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FLOOD HAZARD MAPPING USING ON-SITE SURVEYED FLOOD MAP, HECRAS V.5 AND GIS TOOL: A CASE STUDY OF NAKHON RATCHASIMA MUNICIPALITY, THAILAND

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ABSTRACT: For a small flood affected area, satellite data normally provides physical properties of flood event with low accuracy information (location and boundary). Flood depth and flood duration cannot be identified from a snapshot of satellite image. Therefore, on-site surveying of historical flood properties and its impact are still essential, and this observed flood map is realistic and reliable information for future flood management. The objective of this study is to construct a flood hazard map from available observed flood map of the small flood affected area and use HEC-RAS V. 5 and GIS tool to formulate the flood hazard map for future scenarios. This method was applied for the municipality of Nakhon Ratchasima, Thailand. For a simulation, input physical parameters were generated by Hec-GeoRAS in ArcGIS based on DEM (5×5 m^2). A range of calibrated Manning's n in a main channel was obtained from fitting exercise with observed Rating curve. Land-use map was used to estimate the Manning's n in floodplain depending upon the type of land cover. Simulated results were exported to ArcGIS to delineate water surface on floodplain. Then, the maximum discharge value at the observed station (M. 164) for return periods of 5, 10, 15, 25, 50, and 100 years were used as upstream input flood to simulate the flood map. It is found that, for the 2010 flooding event in the concerning area, the simulated flood hazard map subjected to the discharge of 50 years return period (217 m^3/s) which is almost identical with the observed flood map from the surveying.

Keywords: *Rating curve, Historical flood map, Flood simulation, Land-use, Flood frequency*

1. INTRODUCTION

The most important disaster with higher occurrence is flooding. It is more than any other natural disasters and affects more people than other natural hazards altogether [1]. Floods are interrelated to civil society conflicts [2], environmental problems [3] and economic losses [4]. Floodplains can be defined as the areas that are periodically inundated by the overflow of river [5]. In 2010, Nakhon Ratchasima province received excessive rainfall in successive day during 14 – 16 October 2010. Most of the floodplain areas in Nakhon Ratchasima province suffered from this serious flooding event. Heavy rains caused a large amount of runoff to flow into both upstream and downstream of all reservoirs in Nakhon Ratchasima province including Lam Takong and Lam Prapleng Dams. With ongoing water flowing into these reservoirs until exceeded its capacity, the water level was higher than the level of emergency service spillway, which in turn caused severe uncontrolled flood flow into many municipalities downstream. The large amount of water was a combination of surface runoff and excessive water from many reservoirs flow rapidly to downstream canals. The combination of these events caused widespread flooding on the floodplain in lower basin, including Muang Nakhon Ratchasima district, Pukthongchai district and Chaloemphrakiat district, etc. Flood water from tributary of Mun River was drained slowly into Mun River because the water level in Mun River was higher than the water level in tributary canals and there were obstructions in the canal which resulted in reduced flow speed [6-8].

River flood modelling is a tool for evaluation and prediction of river flood risk in different scenarios. The river flood risk modelling comprises of hydrological modelling, hydraulic modelling, river flood visualization and river flood mapping [9]. A flood hazard map is a graphical representation of flood inundation (inundation depths, extent, flow velocity etc.) expected for an event of given probability or several probabilities [10]. The flood hazard map will help responsible authorities to target on the area with higher hazard where flood mitigation plans have to be effectively implemented. Although flood hazard maps are unable to prevent floods from occurring, they are an essential tool for flood warming and mitigation of property damage and loss of life and it can be used to communicate flood risk to public. The flood hazard map gives the public tangible imagery of its impact on their community. The flood hazard map can be generated from a variety of tools, for example, (1) vertical aerial photographs due to the lack of detailed topographic maps [11], (2) a remote sensing and GIS based flood index [12], field surveying using flood mark data (including flood depth and flood duration) and analytic hierarchy process [13] and (4) a hydraulic simulation tools. Currently, hydraulic simulation tools are available to model channel discharge and flooding in floodplains with 1D and 2D approaches. Commercial software packages are widely used and distributed such as FLO-2D to simulate floods and flows [14] and the MIKE package modelling tools [15]. GIS and intelligent techniques were developed to include flood susceptibility assessment by combining adaptive neuro-fuzzy inference system (ANFIS) with a genetic algorithm and differential evolution for flood map modelling [16]. One of the most popular hydraulic models is the Hydrologic Engineering Center River Analysis System (HEC-RAS). It is a free software with user friendly and graphical user interface that is successfully used for many flood studies [17–20]. HEC-RAS announced and released a new HEC-RAS version 5 with 2D capability, which is a great innovation for flood studies [21]. The Flood map event, simulated by the 2D HEC-RAS V.5, shows good performance when is compared with flood extent generated by satellite images [22]. Furthermore, HEC-RAS has more accurate results of river flood map (flood extent and water depth) in comparison with MIKE11 for urban area. In recent years, GIS integrated modelling application has been made to integrate hydraulic models and GIS to facilitate the manipulation of the model output, which led to the establishment of a new branch of hydraulics and hydrology. There are strong grounds for believing that GIS has an important function because natural hazards are multi-dimensional phenomena, which have a spatial component [23-24].

