IMPACT ASSESSMENT OF LAND USE/LAND COVER AND CLIMATE CHANGES ON FLOOD OCCURRENCES IN CHIANG MAI MUNICIPALITY, THAILAND

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Abstract: Land use/land cover (LULC) and climate are often believed to play crucial roles in determining characteristics of flood event in a particular area and their influences can be accessed through the use of a hydrologic model and GIS application. In this work, a new grid-based hydrologic model was developed and applied to the study of LULC and rainfall influences on runoff discharges and associated flood occurrences in the Chiang Mai municipality area during September 2005. Several case studies of the LULC (focused on forest loss) and rainfall changing scenarios were examined. It was preliminarily found that, in all applied case studies if consider only the closest drainage area of the P1 gauging station on the Ping River (about 1,121 km^2), the considered LULC and rainfall changes generate little impacts on simulated discharge data at the station. However, their impacts are more apparent if those preferred changes were applied to larger associated drainage area of the station situated far upstream (about 6,350 km^2). The observed trends are that amount of the simulated discharges increase with higher rates of forest loss and rainfall intensity. It was found that, the assumed forest loss of 10 and 20% shall result in the average increase of modeled runoff at the station by 3.47% and 7.20%, respectively (compared to the normal 2005 case). And the increase of rainfall intensity by 5%, 10%, and 15% shall result in the increase of the modeled runoff by 13.40%, 27.30%, 41.44%, respectively. For the worst case of forest loss (20% loss), number of flood dates is still similar to that found in 2005 (4 dates) but the total flood area is higher due to higher level of the average flood depth. But for case of 15% rainfall increase, number of flood dates rises to 10.

INTRODUCTION

Floods are destructive natural phenomena which can lead to serious problems in lowland regions, resulting in significant loss of human life and affecting fertility of natural resources and man-made properties. One of the effective approaches to analysis flood development and expansion can be achieved by using the hydrologic model. This model can describe relationship between rainfall distribution data and amount of the runoff discharge (that initiates river flood) based principally on knowledge of some factors such as soil properties, topography, drainage system, and land use/land cover. Most hydrologic models had been developed using complicated mathematical formulation and mainly designed to utilize at basin scale. Some crucial deficiencies of these models are their lump-based segmentation of the study area in which fine details of the water balance process are still not realistically explained. They are also still lack of remote sensing and GIS applications integrated in the processing module. This can hinder ability of the model in predicting near-real time flood forecasting at fine scale.

To demonstrate advantages of using remote sensing (RS) and GIS technology in the prediction of runoff discharge and the associated flooding scenario, this thesis has developed a new grid-based hydrologic model using the Chiang Mai sub-basin (in the upper Ping watershed) as study area. The core processing algorithm of this model is based on the original lump-based model described in Jothityangkoon et al. (2001), Jothityangkoon and Sivapalan (2003), Jothityangkoon and Hirunteeyakul (2006; 2009). However, it has much better spatial resolution on the discharge analysis due to its grid-based nature on the contrary to the referred lumped model that can manage the analysis at basin/sub-basin scale only. The stated model is structured to realistically simulate observed runoff discharge data in the Ping River during September 2005 (daily basis). In addition, impact of the land use/land cover (LULC) or climate changes (rainfall in particular) over runoff discharge data and their associated flooding characteristics can also be readily examined by the proposed model based on the grid-based nature of its processing algorithm. The chosen study area is a part of the upper Ping Basin covering area of about 1,121.09 sq. km in the Chiang Mai Province (Figure 1) and the water level in the Ping River at the P1 station (at Navarat Bridge) was used to generate flood extent in the Chiang Mai inner city area.

Figure 1: Topographic map and stream network of the study area.

RESEARCH METHODOLOGY

There are four main steps that were fulfilled in this research:

1. Construction of the new grid-based hydrologic model;
2. Simulation of LULC changes using the CA-Markov model;
3. Simulation of runoff data at the P1 station based on different LULC and rainfall data;
4. Simulation of flood events based on the known runoff data at P1 station found in Step 3.

