AN INTEGRATED GEOINFORMATICS TECHNOLOGY WITH HYDROLOGICAL MODEL TO IMPACT ASSESSMENT OF LAND USE CHANGE ON RUNOFF IN THE UPPER LAM TA KHONG WATERSHED

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KEY WORDS: Geoinformatics, hydrology, land use change, surface runoff

ABSTRACT The main objective of this study was to evaluate the impact of land use changes on surface runoff in upper Lam Ta Khong watershed, headwaters watershed. The land use during 1993, 2001 and 2009 were classed by visual interpretation methods based on LANDSAT imagery data. The monthly surface runoff simulation by using hydrological SCS-CN model integrated with GIS. Model calibration and validation were performed by comparing observed and simulated results at the M.43A (upstream watershed) and M.89 (downstream watershed) during the water year 1993, 2001 (model calibration) and 2009 (model validation). The impact of land use change on surface runoff was evaluated with scenarios model and simple linear regression. The model was conducted for each land use map in three time periods (1993, 2001 and 2009). The study revealed that 1) the land use type during 1993 – 2009 founded that the forest and agricultural land were decreased, while the urban and built-up area has been continuously increasing. 2) A calibrated model shows that satisfactory of the coefficient of efficiency (E) is 0.39 and 0.45 and coefficient of determination (R^2) is 0.36 and 0.48 at the M.43A and M.89, respectively. 3) The decreased of forest and agricultural land, while urban and built-up area was increased have a negative impact on surface runoff due to decreasing of infiltration and increasing of surface runoff. Especially, urbanization was the strongest contributor to the increase of surface runoff. The results of this study indicate that the changing of land use types from natural surface to impervious surface has a significant impact on surface runoff. This study will provide quantitative information for stakeholders in land use planning and water resource management in the study area.

INTRODUCTION

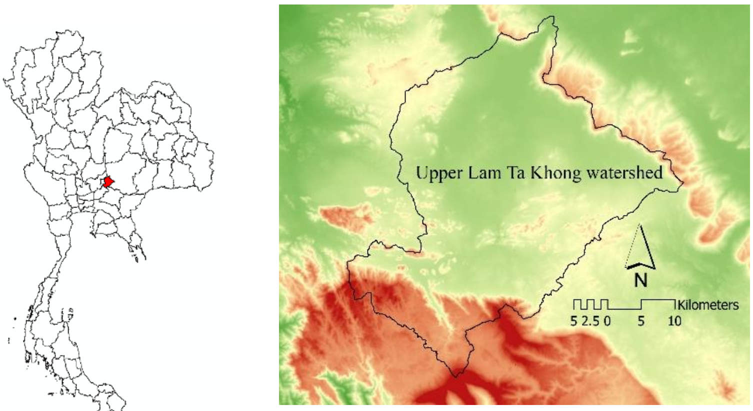
Water availability in a watershed depends on how rainfall over the area is divided into various components such as surface runoff, interflow, groundwater recharge etc. Proportions of these components in the area are principally affected by the land use and land cover (LULC) of the area. Hence, a change in LULC of an area can alter the proportions of the aforementioned components, which in turn, results in the phenomenal change in the hydrological system of the area (Sajikumar and Remya, 2014). Change in LULC is normally induced by human activities such as agricultural expansion, burning activities, deforestation, some construction works and increase in impervious surface area cause by urban sprawl. Poor land use planning and land management practices may adversely impact surface runoff quantities and quality through the reduction natural surface and increase in imperviousness of surface areas (Deshmukh et al., 2013). The impact of land use on runoff has been documented in the literature from different perspectives, including the analysis of runoff change in response to land use changes, the prediction of runoff for future climatic and land use scenarios, and the study of the urbanization and its effect on runoff generation (Chen et al., 2009; Zhang et al., 2014; Ongsomwang and Pimjai, 2015). Study of change in runoff characteristics due to human activities has an important role in understanding the effects of LULC change on hydrological processes over the earth surface. Hence it is crucial that the effect of change in LULC on the runoff characteristics of a watershed be assessed (Shi et al., 2007). Watershed model are very much suited for this purpose.

The Soil Conservation Service-Curve Number (SCS-CN) method is one of the most popular methods for computing the direct surface runoff for given rainfall events from small agricultural, forest and urban watersheds. The purpose of this study is to use the SCS-CN model, which fully considers physiographic heterogeneity (e.g. topography, soil, and land use) to evaluate the impact of land use changes on surface runoff in upper Lam Ta Khong watershed.

