Effect of land cover change in runoff estimation on flood event; case study in the upper part area of Nan river basin, Thailand

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ABSTRACT: Flooding causes significant damage when heavy rainfall occurs. Flood modeling is firstly established for studying the flood characteristic before design of flood mitigation management. The size of flood disaster depends on topography, land cover and rainfall. This study aim to reveal the effect of land covers change on flood simulation. In this study, physically-based distributed hydrologic modeling, Rainfall-Runoff-Inundation (RRI) model is used to evaluate runoff uncertainty on different land cover data by using the Moderate Resolution Imaging Spectroradiometer (MODIS) on product number MDC12Q1. These products collected between 2001 and 2013 are input to RRI model on the Nan River basin, Thailand that is 13,000 km2 of watershed area. Firstly, change detection analysis during 13 years was analyzed and these datasets was used to estimate the Manning's n surface roughness coefficient. The performance of land cover products with the surface roughness, on runoff, was evaluated from storm event on 2011 by using statistical and detection analysis, comparing with observation data, for calibration and verification. The results of change detection analysis revealed that Forestation area have been decreased about 25% and the increasing of Grass land area have about 20%, during the 13 years. The change of land cover have affected to the Manning's n surface roughness coefficient have decreased about 18.5% from the beginning year (2011). The decreasing of surface roughness coefficient implied that the terrain surface at last year has been smoother than the beginning year. The changes of terrain surface in smoother than the first evaluation year have been affected to the runoff estimation in difference peak value about 2% and 2 hours in traveling time. The study presents that change of land cover from satellite product and their potential improved flood mitigation for water resources management in a non-structural measures.

1. INTRODUCTION

Floods are one kind of natural disasters causing human life and economic losses. Approximately about 66% of water related disasters in the world are floods. Nowadays, impacts of floods have been increased because of population growth, decreasing of floods plain, and climate change. Mitigation impacts of floods are implementation of structural and non-structural scheme. The major tools firstly used for planning and developing structural and non-structural flood mitigation and management approaches are Hydrologic and hydraulic models. Mathematic models of floods have been established from peak flow estimation schemes with multi dimension, multi-scale distributed simulations able of demonstrating the spatial and temporal variation of floods runoff over a river basin surface (Singh and Woolhiser, 2002). According to the floods model in historical, hydraulic roughness is a main parameter for analysis floods. The Manning equation has been implemented in several models to relate surface roughness to flow rate that the Manning's roughness coefficient (n) is used for hydraulic roughness of the models. Manning coefficient (n) is empirical parameter normally used for gravity, uniform flow in open channel flow analysis.

The objective of this study is to assess the change of runoff from hydrologic modeling results based on the land cover. In the specific objective, it uses the satellite based land cover data sets for estimating Manning's coefficient for surface roughness in the river basin scale. The impact of generating a Manning's coefficient map in yearly from the satellite sources are presented for land cover effect to flood disaster that is lack of the study to archive from the literature. This study presented a change of Manning's coefficient to estimate the uncertainty created in distributed hydrologic modeling simulation.

2. MATERIAL OF THIS STUDY

2.1 Study area

Either upper part of Nan River Basin or upper part of SIRIKIT dam is the important area because release of the SIRIKIT dam has provided a supply to the central plain including Bangkok area. The upper part of Nan river basin locates in the northern region of Thailand with the total catchment area of 13,000 km^2 that is shown in **Figure 1**. The basin, which originates from Bor Klua District, Nan Province, is situated between latitude 17 42’ 12” to latitude 19 37’ 48” N and longitude 100 06’ 30” to longitude 101o 21’ 48” E.

2.2 Flood model

Rainfall-runoff-inundation (RRI) model, which is a new developed model in a two dimension, was used for simulation in this study (Sayama et al., 2012). **Figure 2** is shown that the model deals with slopes and river channels separately. The river channel is located on the grid cell while the model assumes that both slope and river are positioned within the same grid cell. A channel is discretized as a single vector along its centerline of the overlying slope grid cell. The channel represents an extra flow path between grid cells lying over the actual river course. Lateral flows are simulated on slope cells on a two dimensional basis. Slope grid cells on the river channel have two water depths: one for the channel and the other for the slope (or floodplain). The inflow-outflow interaction between the slope and river is calculated based on different overflowing formulae depending on water-level and levee-height conditions. RRI model was simulated on the 2011 flood in Sukothai province of Thailand. The simulation, which has closed by observation data, was used for estimating damage cost (Sriariyawat et al., 2013). Pakistan flood in 2010 in the Kabul River Basin was simulated with RRI model. The model results showed a good relationship with an inundation map produce base on satellite data (MODIS) (Sayama et al., 2012).

2.3 Land cover data

Land cover distribution in **Figure 3** is presented for the Nan river basin at the 2011. The area is mostly mountain area with relatively mild slopes. The land cover types (15 categorizes) in the watershed as shown in **Table 1** are farm, paddy, agricultural, perennial, orchard, horticulture, swidden cultivation, pasture, aquaculture land, forest, deforestation, miscellaneous land, swamp, urban and water. Topography causes surface runoff to flow from the northern area towards southern area where downstream is the SIRIKIT reservoir. More than 70% of the watershed is the forest area, 25% is the agricultural area, and 5% is developed and open area (Build-up land, deforestation, miscellaneous and water). The 13,000 sq.km area is selected to provide a numerous of land covers.