The available flood map in Thailand from Geo-Informatics and Space Technology Development Agency (GISTDA) presents spatial data of inundation area and expansion of flood boundary. However, it cannot exhibit high resolution of flood depth and flood duration [5]. In order to define measures for flood mitigation and evaluate its results, physical characteristic of inundation area combining with consequent impact must be defined in the form of flood hazard map. Therefore, this study aims to simulate flood hazard map for different return periods by using on-site surveying of the 2010 flood event in Nakhon Ratchasima Municipality and the 2D capabilities of HEC-RAS V.5 application. The model provides the simulation of flood properties such as flood extent, flood depth and velocity. The simulation results can be used to improve the accuracy of recorded flood data in study area.

2. STUDY AREA AND DATASET

Nakhon Ratchasima Municipality is an urban center of Nakhon Ratchasima Province, Thailand. It is located at the downstream of the Lam Ta Kong River, which is a tributary of Mun River basin. The length of main stream of river is 17 km and study area is 37.5 km^2 as shown in Fig. 1 and 3 The observed daily discharge data of the Lam Ta Kong River at station M.164 is provided by Royal Irrigation Department of Thailand. Mean annual rainfall is 1,373 mm and contributes to 510×10^6 m^3 of the total average annual runoff. Fig. 2 shows that majority of the areas are urban and built-up land-uses, where the population is approximately 136,153 people in year 2010 [25]. The geographic data based on the digital elevation model (DEM) from the Land Development Department of Thailand have a grid cell size of 5×5 m^2 demonstrating elevation between 172.6-204.6 m.MSL, shown in Fig. 3.

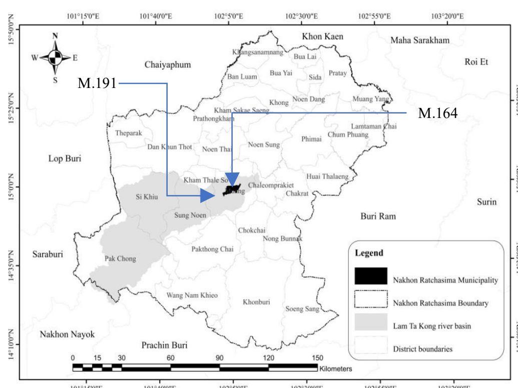

Fig.1 Boundary and location of study area in Nakhon Ratchasima province, Thailand

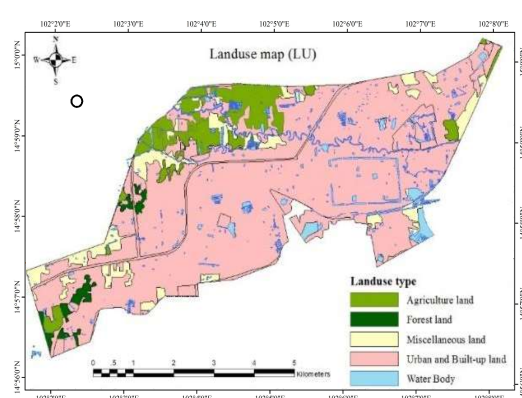

Fig. 2 Land-use of Nakhon Ratchasima Municipality

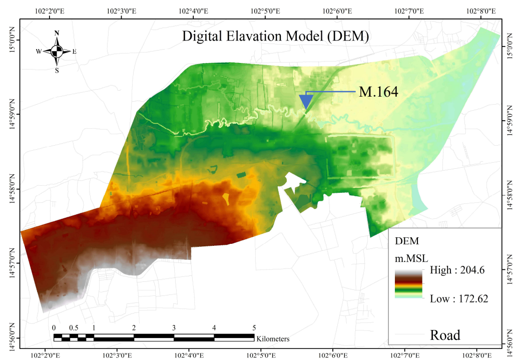

Fig. 3 DEM of Nakhon Ratchasima Municipality

3. METHODOLOGY

The methodology for mapping a flood hazard map (shown in Fig. 4) can be divided into two parts: historical flood investigation and modeling approach for numerical simulation. Important steps of these parts are described below.

