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Research Article

Assessment of Land Use/Land Cover Change Impact on the Hydrology of Asan River Watershed of Dehradun District, Uttarakhand

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Abstract

Land use/Land cover (LULC) change results from the alteration of the earth's surface by human beings and have potentially large impacts on water resources. Some regions of India are facing serious problems of water resources scarcity, especially the regions where the rapid urbanization/industrialization takes place in past few years for example; Asan River Watershed of Dehradun district, India. By using land use supervised classification technique with Maximum Likelihood method, LULC maps were prepared for the year 2000 and 2013. The overall Kappa statistics of classified image is found to be 0.87 & 0.86, respectively, which is fairly acceptable. To evaluate the effect of LULC change on runoff of the study area, hydrological modeling is done by using Soil and Water Assessment Tool (SWAT) model considering the LULC change in 13 years. It was observed that the build-up area has increased dramatically by 88.65% in the watershed (major changes in sub basin no. 20 & 16), the crop land and forest is decreased by 6.61% and 0.25%, respectively. Hydrological modeling results for those sub basins state that there was an average increase of 70% and 65% surface runoff during 13 years due to the rapid growth of industries in the areas.

Keywords: *Land use/Land cover, water resource, SWAT model.*

1. Introduction

Land use/Land cover (LULC) is a product of mutual interactions between human economic activities and the natural environment (Liu and Chen 2002). When the LULC changes, it largely impacts on general environment, especially water resources. General statements about land and water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002; Bewket and Sterk, 2005). With the rapid urbanization/industrialization processing in these day, understanding how LULC change influence water quantity will assistance planners to formulate policies towards an increase of water scarcity and thus contribute dramatically to living conditions.

Hydrological modeling is a powerful technique in integrated approach to assess impacts of LULC change on water resources, e.g., VIC (Liang *et al*., 1994), MIKE-SHE (Refsgaard and Storm, 1995), SWAT (Arnold *et al*., 1998; Birhanu, 2009), RISE model (S. Dutta and M. Zade, 2003). Despite the abundance of modelling systems, the computational resources needed to run detailed models may be excessive for large-scale catchment simulations; models of simpler conceptual techniques are selected for this study, which contains the essential concepts of component sub-processes while also allowing space-time variability to be considered. For the hilly terrains in the upstream of river, physically based semi distributed Soil and Water Assessment Tool (SWAT) has been applied.

As a result, LULC change has been a topic of great interest within the human dimensions of the Environmental change research community (Meyer *et al*., 1996). India is facing a serious problem of natural resource scarcity, especially that of water in view of population growth and economic development (Yadav *et al*., 2013). Hence, the understanding extent and spatial distribution of LULC is a essential importance to the study of water resource change. As the evident urbanization/industrialization has been taken place in the watershed, as Uttarakhand has been confirmed dispersed state from Uttar Pradesh, Asan River watershed area has been taken up this study.

2. The study area

The Asan River watershed is located between latitudes 30°14'14''N to 30°29'54''N and longitudes 77°39' 42''E to 78°05'30''E, Dehradun district, Uttarakhand State,

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India as shown in Figure 1. It covers an area of approximately 669.72 km^2.

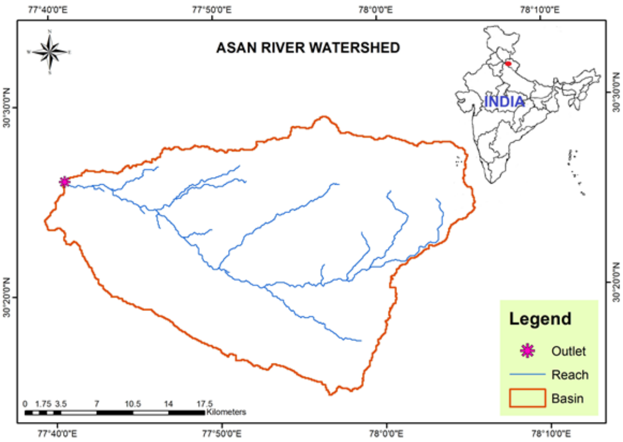

Fig.1 The study area with outlet and reach

The soils encountered in this region are generally classified as clay loam, clay, loamy and clayey soils. The major part of the study area is covered with loamy soil.