Moderate Resolution Imaging Spectroradiometer (MODIS) data have spatial resolution from 250 m to 1 km and offer the possibility for time series coverage at moderate resolution. A numerous from MODIS data in global products are land cover, primary production, and leaf area index. MODIS land cover products is mainly of available set of global MODIS products. The product is established from various MODIS provided input such as surface reflectance, vegetation index, surface temperature and texture, and generated data is provided as global product according to the global IGBP (International Geosphere–Biosphere Program) classification system (Friedl et al., 2002b). Global MODIS land cover product is suitable for global and region scale, however, MODIS surface reflectance has provided at 250 and 500 m can also be used to map regional land cover at higher resolution according to a user-specified classification system. Empirical analyses demonstrated that higher resolutions than 1 km are highly desirable for mapping a land cover, and the MODIS instrument was designed to deliver 250 and 500 m resolution data. MCD12Q1 is one of global MODIS land cover product (see **Figure 4**), which data product is generated at annually over ten years (2001-2012, Friedl et al., 2010). A supervised classification samples for each mapping class is collected from 2,000 training sites in worldwide that are done for training by the decision tree classifier. In this study, the MCD12Q1 product of MODIS is categorized in 12 classes with the global accuracy about 74.8%.

3. METHODOLOGY

In this study, MODIS data sources are selected to evaluate Manning’s coefficient with a look-up table. The study is performed on 13,000 sq.km catchment of the Nan river basin in the northern part of Thailand. The MODIS land cover product has evaluated the accuracy from the observation data, using pixel to pixel based detection method. After the accuracy assessment, the land cover dataset has transformed to the Manning’s n coefficient based on empirical default values from the literature reviews. The transformed surface roughness products are used to run the hydrological model to estimate runoff to reveal accuracy of modeling and effect of land cover change. The accuracy assessment of hydrological model was based on the statistical approach of runoff data.

3.1 Manning’s coefficient estimation

A land cover maps represent a natural surface features based on pixel grid that is interpreted from the aerial photograph for referent map and satellite for candidate data. The map is presented on the raster and digital format. The land cover maps contain the surface feature is identified in the pixel grid and a corresponding Manning’s coefficient value is allocated to that wherever cell based on the proposed values for land surface. Numerical of Manning's coefficient presented in **Table 2** are typical values obtained from the previous studies (Ferguson, 1998). These numerical values are normally correspondence exists between reality and mathematical model of flow over a plan.

3.2 Hydrological modeling

The comparison of the different in runoff results when using the thirteen Manning's coefficient map in distributed hydrologic model as RRI model is involved in this step. The distributed hydrologic model incorporate the spatial variation of input based on the raster format. Input data sets of the RRI model are four data types; rainfall product, topography, land cover and soil type (see **Figure 5**). On the definition of the distributed hydrologic model with the RRI model, the used hydrologic parameters were mentioned such as Green-Amp parameter of soil type. The Manning's coefficient maps candidate input is from MODIS change in yearly. In this study, the input data has been scaled to 500 m of pixel size (about 15 x 15 arc-second). Addition to the numbers of pixel, row and column numbers are 457 and 292 respectively to present the watershed area as 13,000 km^2 for the Nan river basin. Rainfall data was collected from the rain gauges, covering the study area. For the Nan river basin, June 2011 storm event is implemented to evaluate different land cover products that are used to run the RRI model over the basin.

3.3 Performance statistics

Satellite based land cover and Manning's coefficient map spatial extents were evaluated with the referent observed map. The performance verification statistic measure the correspondence between the simulated and observed, was implemented in this research (see **Figure 6**): accuracy (ACC). ACC give the overall correction of simulation data and its perfect values for the statistical as 1.

The estimation results driven by the several methods based on the daily data were evaluated to analysis bias of volume (V_{bias}), bias of peak (P_{bias}), root mean square error ($RMSE$), square of the Pearson correlation coefficient (r), and mean error (ME). The following formulas (see **Table 3**) were applied to evaluate simulation performance. The volume bias and peak bias estimate the systematic bias of modelled runoff in percentage (%). The correlation index is quantification in correlation of two data sets, simulated and observed runoff, which 0 is no correlation while 1 is perfect correlation. The RMSE is a different measure of difference magnitude between two data sets, while the ME is the bias from two data sets.

4. RESULTS AND DISCUSSION

MODIS land cover data represented using MCD12Q1 product was used in this study at 500 m resolution. MCD12Q1 was selected and evaluated for the Nan river basin, Thailand. The MCD12Q1 contained with 12 classes of land cover type was grouped into 6 classes (forest, shrub, grass, agriculture, urban, water) for matching with aerial based land cover as the referent observed data set for the overall area based. For the pixel to pixel based the land cover type was reconstructed at 7 types (forest, shrub, grass, paddy, agriculture, urban, water), dividing the paddy from the agriculture to make more detail of validation. The reconstructed MCD12Q1 product was considered in an accuracy assessment based on the area and pixel based. Finally, the accuracy of both areas was compared with the other area in the world.