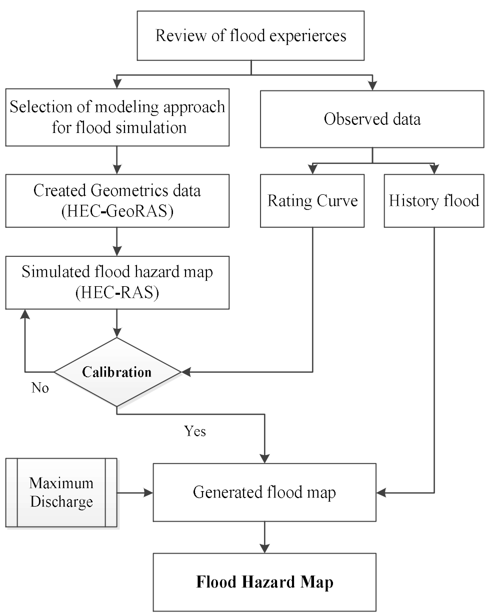

Fig.4 Flowchart of the study step, which is a conceptual framework of this research

3.1. Observed Flood Data

Upstream of Mun River Basin in the northeastern part of Thailand recieved continuous heavy rain during 1-19 October 2010, particularly in mountain part of the Khao Yai National Park, where maximum daily rainfall was recorded about 450 mm, which was around 40 % of the annual amount [6]. The maximum 3 days rainfall (14-16 Oct 2010) in the upstream of Lam Ta Khong Dam was 180.3 mm, while in the downstream was 211.6 mm. The storage of Lam Ta Khong Dam and all nearby reservoirs rose very quickly and its downstream was extensively flooded. The dam operator failed to keep flood water in the reservoir. Since 17 October 2010, excess volume of flood began to overflow the service spillway at +277.30 m.MSL [6-8]. Previous study [5] on analyzed water balance of runoff found that accumulated depth of rainfall and volume of surface water in the year 2010 was higher than the other years. The severe scaling of flooding problem can be captured in the form of inundation map. Although the boundary and location of 2010 flood inundation area are provided by GISTDA, its accuracy is low for small urban area. Fig. 5 shows the surveyed point of flooding and the flood map obtained from field surveyed data, representing an inundation area and flood depth of Nakhon Ratchasima Municipality of 2010 flood event. This map can be developed further to include spatial variability of the depth and area and can be used to evaluate the hazard area and mitigation measures.

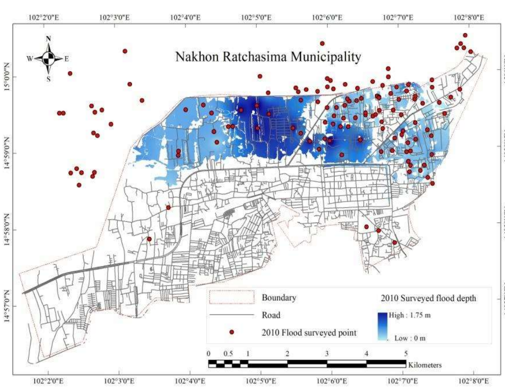

Fig.5 The 2010 surveyed point of flooding of Nakhon Ratchasima Municipality [5]

3.2. Modeling Approach for Numerical Simulation

Several hydraulic simulation tools are available to model channel discharge and flooding in a floodplain with 1D and 2D approaches. One of the tools is provided by the Hydrology Engineering Center River Analysis System (HEC-RAS) which is available in public domain. Hence, a new HEC-RAS V.5 model developed by the United States Army Corps of Engineers (USACE) is used in this study to simulate the flood event in Nakhon Ratchasima Municipality. The new HEC-RAS V.5 can solve either the full 2D Saint Venant equations or the 2D diffusive wave equations.