In Step 1, the new grid-based hydrologic model was developed based on the following water balance equation,

$$\frac{ds(t)}{dt} = p(t) - q_{ss}(t) - q_{se}(t) - e_b(t) - e_v(t)\,, \tag{1}$$

where $s(t)$ is the volume of soil moisture storage, $p(t)$ is the rainfall input rate, q_{ss} is subsurface runoff, q_{se} is saturation excess runoff rate, e_b is bare soil evaporation rate and e_v is the transpiration rate. The formulated hydrologic model receives values of all physical parameters from GIS model and generates simulated runoff for each grid cell. Then, the flow path and flow accumulation are formulated using DEM and converted to parameters for the routing model. Simulated runoff discharges from the invented model (at P1 station) were compared to the observed one at the same stations. And model's modification is accepted if it can produce moderate to good agreement between both set of data in term of the coefficient of determination (R^2), e.g., with $R^2 \geq 0.5$, and also satisfies the acceptable Nash-Sutcliffe efficiency criterion of $E \geq 0$ (Moriasi et al., 2007).

In Step 2, the LULC maps in years 2020 were produced using the CA-Markov model based on knowledge of the LULC maps in years 2000 and 2010 classified from Landsat-TM imagery. In this study, the transformation rates of forest/perennial class to other LULC classes were also adjusted in order to quantify impacts of different forest-loss scenarios.

In Step 3, data of water level at the P1 station were simulated through the use of the newly-developed hydrologic model mentioned earlier based on different LULC and rainfall input data. Here, the forest/perennial loss of 10 and 20% and increase of rainfall intensity by 5%, 10%, and 15% (from the 2005 data) were considered.

In Step 4, flood events based on the known water levels at P1 station in Step 3were simulated through the DEM-based interpolation of the flood extent from the river bank into the lowland areas nearby.

RESULTS AND DISCUSSION

In Step 1, the simulated daily runoff data at the P1 station during September 2005 show high correlation level to the actual observed data with R^2 = 0.956 and E = 0.94 (Figure 2) .

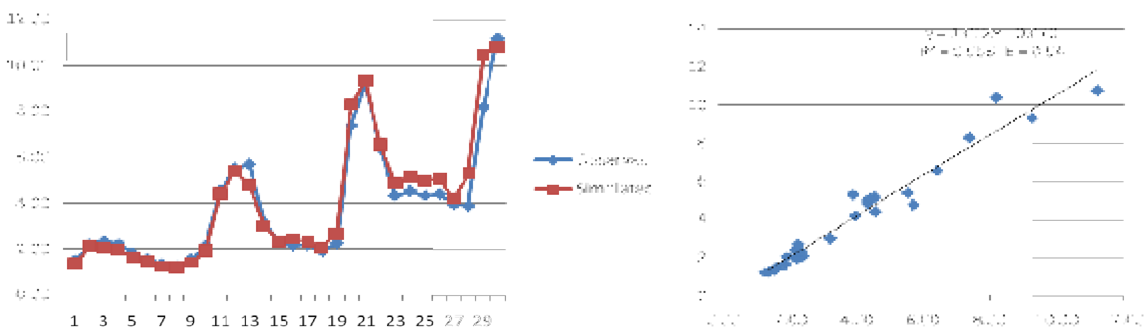
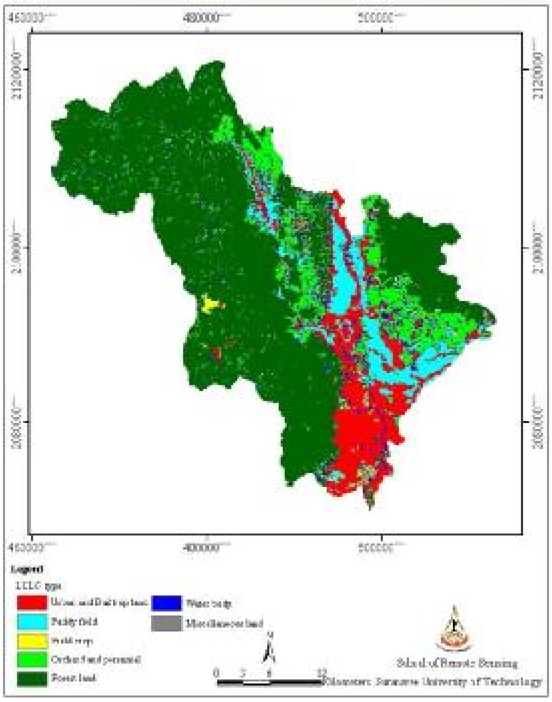