The deep detail of validation on the pixel to pixel based was a comparison between observed and satellite based data set with the 7 classes as mention in above. **Table 4** presents an accuracy assessment of 2011 MODIS data. The overall accuracy was about 75.79% with the hit pixel at 3,895,311 pixels of a total pixel about 5,139,836 pixels. The forest area outperformed among the six land cover types with highest accuracy and followed by agriculture (6.09%), and shrub (1.41%), while the grass showed as the lowest accuracy at 0.02%.

The hydrological model (RRI model) was driven for July 2011 storm events, using the similar hydrologic parameters set. The evaluated data were estimated at daily on a temporal scale to match the Royal Irrigation Department Thailand observed streamflow data. Three runoff stations were selected in the Nan river basin as mention in **Figure 5**, the first one belonging to the upstream sub-catchment (N.64), the second one belonging to the middle area (N.1) and the third one belonging to the downstream area (N.13A), to show the daily hydrograph that results from the different interpolation scenario. **Figure 7** presents the hydrographs from the storm event at runoff station N64, N.1 and N.13A. All of three runoff station on the daily hydrograph were analyzed and calculated for evaluation by the performance statistical. The results are given in **Table 5** that is concluded by five indexes. The discharge matched the observed runoff with the r of 0.881 and RMSE of 387.63 cms. This simulated runoff overestimated the runoff volume, peak flow and mean runoff by 19.26%, 22.22% and 139.04 cms, respectively.

Table 6 showed the change detection of land cover change between 2001 and 2013. The change detection analysis revealed that Forestation area have been decreased about 25% and the increasing of Grass land area have about 20%, during the 13 years. **Figure 8** presented the Manning's n coefficient (surface roughness) of both candidate years (2001 and 2013). The change of average surface roughness based on the MODIS land cover product was presented in **Figure 9** during the 13 years. The change of land cover have affected to the Manning's n surface roughness coefficient have decreased about 18.5% from the beginning year.

The both dataset of surface roughness was used to reveal the effect of land cover change on the runoff in hourly simulation to reveal the flood disaster in this area. **Figure 10** showed the flood event simulation results based on runoff data for each observation runoff station. The change of runoff hydrograph each station has been explained by the peak and time concentration change. For N.64, the peak value have been changed by the different land cover data from 1644.08 cms of 2001 to 1678.6 cms of 2013, in the change about 34.5 cms. The time to peak have differential about 2 hours on this station. The change of N.1 present that peak value changes from 1906.32 cms to 1951.79 cms and the time had shifted same the station N.64. On the N.13A, the peak value have been changed by the different land cover data from 2783.43 cms to 2852.27 cms, in change about 68.84 cms and the time to peak have differential about 4 hours on this station.

Addition to travel time of peak from upstream station to downstream station, the different is about 17 hours on the both dataset of land cover. It recommends modeling to the flood in this area that the daily simulation is not enough for flood modeling to use in the flood mitigation project decision.

4. CONCLUSION

This study is done on the recommendation of land cover change effect to runoff estimated on the hydrological modeling by the RRI model. The flood model has contained the accuracy about 387.63 cms on RMSE and 0.888 on correlation. Land cover product from MODIS data as MCD12Q product has accuracy about 75.8% on 2011. The land cover product have provided in yearly and used to present the land cover change during 13 years (2001 and 2013). From the change detection analysis, it presents the change of main land cover type about forestation area in 25% decreasing and increasing of grass land about 20%. Next, the land cover was transferred to the Manning's n coefficient as the surface roughness. Based on the different during 13 years, the average of Manning's n coefficient have changed about 18.5%. The runoff hydrograph from the different surface roughness have changed about 2% on peak and 2 hours on time to peak.

5. ACNOWLEDGMENTS

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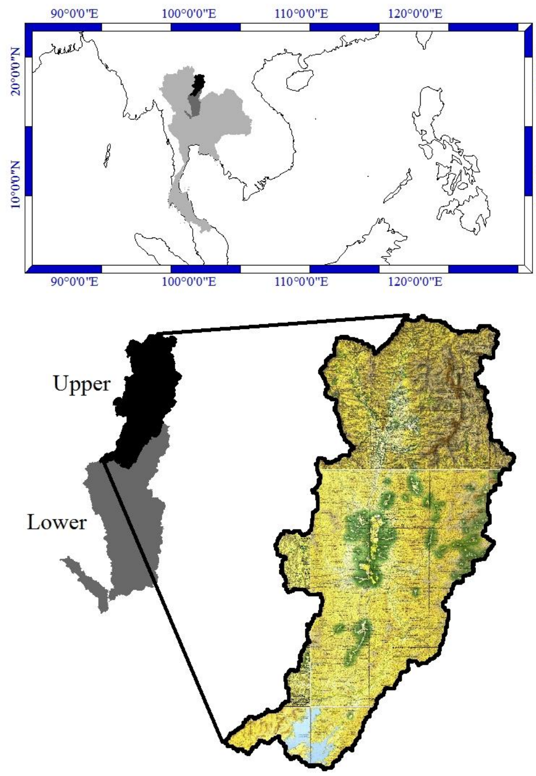