$$\frac{\partial \delta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \quad (1)$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{pq}{h}\right) = \frac{n^2 pg\sqrt{p^2+q^2}}{h^2} - gh\frac{\partial \delta}{\partial x} + pf + \frac{\partial}{\rho \partial x}(h\tau_{xx}) + \frac{\partial}{\rho \partial y}(h\tau_{xy}) \quad (2)$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) = \frac{n^2 qg\sqrt{p^2+q^2}}{h^2} - gh\frac{\partial \delta}{\partial y} + qf + \frac{\partial}{\rho \partial y}(h\tau_{yy}) + \frac{\partial}{\rho \partial x}(h\tau_{xy}) \quad (3)$$

where h is the water depth (m), p and q are the specific flow in the x and y directions (m/s), δ is the surface elevation (m), g is the acceleration due to gravity (m/s^2), n is the Manning resistance, ρ is the water density (kg/m^3), τ_{xx} τ_{yy} and τ_{xy} are the components of the effective shear stress and f is the Coriolis (s^{-1}). When the diffusive wave is selected the inertial terms of the momentum equations Eq. (2) and (3) are neglected.

The geometric data including streamline, bank stations, cross section and flow path line were digitized and generated from DEM by Hec-GeoRAS tool in ArcGIS application. Generally, the simulation of flood map can be modelled as a fully 2D model. However, a hybrid model (1D and 2D model) can be used to simulate flood map when the main rivers are modelled as 1D model and the floodplains are modelled as 2D model. Although this hybrid model is faster than a fully 2D model, the hybrid model requires user to define the connections between the 1D and the 2D models to obtain the overflow locations [21].

The Extreme Value Type I distribution or Gumbel distribution is used to fit the observed or simulated annual maximum runoff by using frequency factors [26].

4. RESULTS AND DISCUSSION

4.1. Observed Annual Maximum Discharge

The observed annual maximum discharge at gauge station (M.164) was analyzed by Gumbel distributions shown in Table 1. The daily discharge recorded was 123.9 m^3/s on 18th October 2010 as around 8 years return period which was too low compare to observed flood area. The previous study found that the recorded discharge was possibly underestimated values [5]. This error of observed maximum discharge have to be examined before using as input condition for the simulation of floodplain inundation.

4.2. Roughness Coefficients (Manning's n)

The Rating curve at M.164 on 2010 and 2013 from the Royal Irrigation Department data were used to calibrate and validate the geometric data along the river by varying the Manning's n values. As a result, Figure 6 clearly shows that the n values between 0.020-0.035 (vary with elevation of main channel), provides the simulated rating curve with good agreement to the observed rating curve, the lowest RMSE in Table 2. Therefore, this range of n values was used as the suitable physical data for the further simulation. In addition, the n values for the floodplain consisting of different land-use type were selected based on the observed and recommended data as summarized in Table 3 [21].

4.3. Flood Hazard Map

Fig.7 (a) to (f) illustrate flood hazard map subjected to various maximum discharges with different return periods (T=5, 10, 15, 25, 50 and 100 years) by fitting observed annual maximum discharge with Gumbel distribution. Flood extent for all return periods are shown as a similar pattern. The floods inundation areas are located at northern part of the river when the discharge is higher than the maximum capacity of the main channel (40 m^3/s) and extend with increasing discharges. Fig. 8 represents a comparison of flood depth between 2010 surveyed depth of flooding and simulated flood depth from received annual maximum discharges with different return period. The results also show that the simulated flood areas of flood hazard map subjected to the 50 years return period (Fig. 7 (e)). It is almost identical with onsite surveying flood map.

4.4. Correction of Flood Hydrograph

During 2010 flood event, there was an error of recorded hydrograph at station M.164. Peak discharge of observed hydrograph of M.191 upstream of M.164 was 410 m^3/s, whereas peak discharge of M.164 downstream was too low only 123.9 m^3/s (Fig. 1 and 9) [5]. After successful mapping of the flood hazard map and found that the frequency of 2010 flood event was about 50 years return period. Based on this approach and simulation, a new hydrograph was generated and compared to recorded hydrograph by using 1D model of HEC-RAS. These results confirmed that the recorded hydrograph at M.164 was underestimated values. To correct this flood hydrograph, the new hydrograph represented by a dash line in Fig. 9 was simulated to adjust the peak of observed hydrograph from 123 to 217 m^3/s.

Table 1 Observed annual maximum discharges for different return period (T) at M.164.