MATERIALS AND METHODS

Study area

The upper Lam Ta Khong watershed covers an area of 1,241 km^2 in Nakhon Ratchasima province, Thailand (Figure 1). The study are lies between latitudes 14º 23′ 07” N to 14º 51′ 53” N and longitudes 101º 16′ 27” E to 101º 44′ 09” E. The topography of the area is characterized by generally hilly-rolling terrain, with less undulating area. Elevation ranges from 255 m above mean sea level (msl.) in the northeastern parts to about 1,330 m above msl. in the southwestern parts of the watershed. The weather is characterized by monsoon tropical climate with dry and wet seasons. The wet season is from mid-May to October but its intensity increases in June to August and subsides in mid-September. The dry season is from November to April. The average annual rainfall is about 960 mm. The soil in the area varies in 24 series with different soil textures such as clay, sandy loam, loamy sand, clay loam, silty clay, sandy clay loam, loam. The upper Lam Ta Khong watershed is the upstream area of the Lam Ta Khong dam which is mainly water supply source for Nakhon Ratchasima municipality.



STRM DEM

Figure 1 Map of study area.

Data sources

The cloud free LANDSAT data acquired in 1993, 2001, and 2009 were used for LULC classification. The Royal Irrigation Department (RID) provided rainfall data from 1993 – 2009 with 2 manual rain gauges , located within the watershed (Fig. 2a). Topographic maps of Royal Thai Survey Department (RTSD) at the scale of 1:50,000 were used to generate Digital Elevation Model (DEM) (Fig. 2b). For the model, relevant parameters generated from DEM were flow direction and flow accumulation. Flow direction was extracted from DEM. Observed runoff data of the RID hydrological station, M.43A with 153 km^2 drainage area at the upstream outlet and M.89 with 713 km^2 drainage area at downstream outlet, are used for model calibration and validation. The soil properties and soil map at scale 1:25,000 were obtained from Land Development Department (LDD). The soils were reclassified into hydrologic soil groups (HSG) (Fig. 2c) according to the infiltration rate, which was calculated from soil texture properties based on criteria provided by National Resources Conservation Service (NRCS) (2007). All GIS data were projected to the UTM WGS 1984 Zone 47N coordinate system.

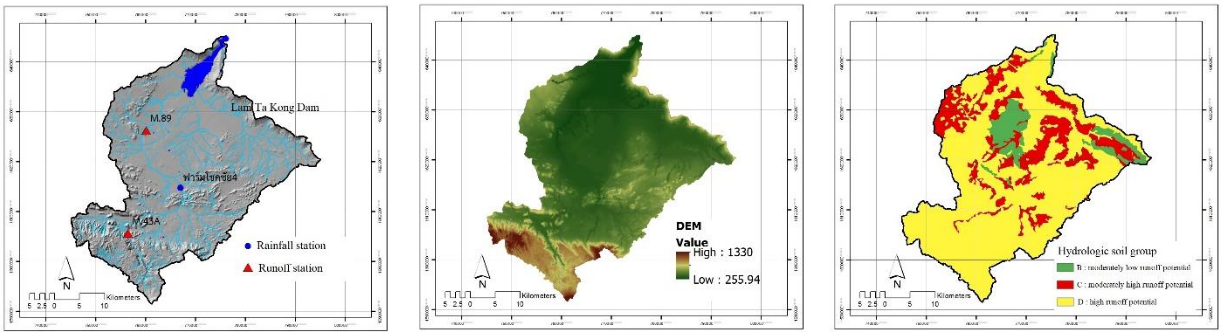


Figure 2 a) Rainfall-runoff gauge map, b) DEM, c) Hydrologic soil group map.

SCS-CN method

The SCS-CN method is based on the water balance equation and two fundamental hypotheses (NRCS, 2004). The first hypothesis equates the total rainfall (P; or maximum potential runoff) to the actual amount of direct runoff (Q), the amount of actual infiltration (F), and the initial abstraction (I_a). The second hypothesis shows the relationship between I_a and the amount of the potential maximum retention (S). Thus, the SCS-CN method is consists of the following equations (Mishra and Singh, 2003):