Figure 1 Upper part of Nan River Basin area

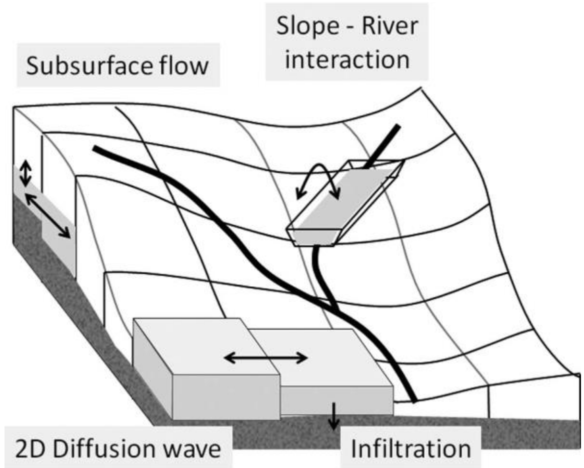


Figure 2 Schematic of RRI model

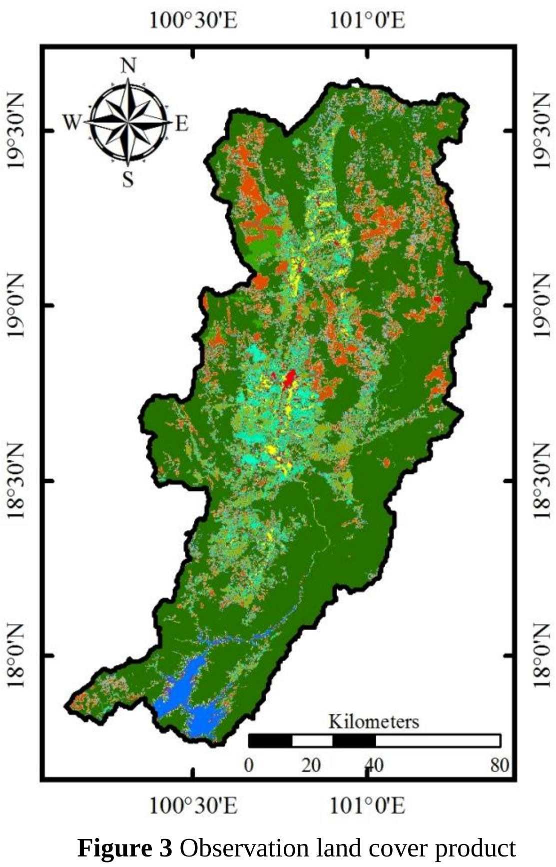


Figure 3 Observation land cover product