T(year)	2	5	10	15
Q(m^3/s)	52	105	140	159
T(year)	20	25	50	100
Q (m^3/s)	173	184	217	249

Table 2 Root mean square error (RMSE) between simulated and observed rating curve with different Manning' n

Manning's n	0.020	0.025	0.030	0.035
RMSE	0.143	0.127	0.136	0.159
Manning's n	0.040	0.045	Vary (0.020-0.035)	
RMSE	0.189	0.219	0.100	

Table 3 The value of the Manning roughness (n) for different land-use types [21].

Land-use Types	Value
Main channel of river	0.020-0.035
Land-use on floodplain	
Agriculture land (A)	0.045
Forest land (F)	0.060
Urban and built-up land (U)	0.055
Miscellaneous land (M)	0.050
Water Body (W)	0.040

5. CONCLUSION

To construct flood hazard map for a small flood affected area such as the Nakhon Ratchasima Municipality, studying step starts from (1) on-site surveying on 2010 flood event to construct observed flood map (2) applying HEC-RAS V.5 and GIS tool to receive high resolution geometric data (DEM 5 × 5 m^2) from HEC-GeoRAS in ArcGIS application and calibrated value of Manning's n for simulating 2D flood inundation extent and flood depth. Simulated flood hazard map based on input maximum discharge at different return periods confirms that the simulated flood hazard area at 50 years return period is almost identical to 2010 observed flood event. One more application of the constructed flood hazard map is to correct the relative magnitude of peak discharges between upstream and downstream hydrographs to realistic manner.

Maximum discharges for different return periods from HEC-RAS V.5 were simulated based on the assumption of steady flow condition. Therefore, flooding durations of inundation for each grid cells were unable to estimate.

From physical properties of flood characteristics presented by the flood hazard map will be developed further to construct a flood risk map by formulating flood risk index (combination of flood properties, socio-economic factor and land-use) and using GIS raster index model. The flood risk map can be utilized as a tool to identify priority of the area for planning of flood prevention, flood mitigation, and flood risk management.

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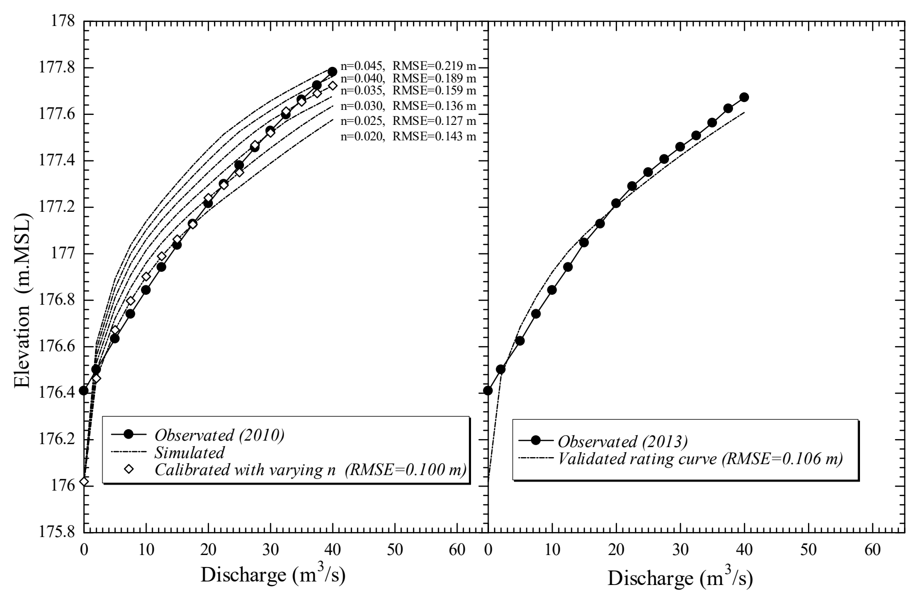