1) Water balance equation

$$P = I_a + F + Q \tag{1}$$

2) Proportional equality hypothesis

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{2}$$

3) $I_a - S$ hypothesis

$$I_a = \lambda S \tag{3}$$

where, P is the total rainfall; I_a is the initial abstraction; F is the cumulative infiltration excluding I_a; Q is the direct runoff; S is the potential maximum retention of infiltration; and λ is the regional parameter dependent on geologic and climate factors ($0.1 \leq \lambda \leq 0.3$). Combining the water balance equation and proportional equality hypothesis, the CN method is represented as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{4}$$

The potential maximum retention storage (S) of watershed is related to a curve number, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. Curve number is dimensionless and its value varies from 0 to 100. The S value in mm units and can be obtained from CN by using the relationship:

$$S = \frac{25400}{CN} - 254 \tag{5}$$

where S is in mm and CN is the curve number values, which varies based on a function of land use, land treatment, hydrologic soil group, and antecedent moisture condition (AMC) of a watershed. A combination of these is a hydrologic soil cover complex. The CN values were assigned to each grid cell to such complex to indicate their specific runoff potential.

The CN values were adjusted based on AMC. AMC is an indicator of watershed wetness and availability of soil storage prior to a storm. Three level of AMC are used: AMC-I for dry, AMC-II for normal and AMC-III for wet conditions. The CN values were adjusted based on the season and 5-day antecedent precipitation. Mathematically, adjustment to CN values for the cases of AMC-I and AMC-III, the following equation are used (Chow et al., 1988):

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \tag{6}$$

$$CN_{III} = \frac{23CN_{II}}{10 - 0.13CN_{II}} \tag{7}$$

The tools were applied based on the grid-based or raster-based operation of GIS-processes. All GIS layer of hydrological factors were prepared in raster format with grid cell size of 30 x 30 m. Each cell homogenously represented characteristics of the hydrological factors. The computer program ArcGIS^{TM} was used to create the model toolbox with a required set of spatial analyses. The runoff depth in each grid cell was computed using the SCS-CN method, and then routed through the watershed based on flow direction and flow accumulation from one grid cell to next until it reached the watershed outlet. The outputs of model simulations and observed values of all events at these two cells were tabulated to estimate the statistical indices for model evaluation.

The model evaluation procedure included calibration and validation. The runoff model used the year 1993 and 2001 monthly runoff for calibration and the year 2009 for validation. In each calibration step the simulation result of runoff was compared to actual ones of selected events observed from M.43A and M.89 runoff gauge stations. The parameter providing the most fit of simulation and observation of events were taken for the model operation. To evaluate the calibrated model, the optimized parameters for the other events were used for model validation. The agreement between the simulation and observation results for selected events were assessed by using coefficient of determination (R^2) and Nash-Sutcliffe coefficient of efficiency (E).

The impact of land use change on surface runoff was evaluated with scenarios model and simple linear regression. The model was conducted for each land use map in three time periods (1993, 2001 and 2009). The derived R^2 values of the regression analysis were used to explain the impact of LULC change on total surface runoff depth.