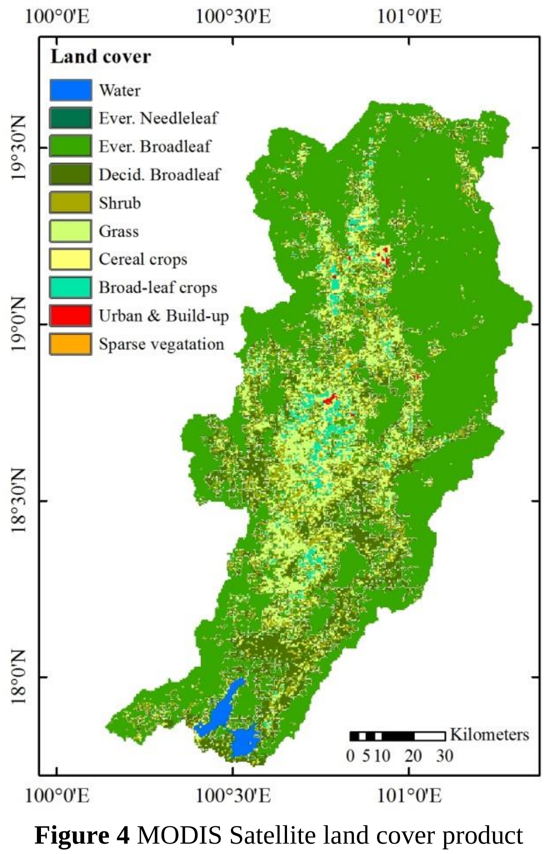


Figure 4 MODIS Satellite land cover product

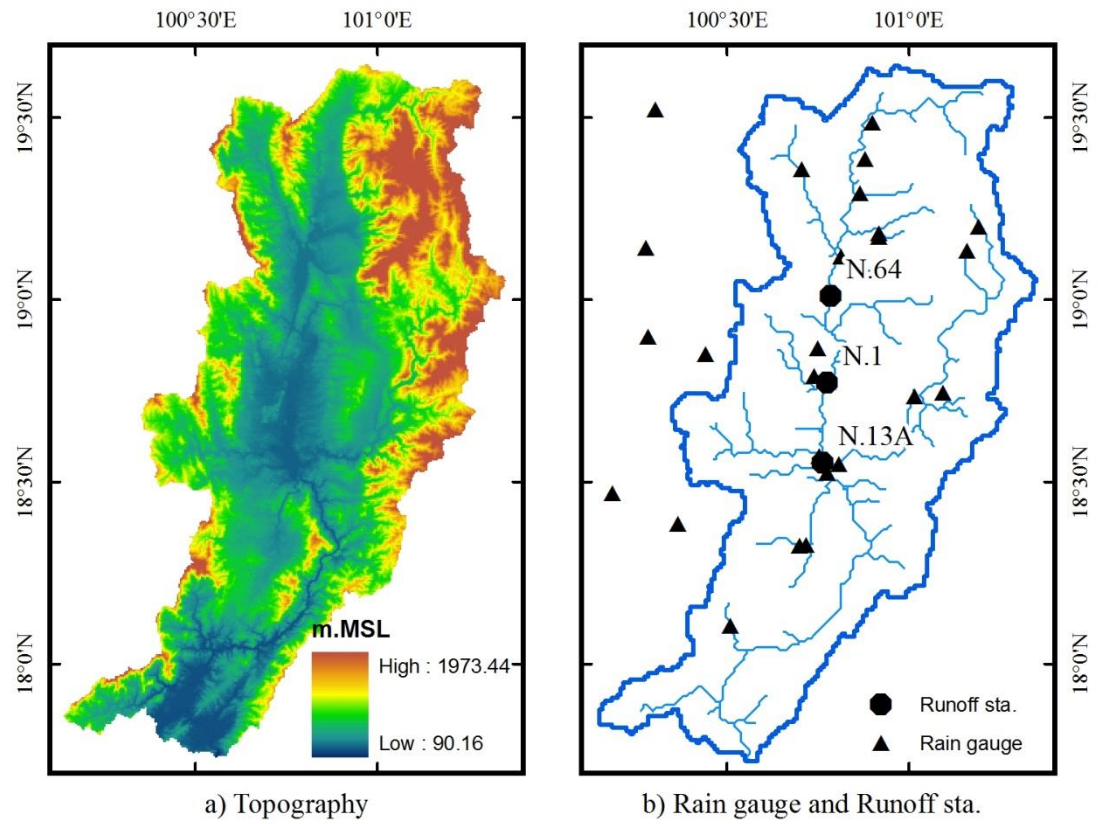
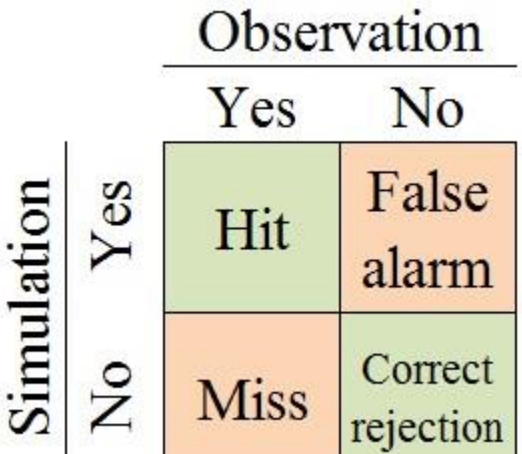
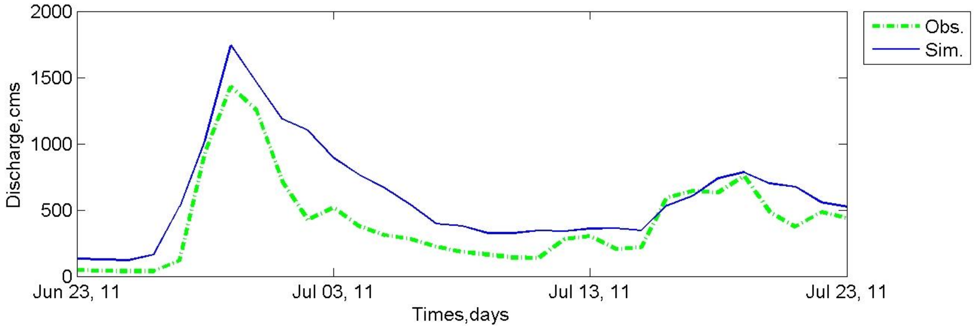