Figure 2: Efficiency of the developed model on the simulation of daily runoff during September 2005.

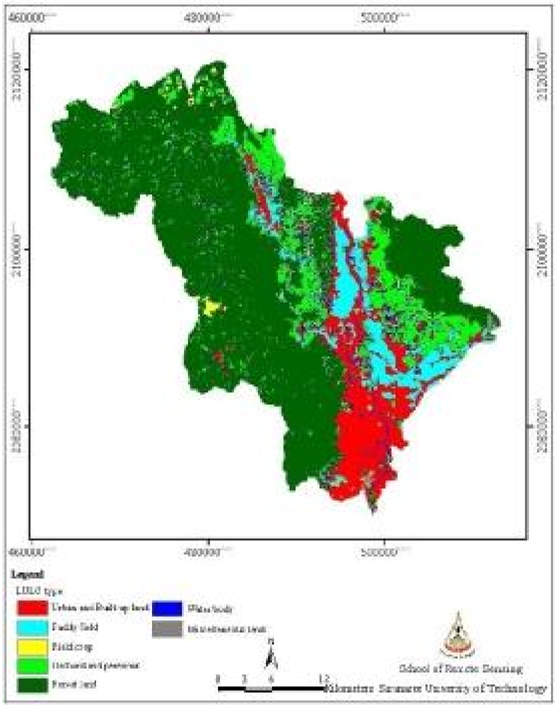
In Step 2, the LULC maps in years 2015 and 2020 were produced by using the CA-Markov model based on knowledge of the LULC maps in years 2000 and 2005 classified from the Landsat-TM imagery. In this study, the transformation rates of forest/perennial class to other LULC classes were also adjusted in order to quantify impacts of different forest/perennial loss scenarios (10 and 20%). Results are shown in Table 1 and Figure 3.

Table 1: LULC area allocation for years 2005 and 2020 (4 cases) as presented in Figure 3.

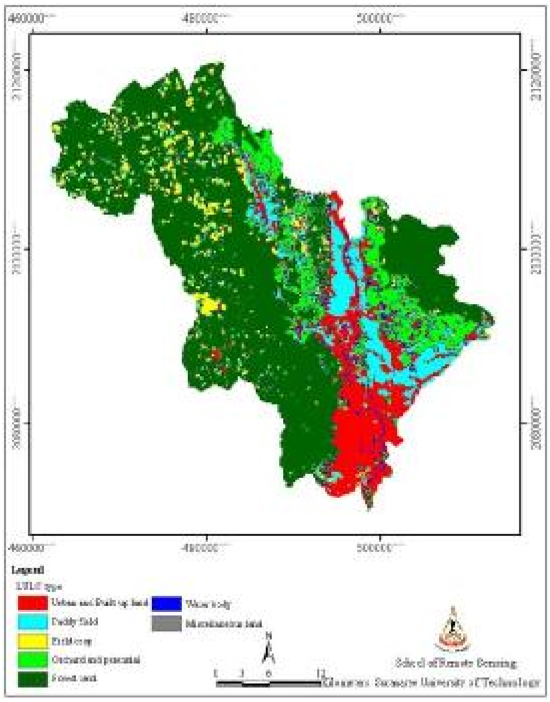
LULC type	2005 (normal scenario)		2020 (normal scenario)		2020 (10% loss)		2020 (20% loss)	
	km^2	%	km^2	%	km^2	%	km^2	%
Forest	700.31	62.47	676.62	60.35	625.94	55.83	607.55	54.19
Orchard/Perennial	128.33	11.45	143.82	12.83	131.72	11.75	61.11	5.45
Crop	22.23	1.98	26.65	2.38	91.73	8.18	109.16	9.74
Paddy field	102.92	9.18	100.21	8.94	102.22	9.12	113.90	10.16
Urban/built-up	152.69	13.62	162.09	14.46	157.45	14.04	217.34	19.39
Water body	8.10	0.72	7.53	0.67	7.85	0.70	7.84	0.70
Miscellaneous	6.52	0.58	4.18	0.37	4.19	0.37	4.19	0.37
Total	1121.09	100.00	1121.09	100.00	1121.09	100.00	1121.09	100.00