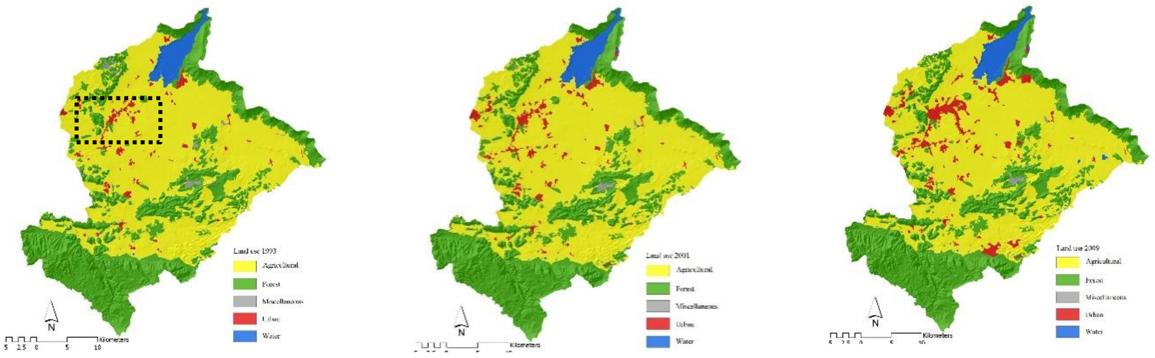
RESULTS AND DISCUSSIONS

LULC changes

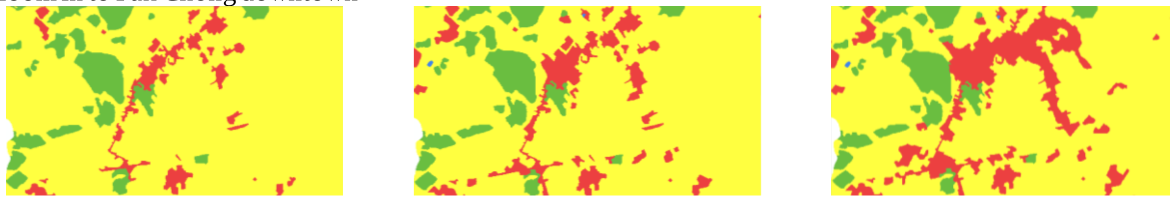
The LULC classification in 1993, 2001, and 2011 were extracted from visual interpretation. The LULC types were urban, agricultural, forest, water and miscellaneous (Table 1 and Fig. 3). The classified LULC were compared with ground information for accuracy assessment, it was found that the overall accuracy were 66.05%, 71.60 % and 78.47% and Kappa hat coefficient of agreement were 0.43, 0.52 and 0.66 for the year 1993, 2001 and 2011, respectively. According to Landis and Koch (1977), a Kappa hat coefficient between 0.41 and 0.80 represents moderately to substantial agreement or accuracy between the classification map and the ground reference map.

Table 1 LULC classification

Land use	1993		2001		2011	
	km^2	Percent	km^2	Percent	km^2	Percent
Urban	22.83	1.84	33.44	2.69	54.47	4.39
Agricultural	715.85	57.67	707.71	57.02	689.34	55.54
Forest	459.67	37.03	458.27	36.92	455.76	36.72
Water	36.85	2.97	37.69	3.04	38.70	3.12
Miscellaneous	6.05	0.49	4.13	0.33	2.98	0.24
Total	1,241.25	100.00	1,241.25	100.00	1,241.25	100.00
Overall accuracy	66.05%		71.60		78.47	
Kappa coefficient	0.43		0.52		0.66	



Zoom in to Pak Chong downtown



1993 2001 2009

Figure 3 Map of LULC 1993, 2001, and 2009.

The study revealed that the land use type during 1993 - 2009 founded that the forest and agricultural land were decreased, while the urban and built-up area has been continuously increasing (Table 2). The percentage of change for urban between the year 1993-2001 and 2001-2009 was about 46.47% and 62.89%, respectively. In the other hand, the percentage of change for agricultural, forest and miscellaneous has been continuously decreasing. These phenomena correspond to increase in the tourism activities and population growth in the Pak Chong District located in the upper Lam Ta Khong watershed.

Table 2 LULC change

Land use	Change between 1993-2001			Change between 2001-2009		
	km^2	% of change	annual rate (km^2)	km^2	% of change	annual rate (km^2)
Urban	10.61	46.47	1.33	21.03	62.89	2.63
Agricultural	-8.14	-1.14	-1.02	-18.37	-2.60	-2.30
Forest	-1.40	-0.30	-0.18	-2.51	-0.55	-0.31
Water	0.84	2.28	0.11	1.01	2.68	0.13
Miscellaneous	-1.92	-31.74	-0.24	-1.15	-27.85	-0.14

Runoff model calibration and validation

The calibration results showed that the model could provide the best simulation results with E = 0.36 and R^2 = 0.32 for M.43A station and E = 0.39 and R^2 = 0.30 for M.89 station when adjusting λ = 0.2. The validation results showed that E = 0.39 and R^2 = 0.36 for M.43A station and E = 0.45 and R^2 = 0.48 for M.89 station. Comparison between observed and simulated runoffs for calibration and validation are shown in Figures 4 and 5, respectively.