Fig. 6 Comparison of observed, simulated and validated Rating curve

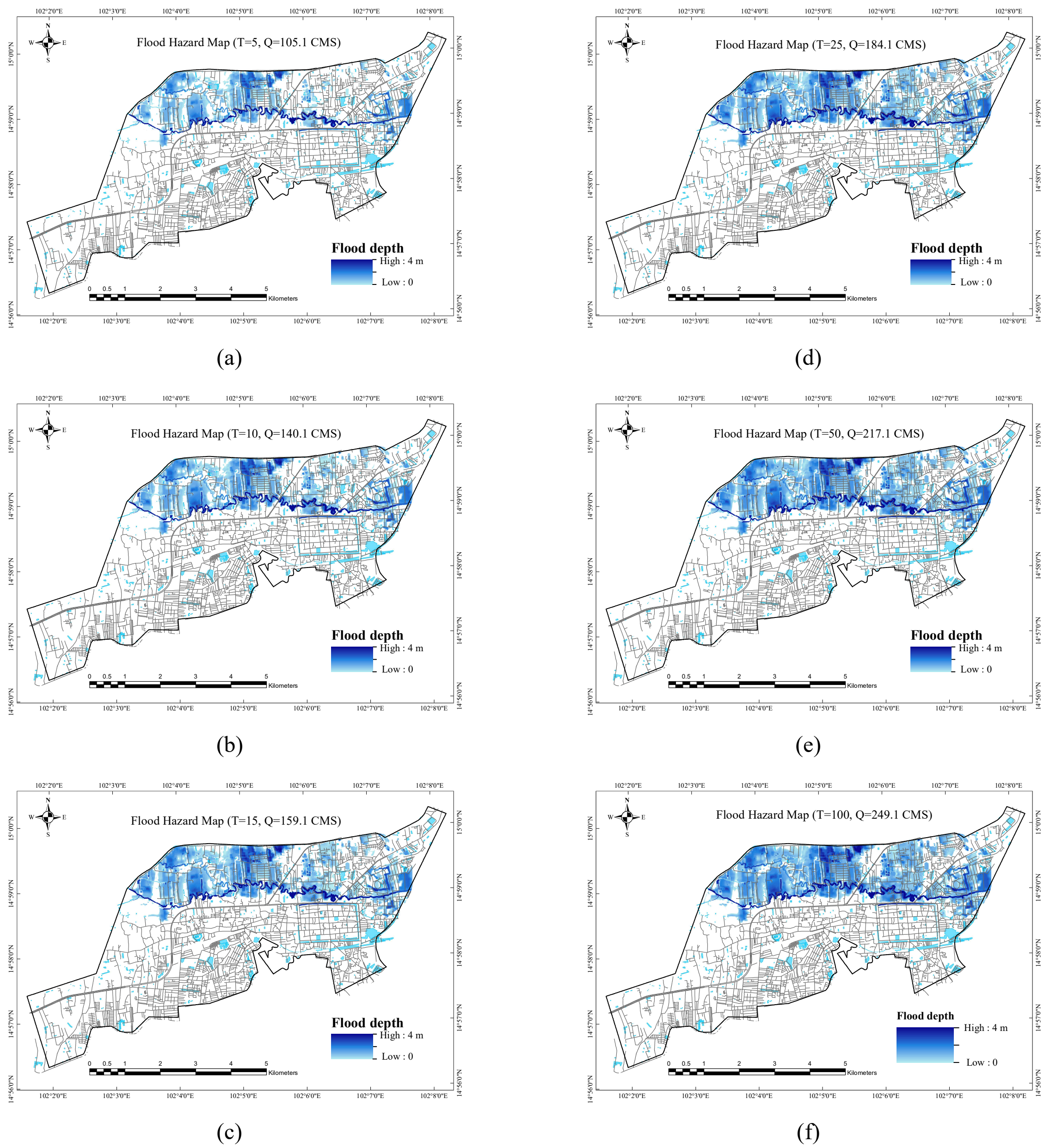

Fig. 7 Simulated flood hazard area at the return period (a) T=5 year Q=105.1 m^3/s, (b) T=10 year Q=140.1 m^3/s, (c) T=15 year Q=159.1 m^3/s, (d) T=25 year Q=184.1 m^3/s, (e) T=50 year Q=217.1 m^3/s and (f) T=100 year Q=249 m^3/s