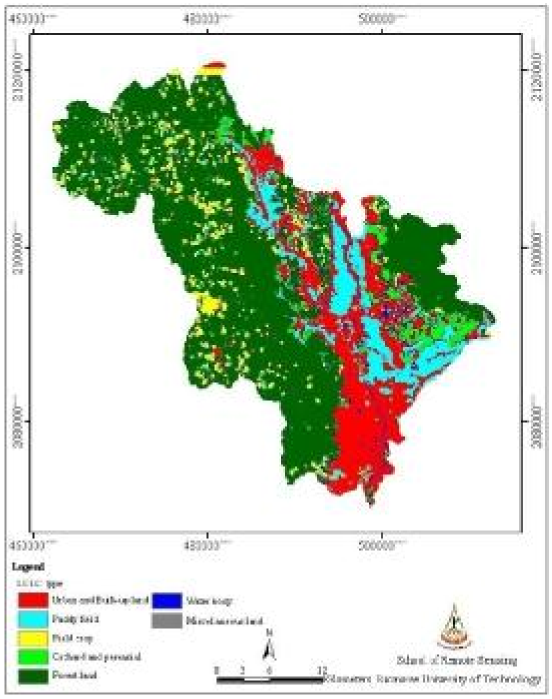
(a) 2005 classified LULC map (normal case)



(b) 2020 classified LULC map (normal case)



(c) 2020 classified LULC map (10%-loss case)

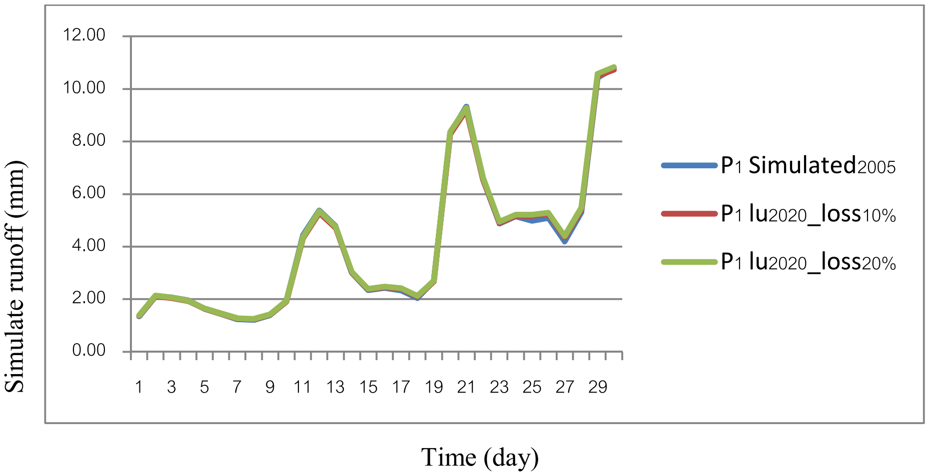


(d) 2020 classified LULC map (20%-loss case)