Figure 5 Datasets for modeling in the Nan river basin, Thailand

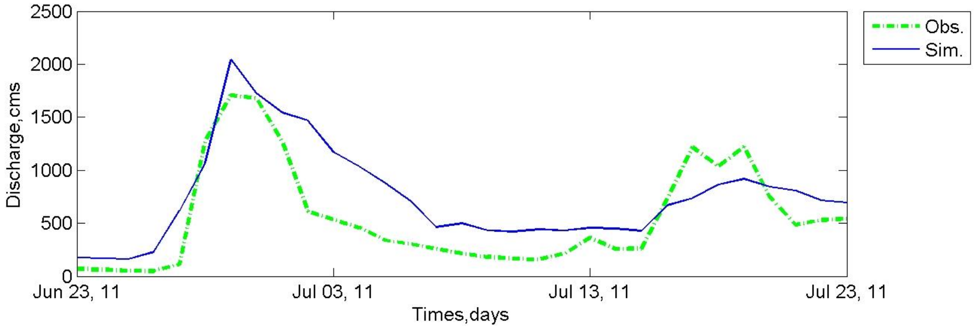


$$ACC = \frac{Hit + Corr.}{Hit + False + Miss + Corr.}$$

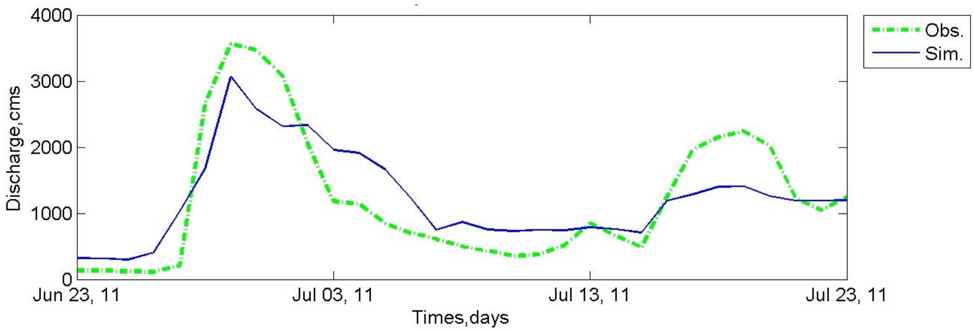
Figure 6 Detection analyses to reveal the accuracy of satellite land cover product



a) N.64



b) N.1



c) N.13A

Figure 7 Daily discharge hydrograph at runoff observation station of 2011 storm event

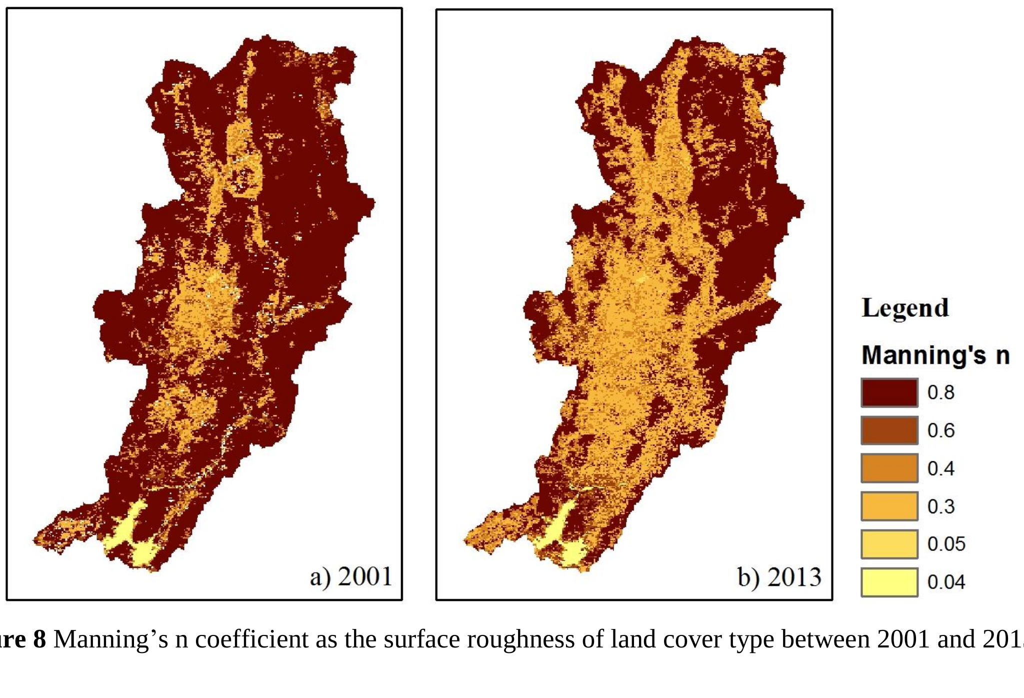


Figure 8 Manning’s n coefficient as the surface roughness of land cover type between 2001 and 2013