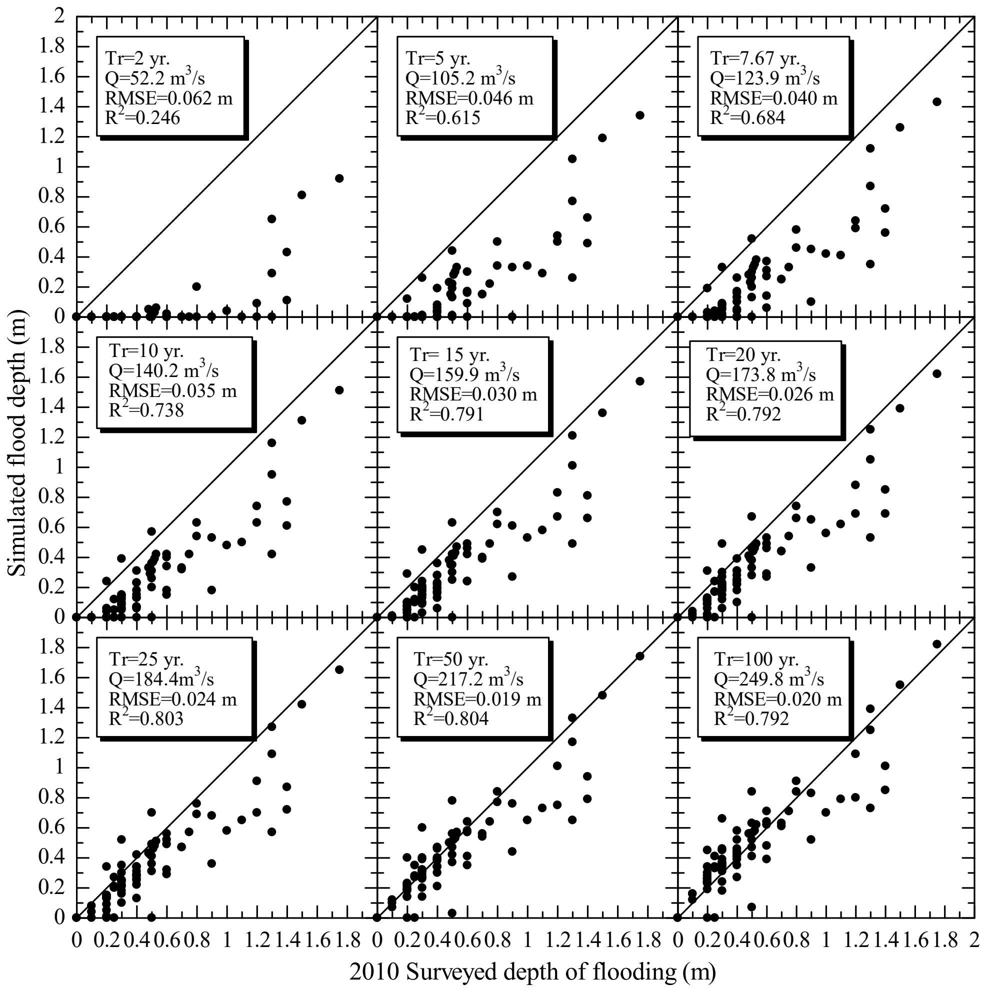

Fig. 8 Comparison on surveyed and simulated flood depth for different return period

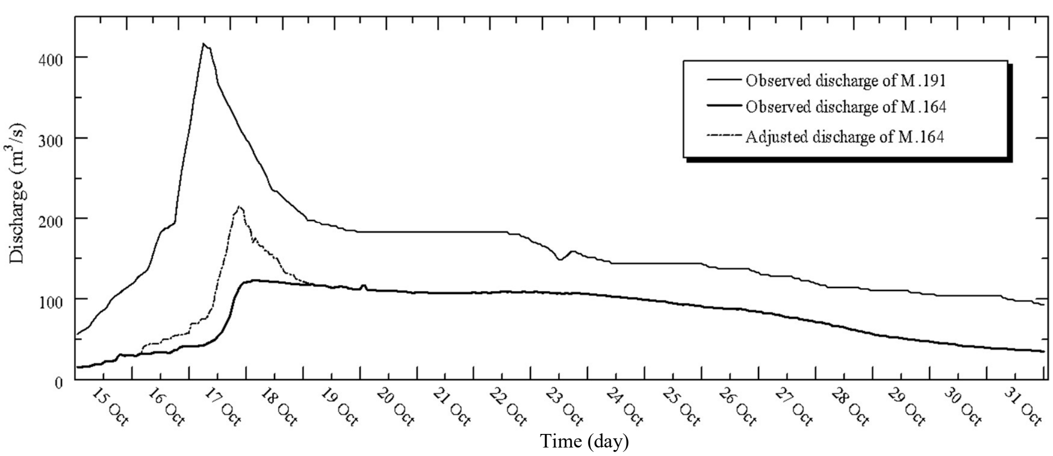

Fig. 9 Comparison of observed and corrected 2010 flood hydrograph at M.164 with upstream at M.191

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