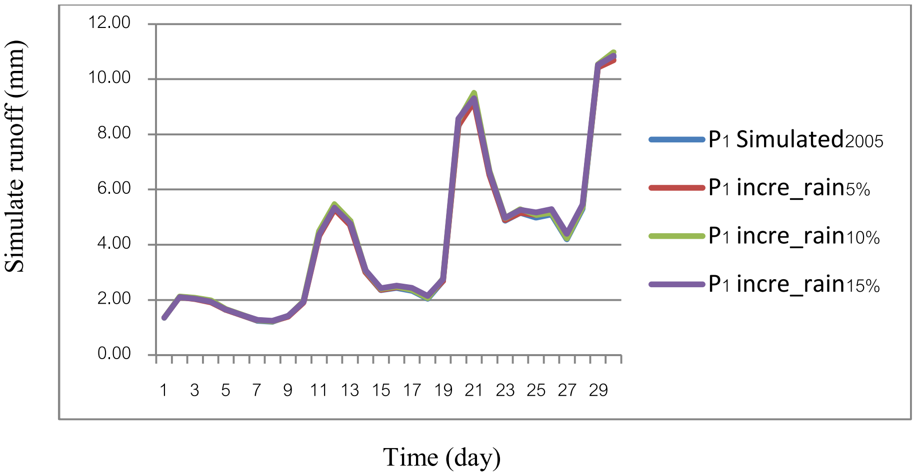
Figure 3: Classified LULC maps for years 2005 and 2020 (4 cases).

In Step 3, data of runoff data at P1 station were simulated by using the newly-developed hydrologic model mentioned earlier based on different LULC and rainfall input data. Here, the forest/perennial loss of 10 and 20% and increase of rainfall intensity by 5%, 10%, and 15% (from the 2005 data) were considered. Results at this step are presented in Figure 4. It was found that differences of simulated runoff data in 2020 (3 cases of forest/perennial loss and 4 cases of rainfall increase) and those of 2005 (normal case) at the P1 station are significantly low (less than 1-2%). This indicates that under given assumptions, impacts of the forest/perennial loss and rainfall increase to runoff data at the P1 station are still insignificant.

To improve our knowledge on impacts of forest/perennial loss and rainfall increase to runoff data at the P21 station, the original study area (about 1,121 km^2) was expanded to include the associated basin upstream (about 6,350 km^2). This resulted in more notable changes of the runoff data in all cases of forest/perennial loss and rainfall increase (Figure 5 and Table 2). It was found that, the assumed forest loss of 10 and 20% shall result in the average increase of modeled runoff at the P1 station by 3.5% and 7.2%, respectively (if compared to the normal 2005 case). And the increase of rainfall intensity by 5%, 10%, and 15% shall result in the increase of the modeled runoff by 13.4%, 27.3%, 41.4%, respectively. These results mean impacts of the forest/perennial land loss and increase in the rainfall amount on the observed runoff data at the P1 station (of Chiang Mai Province) shall be strongly pronounced if wider associated basin (or drainage) area is considered.



(a) Simulated runoff data for different cases of forest/perennial loss.



(b) Simulated discharge data for different cases of rainfall increase.

Figure 4: Simulated runoff data at P1 station for years 2005 and 2020 (basin area = 1,121 km^2).

Table 5: Simulated runoff data at P1 station for years 2005 and 2020 (basin area = 6,250 km^2). Highlighted numbers are for flooding days in each considered case.