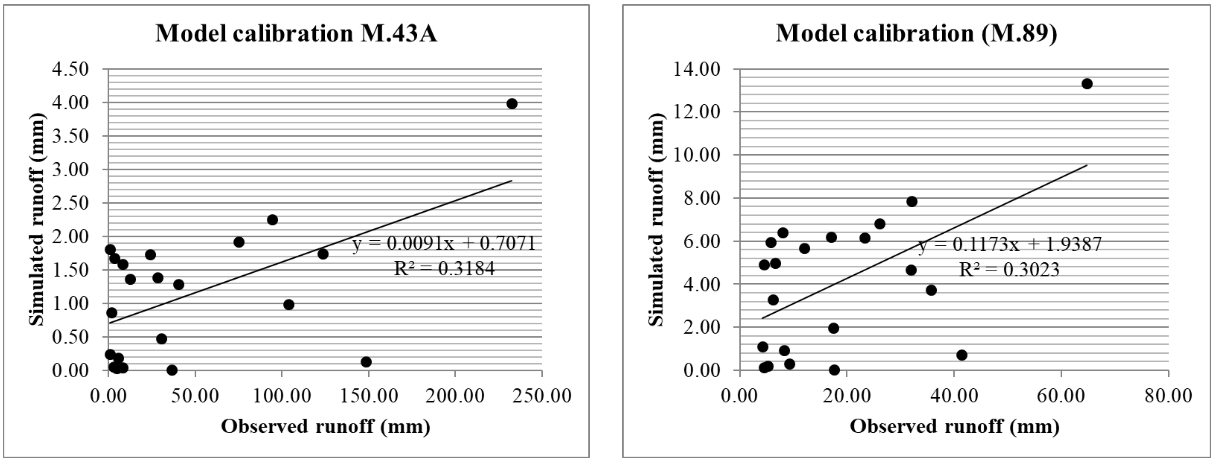


Figure 4 Comparison of observed and simulated runoffs for calibration.

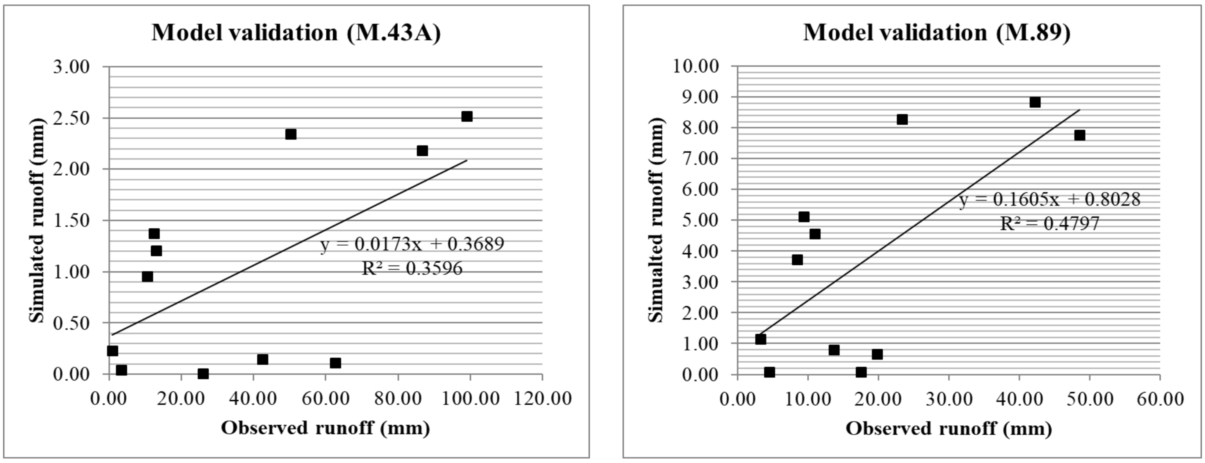


Figure 5 Comparison of observed and calibrated-simulated runoffs for validation.

From scatter plot of observed and simulated runoffs for calibration and validation has overestimation. It can be concluded that the comparison results at both the M.43A and M.89 stations, as shown in the scatter plot are slightly poor model although values of R^2 are considered to be satisfactory (Motovilov et al., 1999). The error encountered at both stations could be explained by the model really providing every cell simulation and accumulating them from upstream to the cells at the station while the actual processes were hardly able to exist in the cells, especially high spatial variability factor.

Impact of LULC change on surface runoff

The results of the regression analysis suggest that human activities and urbanization have had an increasing impact on runoff (Fig. 7). The decreased of forest and agricultural land, while urban and built-up area was increased have a negative impact on surface runoff due to decreasing of infiltration and increasing of surface runoff. Especially, urbanization was the strongest contributor to the increase of surface runoff. This result also accordingly the finding of Ongsomwang and Pimjai, 2015; Ozdemir and Elbasi, 2015. These authors noted that the increasing of urbanization and impervious surface in a watershed strongly impact the stream hydrology and runoff increased linearly with the develop area.