The climate of study area is sub-tropical to temperate on higher elevation (more than 1,800 m). The average annual temperature ranges from 21°C in summers to 5°C in winters. Most of the annual rainfall in study area received during the months from June to September, July and August being rainiest. The mean annual rainfall in the watershed is around 1,917 mm. Relative humidity is recorded as 91% in January.

3. Methodology

The main objective of this research is to determine the influence of LULC categories on water resources. Semi-distributed hydrological model (SWAT) is used to simulate the hydrological processes in different LULC conditions. The input database to set up the model includes DEM, LULC maps, soil map and hydro meteorological data. After setting up of the model, calibration is done by using Sufi2 Optimization algorithm of Swat-Cup. Finally, model validation has been done to assess the effect of LULC change on hydrological regime in the study periods.

3.1. Preparing LULC maps

Four geometrically corrected Landsat images of 31-01-2000, 28-09-2000, 18-09-2013 and 24-01-2014 with spatial resolution of 30 m were used in the study which were downloaded freely from the http://earthexplorer.usgs.gov/.

The images were classified using Maximum Likelihood technique and visual interpretation. Seven types of LULC classes were obtained for Asan River area as follows: build up, crop/fallow, forest, plantation/shrub, grass, water bodies/dry river, and waste land.

For each Landsat image, about 180 training sites were chosen to complete supervised classification by Maximum Likelihood technique. By using the ArcMap tool, raster images were converted into vector formats and then merged to create the LULC maps for 2000 and 2013.

In order to evaluate accuracy assessment for classified images, the error matrix method was used. In the absence of historic ground truth data, the LULC map of 2000 was validated by using Survey of India Toposheet and the fieldwork. For LULC map of 2013, 44 samples of the actual field class were collected from the fieldwork. By determining the overall, accuracies of the 2000 and 2013 supervised classification, the overall accuracy of the remaining supervised classifications and Kappa coefficient were calculated.

To detect the change which occurred on the study area, multi-temporal analysis has been done by considering differences between 2000 and 2013. Using intersection analysis tool of ArcGIS, the changes were detected and quantified.

3.2. Watershed delineation

ArcSWAT automatically delineates a watershed into sub watersheds based on DEM and drainage network. The standard methodology, based on the eight –pour algorithm (Jensen and Domingue, 1988) is applied for automatic delineation. The DEM (Aster) with a pixel size of 30m prepared was loaded to the ArcSWAT model. The DEM was then preprocessed in order to determine the size and number of sub watersheds based on the threshold area or critical source area. The critical source area is the minimum drainage area required to form the origin of a stream. In the present study the minimum threshold area was taken to be 1342.6722 ha which formed 27 sub watersheds.

Herbetpur (upstream point of Asan Barrage) is selected as an outlet then run the calculation of the subbasin parameters which will calculate geoporphic parameters for each subbasin and the relative stream reach

3.3 HRU Analysis

HRU Analysis includes land use, soil and slope characterization. Soil and land use plays a significant role in the water movement process. Since the infiltration capacity of soil depends on the soil texture the highest infiltration rates are observed in sandy soils. This indicates that surface runoff is highest in clay or loamy soils which has low infiltration rates. Vegetation on the other hand acts as a barrier to flow of water. Forest covers the soil from raindrop impact and reduces the problems of erosion.

Soil data spatial distribution (soil map) was with the scale 1: 25 000 which in vector format. It was converted to raster format in ArcGIS. The attributes of soil map, in which only soil name is available, cannot meet the requirement of the ArcSWAT. The soil parameters required in the ArcSWAT were derived by Water Resource Department, IIRS.

LULC maps of 2000 and 2013 were prepared form the Landsat images maps. The LULC classes were reclassified based on the condition of the watershed which need to convert to the classes in the model by establish some relationship between them. Slope discretization was classed into 3 levels: 0-5%, 5-10% and > 10%.

HRU represents the areas having unique land use and soil combination which enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land cover and soils. Multiple HRUs per sub watershed were selected in this study. The land use threshold and soil threshold were set as 5% for both 2000 and 2013.

3.4 Write Input Table

One of the main sets of input for simulating the hydrological processes in SWAT is climate data. Daily climate data input for 2000 consists of average precipitation, maximum and minimum temperature, wind speed and relative humidity and the weather generator file. The climate data for study periods were prepared in .dbf format and then imported in the SWAT model.