Date (September)	Normal (2005)	Forest/perennial loss		Rainfall increase		
		10%	20%	5% up	10% up	15% up
1	1.35	1.41	1.46	1.55	1.74	1.94
2	2.11	2.18	2.25	2.38	2.68	2.98
3	2.06	2.13	2.21	2.34	2.62	2.92
4	1.96	2.00	2.08	2.20	2.46	2.73
5	1.64	1.70	1.76	1.87	2.10	2.33
6	1.44	1.49	1.54	1.63	1.83	2.04
7	1.24	1.30	1.35	1.44	1.61	1.79
8	1.21	1.28	1.33	1.40	1.57	1.76
9	1.40	1.45	1.51	1.59	1.79	1.99
10	1.92	1.97	2.05	2.17	2.44	2.72
11	4.42	4.45	4.61	4.88	5.48	6.09
12	5.38	5.48	5.68	6.02	6.75	7.49
13	4.78	4.85	5.02	5.32	5.96	6.62
14	3.00	3.12	3.23	3.41	3.82	4.24
15	2.35	2.45	2.53	2.68	3.00	3.32
16	2.43	2.53	2.62	2.78	3.11	3.45
17	2.33	2.45	2.54	2.69	3.01	3.35
18	2.04	2.18	2.25	2.39	2.68	2.97
19	2.69	2.74	2.83	3.01	3.37	3.74
20	8.30	8.55	8.85	9.41	10.57	11.77
21	9.33	9.49	9.83	10.40	11.65	12.94
22	6.56	6.78	7.02	7.42	8.31	9.22
23	4.87	5.07	5.24	5.55	6.21	6.89
24	5.16	5.34	5.52	5.84	6.54	7.26
25	4.99	5.27	5.45	5.77	6.47	7.19
26	5.10	5.43	5.62	5.94	6.67	7.41
27	4.20	4.49	4.66	4.93	5.51	6.14
28	5.30	5.61	5.82	6.15	6.91	7.68
29	10.43	10.83	11.23	11.87	13.33	14.83
30	10.8	11.11	11.51	12.18	13.67	15.21
Total	120.79	125.12	129.59	137.20	153.88	171.01
Average	4.03	4.17	4.32	4.57	5.13	5.70
Change (%)	0.00	3.47	7.20	13.40%	27.30%	41.44%

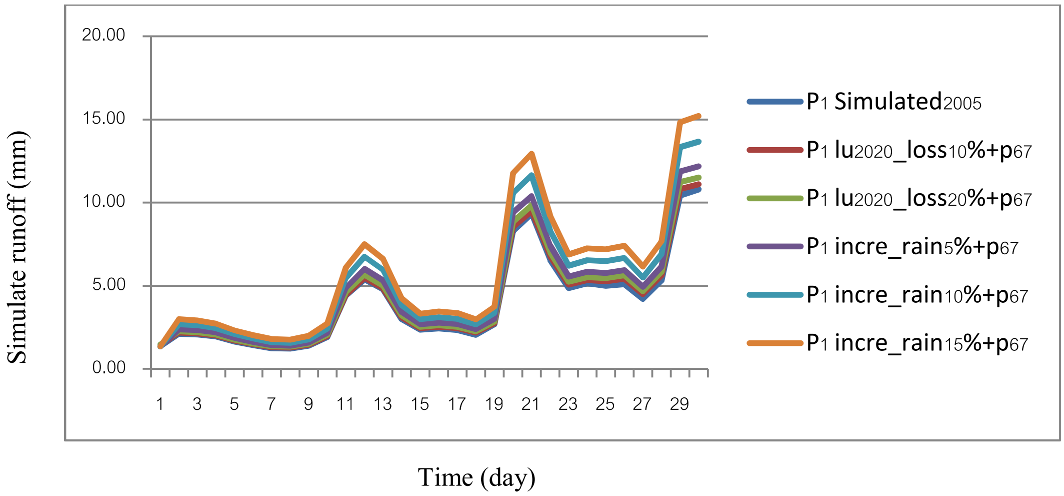
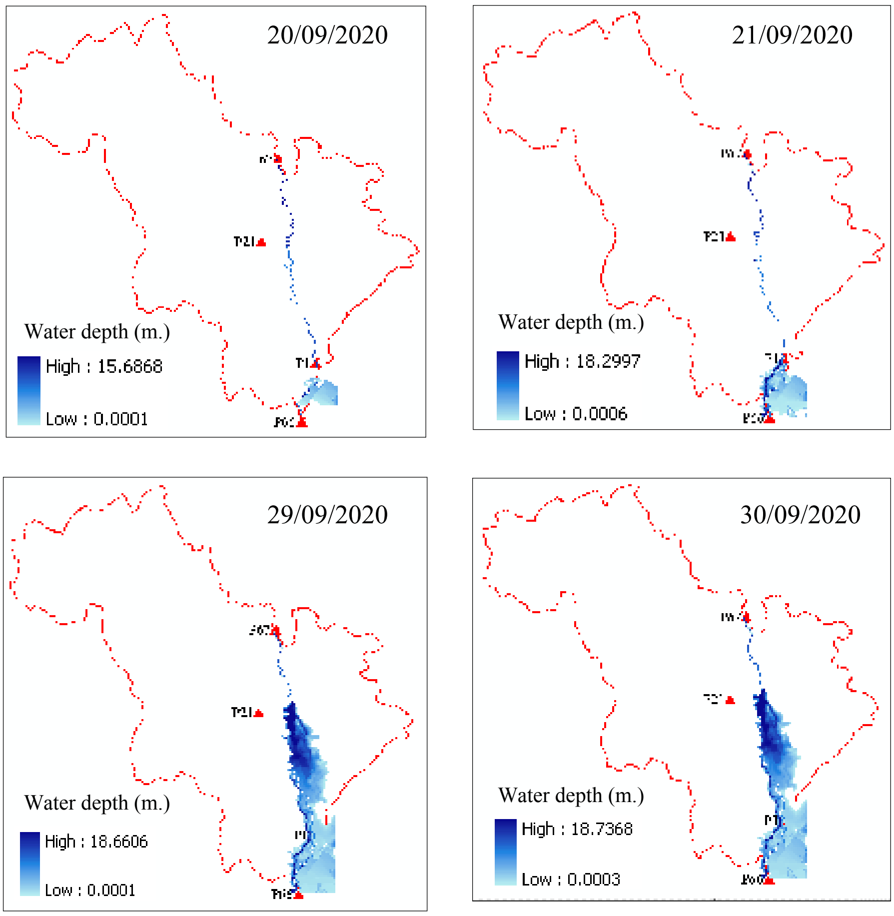