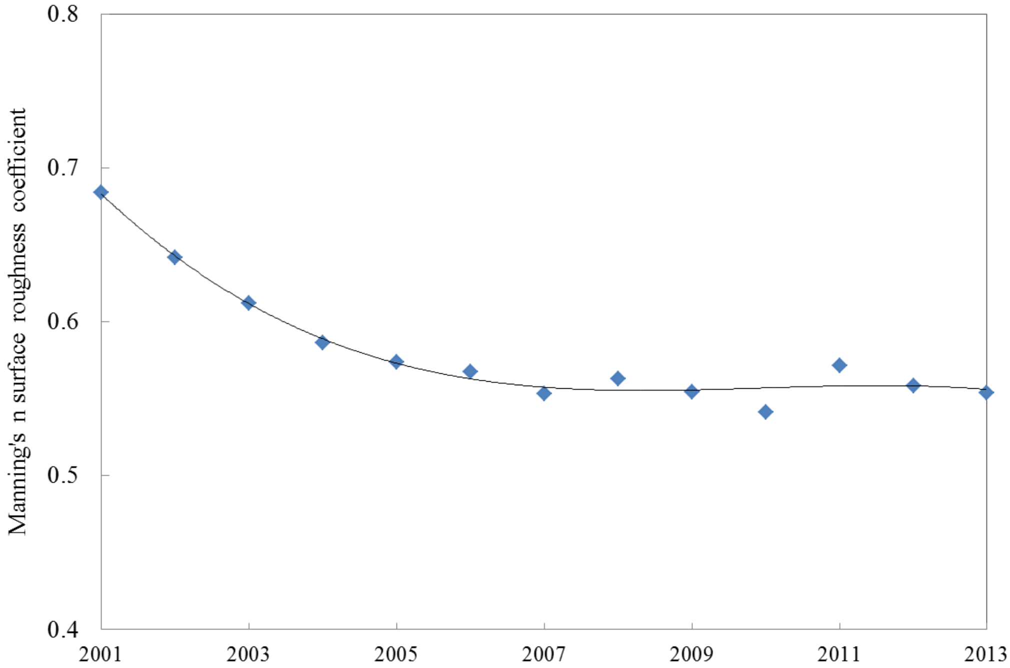


Figure 9 Change of Manning's n surface roughness coefficient in time series

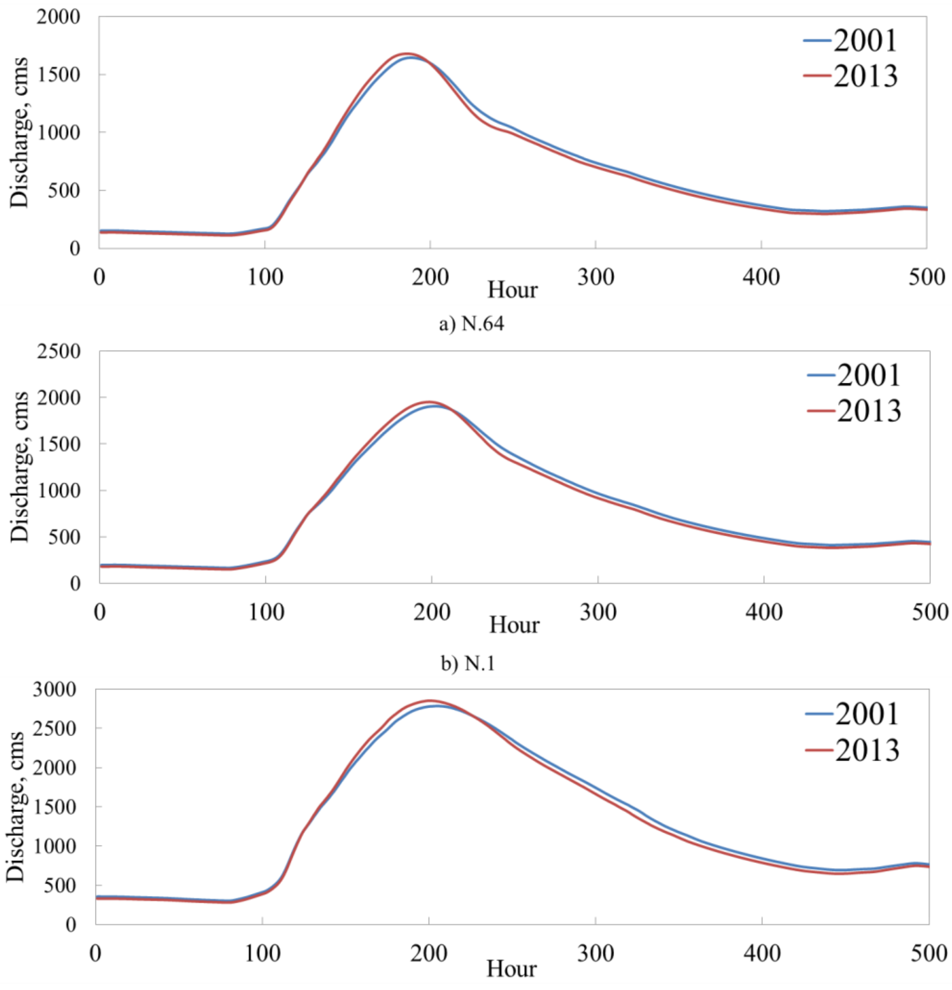


Figure 10 Hourly runoff at observation station of 2011 storm event based on different land cover data

Table 1 Land cover type area in the Nan river basin area

No	Land cover name	Pixel	Area, km2
1	Integrated farm	11	0.03
2	Paddy	143,123	357.81
3	Agricultural	348,229	870.57
4	Perennial	86,871	217.18
5	Orchard	141,175	352.94
6	Horticulture	39	0.10
7	Swidden cultivation	546,243	1,365.61
8	Pasture and farm house	302	0.76
9	Aquacultural land	21	0.05
10	Forest	3,529,820	8,824.55
11	Disturbed forest land	107,806	269.52
12	Miscellaneous land	26,541	66.35
13	Marsh and Swamp	70	0.18
14	Build-up land	81,127	202.82
15	Water	128,458	321.15
	Total	5,139,836	12,849.59