Then creation of input: input database files included watershed configuration file (cio.dbf), soil data (sol.dbf), weather generator data (wgn.dbf), general subbasin data (bsn.dbf), hru general data (hur.dbf), main channel data (rte.dbf), groundwater data (gw.dbf), water use data (wus.dbf), management data (mgt.dbf), soil chemical data (chm.dbf), pond data (pnd.dbf), stream water quality data (swq.dbf). Write all command was selected to build the initial vales.

3.5 Simulation conditions

Once finishing the creation of input files, the simulation toolbox was activated. First simulation period from 01/01/2000 to 31/12/2000; Printout frequency was selected as daily option; Rainfall distribution was selected as skewed normal; Priestley- Taylor method was selected to calculate potential ET; Muskingum method was selected for channel water routing; Active crack flow. Other option were kept as default, and then run the model.

For LULC of 2013, create new projects for two years. Change the land use theme and setup the model again, the simulation period were from 01/01/2000 to 31/12/2000.

3.6 Model Calibration and Validation

a. Model Calibration

Calibration is the process whereby selected parameters and variables of the model are adjusted to make the model output match observations. Its main purpose, therefore, is to obtain an economical and reproducible method of identifying a parameter set for a particular catchment under particular conditions which gives the best possible fit between the simulated and observed stream flows for a particular calibration i.e. the calibrated parameter set aims at minimizing the difference between simulated and observed stream flows. Calibration is considered to be necessary because there may be uncertainties in the model input and because models give only simplified representations of the catchment's physical processes, which operate at a range of scales which are not always compatible with the catchment or grid scale.

In the present study the ArcSWAT model was calibrated for the year 2000 based on the observed daily runoff data by SWAT-CUP software (developed by Neprash Technology in 2012).

b. Model Validation

Model validation is the process of re-running the simulation, using a different time-series for input data, without changing any parameter values which had been adjusted during calibration. In the present study, after proper calibration the model was validated for monthly and daily surface runoff for the year 2000.

3.7 Performance Evaluation for Model

Evaluation of models is done in order to compare how the model simulated values fit with the observed values. The following graphical a numerical performance criterion was used in the present study:

a. The coefficient of determination (R^2) describes the proportion of the total variance I the measured data that can be explained by the model. It ranges from 0 to 1, with higher values indicating better agreement, and is given by,

$$R^2 = \left[\frac{\sum_{i=1}^{N}(C_i - C_m)(O_i - O_m)}{\sqrt{\sum_{i=1}^{N}(C_i - C_m)^2} \cdot \sqrt{\sum_{i=1}^{N}(O_i - O_m)^2}} \right]^2$$

where C_i is the i^{th} observed parameter, C_m is the mean of the observed parameters, O_i is the i^{th} simulated parameter, O_m is the mean of model simulated parameter and N is the total number of events.

b. Coefficient of simulation efficiency (COE), also known as the Nash-Sutcliffe coefficient (Nash & Sutcliffe, 1970) recommended by ASCE Task Committee (1993) is the second basic goodness-of-fit criterion used to evaluate the model performance. The equations is as follows:

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_0^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_0^t - \overline{Q}_0\right)^2}$$

where Q_0^t and Q_m^t are the measured discharge and computed discharge, $\overline{Q_0}$ is the average measured discharge values. The values for E can be varied from 0 to 1, with 1 indicating a perfect fit. A value for E equal to zero indicates that the model was simulating no better than using the average of the observed data.

4. Results and Discussion

4.1 Land use/ Land cover maps

4.1.1 LULC for 2000 and 2013

Based on the classified images, crop/fallow and forest were observed as the dominant in the study area. LULC classes were observed varied temporally. The area rate of crop/fallow, plantation/shrub, forest, waste land, water bodies/dry river, grass, and build up classes in 2000 were 33%, 1.7%, 56.1%, 0.26%, 5.26, 1.11% and 2.63%, respectively. They are 30.8%, 1.67%, 55.95%, 0.24%, 5.3, 1.11% and 4.96%, respectively in 2013. The area of LULC of the Asan watershed in 2000 and 2013 were summarized in the table 1.