Figure 5: Simulated runoff data at P1 station for years 2005 and 2020 (basin area = 6,250 km^2).

In Step 4, flood events based on the known water levels at P1 station in Step 3were simulated through the DEM-based interpolation of the flood extent from the river bank into the lowland areas nearby. It was found that, for the worst case of forest/perennial loss (20% loss), number of flood dates is still similar to that found in year 2005 (4 dates) (Figure 6) but the total flood area is higher due to higher level of the average flood depth. But for case of 15% rainfall increase, number of flood dates rises to 10 (Figure 7). See Table 5 for more information of the flooding dates for each case.



Figures 6: Flood depth maps in case of the worst forest loss rate (20%).

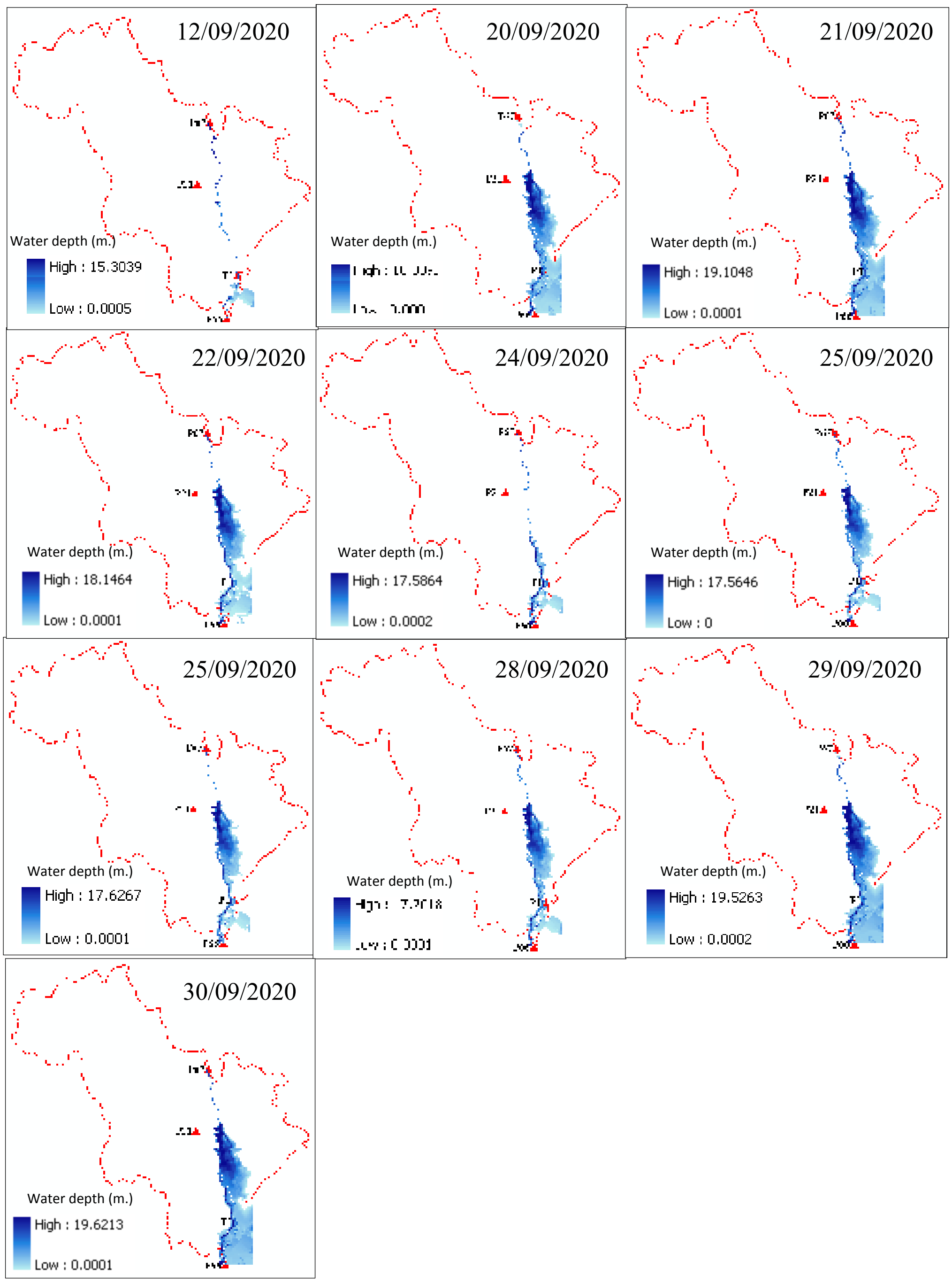


Figure 7: Flood maps for case of most rainfall increase (15%).

CONCLUSIONS

The newly-built grid-based hydrologic model can be used efficiently to simulate runoff data at the P1 station with R^2 = 0.956 and Nash-Sutcliffe efficiency index (E) = 0.94. Knowledge of these data can be used to predict flooding scenarios in the Chiang Mai inner city area based on height of water level at the P1 station (at Navarat Bridge) under some proposed criteria of LULC (forest/perennial classes) and rainfall data changes. It was found that, for cases of forest/perennial loss (10, 20%) and rainfall increase (5, 10, 15%) in the original basin area (1,121 km^2), there was no obvious subsequent changes in the runoff data shown. However, if the study area was extended to include the associated upper-stream basin (6,250 km^2), the notable changes in modeled runoff data were clearly seen where cases of 10 and 20% loss shall result in the average increase of modeled runoff at the station by 3.47% and 7.20%, respectively (compared to the normal 2005 case). And the increase of rainfall intensity by 5%, 10%, and 15% shall result in the increase of the modeled runoff by 13.40%, 27.30%, 41.44%, respectively. In term of the flooding resulted from the overbank flow of the excessive water volume in the Ping River, for the worst case of forest loss (20% loss), number of flood dates is still similar to that found in 2005 (4 dates) but the total flood area is higher due to higher level of the average flood depth. But for case of the 15% rainfall increase, number of flood dates rises to 10.

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