Table 2 Default parameter of Land cover classes

No	Land cover	Manning's n coefficient
1	Evergreen Needle leaf forest	0.40
2	Evergreen Broadleaf forest	0.60
3	Deciduous Needle leaf forest	0.40
4	Deciduous Broadleaf forest	0.80
5	Mixed forest	0.55
6	Closed Shrub lands	0.40
7	Open Shrub lands	0.40
8	Woody savannah	0.50
9	Savannahs	0.40
10	Grasslands	0.30
11	Permanent wetlands	0.50
12	Croplands	0.35
13	Urban and build-up	0.05
14	Natural vegetation	0.35
15	Snow and ice	0.05
16	Barren or sparsely vegetation	0.10
17	Water bodies	0.05

Table 3 Description of performance statistical

Statistical index	Description	
Volume bias (%)	$V_{bias} = \frac{\lvert Q_{vo} - Q_{vs} \rvert}{Q_{vo}} \times 100$	where Q_{vo} is observation volume Q_{vs} is simulation volume Q_{po} is observation peak Q_{ps} is simulation peak Q_o is observation data Q_s is simulation data n is total number of sample
Peak bias (%)	$P_{bias} = \frac{\lvert Q_{po} - Q_{ps} \rvert}{Q_{po}} \times 100$	
Root mean square error	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Q_{o(i)} - Q_{s(i)})^2}{n}}$	
Correlation	$r = \frac{\sum_{i=1}^{n}((Q_{o(i)} - \overline{Q_o}) \cdot (Q_{s(i)} - \overline{Q_s}))}{\sqrt{\sum_{i=1}^{n}(Q_{o(i)} - \overline{Q_o})^2 \cdot \sum_{i=1}^{n}(Q_{s(i)} - \overline{Q_s})^2}}$	
Mean bias	$ME = \frac{\sum_{i=1}^{n}(Q_{o(i)} - Q_{s(i)})}{n}$	

Table 4 Accuracy assessment of MODIS land cover product between pixel to pixel in the Nan

		Reference data						
		Forest	Shrub	Grass	Agriculture	Paddy	Urban	Water
MODIS	Forest	**3,389,137**	459,554	12,752	189,273	41,460	31,632	57,345
	Shrub	220,634	**72,240**	7,913	1,202	33,231	-	7,105
	Grass	4,643	2,046	**1,205**	11,750	20,178	8,033	5,258
	Agriculture	218	28	276	**313,044**	2,675	3,510	156
	Paddy	22,510	12,364	4,697	61,053	**45,579**	20,702	1,798
	Urban	-	-	-	-	-	**17,219**	-
	Water	484	11	-	3	-	31	**56,887**
		65.94%	1.41%	0.02%	6.09%	0.89%	0.34%	1.11%

Table 5 Performance statistics of runoff results in summary all station

Performance statistics	Simulated runoff
Volume bias, %	19.26
Peak bias, %	2.22
RMSE, cms	387.63
Correlation	0.881
Mean bias, cms	139.04

Table 6 Change detection analysis from 2001 to 2013 (unit: km^2)

			2001												
			Water	Evergreen Needle	Evergreen Broad	Deciduous Needle	Deciduous Broad	Shrub	Grass	Cereal crops	Broad-leaf crops	Urban	snow	Bare	Unclassed
		Total	224.00	30.50	11,904.00	0	684.25	914.25	1,896.75	147.50	232.50	24.50	0	0	191.25
2013	Water	213.00	**198.25**	0	0	0	0	4.50	10.25	0	0	0	0	0	0
	Evergreen Needle	6.00	0	**5.50**	0.50	0	0	0	0	0	0	0	0	0	0
	Evergreen Broad	7,221.75	0	6.00	**7,146.00**	0	48.25	0	0	0	0	0	0	0	21.50
	Deciduous Needle	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0
	Deciduous Broad	1,084.75	0	4	912.00	0	**68.25**	78.00	0	0	0	0	0	0	22.50
	Shrub	2,264.75	10.00	5.50	1,282.25	0	145.75	**312.50**	416.50	18.25	30.25	0	0	0	43.75
	Grass	4,434.75	8.50	3.50	2,371.50	0	348.75	411.00	**1,072.50**	43.00	84.00	0	0	0	92.00
	Cereal crops	268.25	6.75	5.00	49.50	0	9.75	23.25	90.25	**41.25**	38.75	0	0	0	3.75
	Broad-leaf crops	730.00	0.25	0.25	142.25	0	63.5	84.75	306.75	45.00	**79.50**	0	0	0	7.75
	Urban	24.50	0	0	0	0	0	0	0	0	0	**24.50**	0	0	0
	snow	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0
	Bare	1.75	0.25	0.75	0	0	0	0.25	0.50	0	0	0	0	**0**	0
	Unclassed	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**