based on modeling of water surface elevations for design flood events. The evaluation of floodplain delineation are rather complex and demanding activities, which require a comprehensive approach to hydraulic floodplain simulation and can be largely enhanced by using GIS capabilities. It can be concluded that the usage of GIS for the undertaking of a hydraulic simulation is as the potential to both of accuracy improvement and cost-saving for floodplain and flood hazard mapping. Moreover, the combination of ArcView GIS and HEC-RAS provides powerful tools for planners and decision makers.

ACKNOWLEDGEMENTS

Authors would like to acknowledge for the financial support from The Greater Mekong Subregion (GMS) and also grateful thank to Assoc. Prof. Dr. Vichai Sriboonlue and staffs at Water Resources and Environmental Institute (WREI) and Department of Agricultural Engineering, Faculty of Engineering, Khon Kaen University (KKU) for their support and data collection for the research process.

REFERENCES

Abdalla, R., Vincent, T.C., Wu, H., and Maqsood, I. 2006. A GIS-supported 3D approach for flood risk assessment of the Qu'Appelle River, Southern Saskatchewan. Int. J. Risk Assess. Manage., 6, 440-455.

Barbad, M., Behnia, A., and Motiei, H. 2002. Flood zoning in watersheds by combining GIS and mathematical models. 6th International Seminar of River Engineering.

Beven, K., and Carling, P.A. 1992. Velocities, roughness and dispersion in the lowland River Severn. In: Lowland Floodplain Rivers: Geomorphological Perspectives (ed. by Carling, P.A. and Petts, G.E.), 71-93, John Wiley, Chichester, UK.

Chow, V.T. 1959. Open Channel Hydraulics. McGraw Hill Inc., Singapore.

Earles, T.A., Wright, K.R., Brown, C., and Langan, T.E. 2004. Los Alamos forest fire impact modeling. J. Am. Water Resour. Assoc., 4, 371-384.

Food and Agricultural Organization (FAO). 1985. Inland fisheries in multiple-purpose river basin planning and development in tropical Asian countries three case studies. (Retrieved from http://www.fao.org /DOCREP/ 003/ X6861E/X6861E00.)

Gilard, O. 1996. Flood risk management: Risk cartography for objective negotiations. Proc., 3rd IHP/IAHS George Kovacs colloquium, UNESCO, Paris.

Khon Kaen University (KKU). 2003. Research on environmental management of the Pong watershed. Khon Kaen University, Thailand.

Noori, S.A. 2001. GIS in flood warning systems. M.Sc. thesis, University of Ferdowsi Mashhad, Iran.

Noman, N.S., Nelson, E.J., and Zundel, A.K. 2003. Improved process for floodplain delineation from digital terrain models. J. Water Resour., 129, 427-436.

Water Resources and Environmental Institute (WREI). 2012. GIS topographic data of Lower Nam Phong watershed. Unpublished.

Yang, J., Townsend, R.D., and Daneshfar, B. 2006. Applying the HEC-RAS model and GIS techniques in river network floodplain delineation. Can. J. Civil Eng., 33, 19-28.