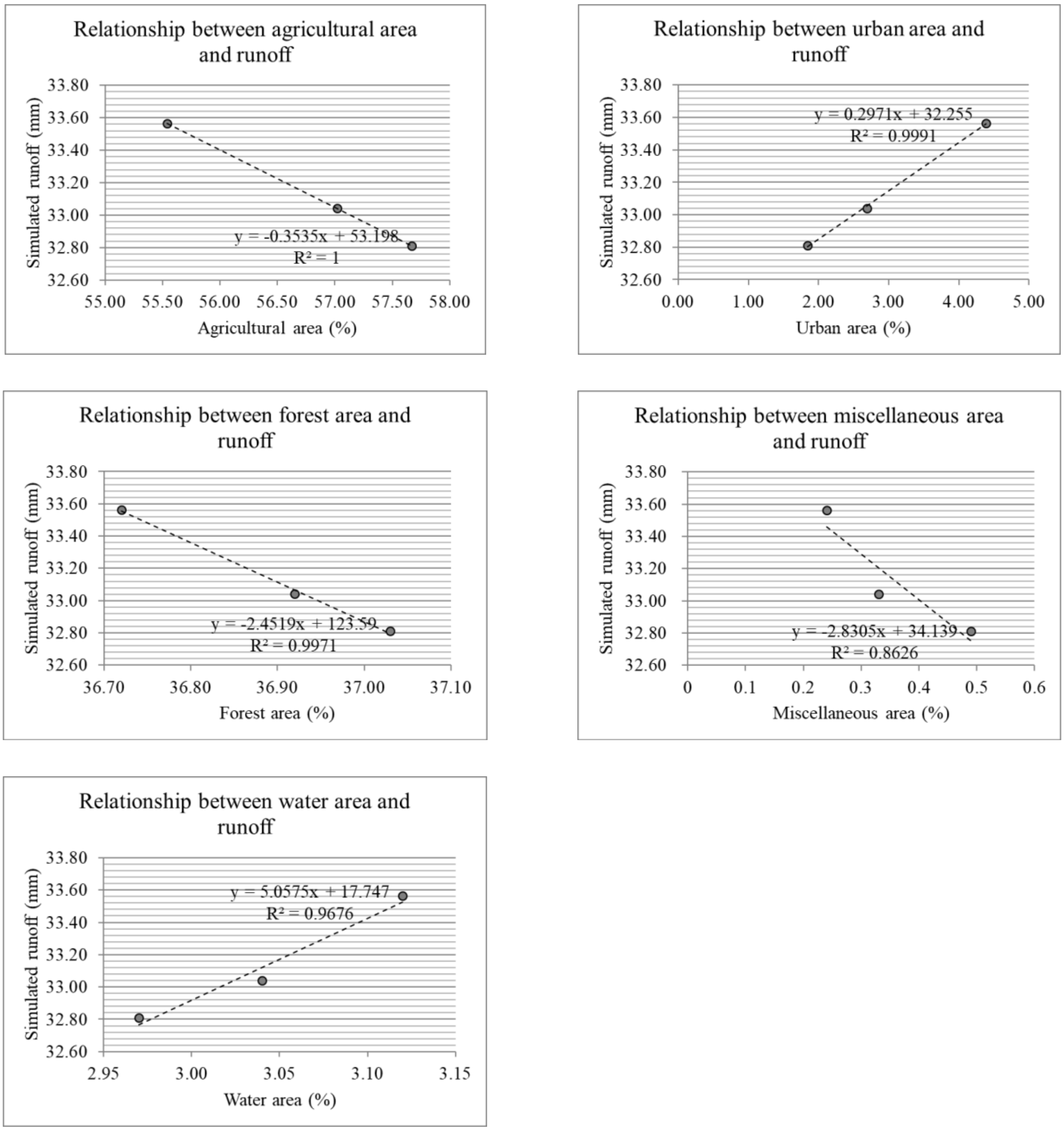


Figure 7 Simple linear regression between difference type of land use area and surface runoff.

Conclusion

From the results, the land use type during 1993 – 2009 founded that the forest and agricultural land were decreased, while the urban and built-up area has been continuously increasing. The decreased of forest and agricultural land, while urban and built-up area was increased have a negative impact on surface runoff due to decreasing of infiltration and increasing of surface runoff. Especially, urbanization was the strongest contributor to the increase of surface runoff. The results of this study indicate that the changing of land use types from natural surface to impervious surface has a significant impact on surface runoff. This study will provide quantitative information for stakeholders in land use planning and water resource management in the study area.

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