Fig.2 LULC map of the study area year 2000

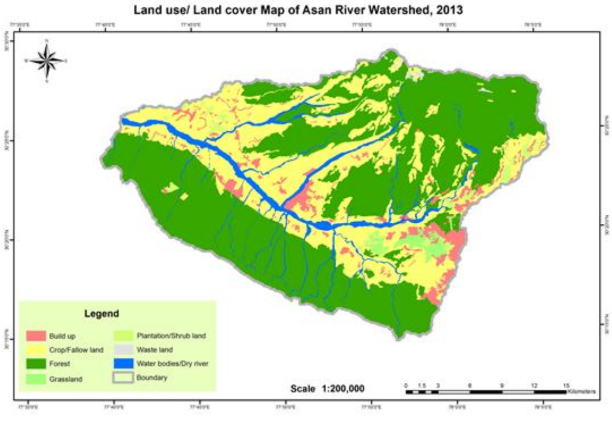

Fig.3 LULC map of the study area year 2013

4.1.2 Land use map accuracy assessment

a. LULC map of 2000

After selecting 38 random locations on the SOI Toposheets for the watershed and fieldwork, accuracy assessment has been done. LULC map of 2000 were assessed and acquired overall Kappa statistics 0.87. This result shows relatively a high accuracy for the map produced from image of Landsat ETM+ with 30m resolution.

b. LULC map of 2013

Accuracy assessment of the LULC maps prepared for 2013 was carried on 44 samples of the actual field LULC classes. And the overall Kappa statistics was calculated with a moderately accuracy which is 0.86.

4.1.3 Land use/ Land cover change between 2000 and 2013

The change of each LULC class from 2000 to 2013 in the study area was illustrated clearly in the table 1. Compare the LULC of 2000 and 2013; some LULC change trend can be drawn as follows. During study period, build up rose significantly (88.65%), while crop/fallow and forest decreased trend, which is 6.6%, 0.25%, respectively.

Spatial LULC change distribution was illustrated in the figure 4. The map revealed that there are seven alterations of the Asan River watershed. As shown in the table 1, it is the dramatic boomed of build up in the study area. This significant change is transforming most of crop/fallow at 89.62%, forest at 5.85%, and plantation- build up (1.58%). Also there are slow fluctuations of other LULC categories: crop/fallow-water bodies/dry river (2.03%), waste land-crop/fallow (0.73%), and grass- plantation (0.19%).

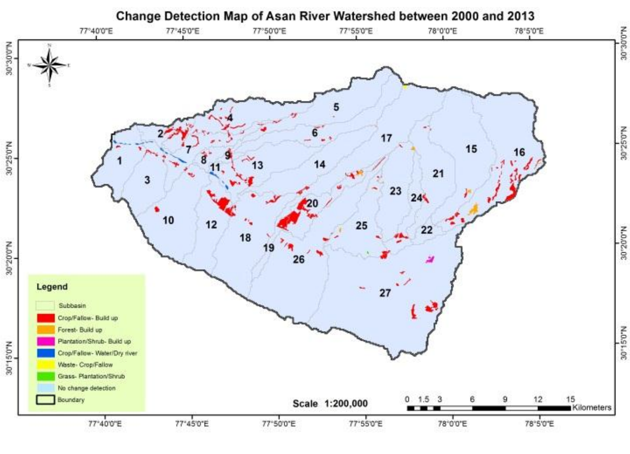

Fig.4 Change detection of Asan River watershed, 2000-2013

Table 1 List of LULC change of Asan River watershed, 2000-2013

Name	2000		2013		Change	
	Area (km²)	**Area (%)**	**Area (km²)**	**Area (%)**	**Area (km²)**	**Area (%)**
Crop/Fallow	220.71	32.96	206.11	30.78	14.60	**6.61**
Waste land	1.71	0.26	1.59	0.29	0.12	**6.89**
Water/Dry river	35.20	5.26	35.53	5.31	-0.33	**-0.93**
Plantation/Shrub	11.37	1.70	11.12	1.66	0.25	**2.24**
Forest	375.66	56.09	374.72	55.95	0.94	**0.25**
Build up	17.61	**2.63**	33.23	**4.96**	-15.62	**-88.65**
Grass land	7.45	1.11	7.42	1.11	0.03	**0.40**
	669.72	**100.00**	**669.72**	**100.00**	**0.00**	**0.00**

4.2 Model Calibration and Validation

4.2.1 Model Calibration

Once finishing the creation of input files, the simulation menus was ready for 2000. The results obtained from the model are hydrographs and time series of daily outflow data for each sub basin, reach and hydrological response units. The figure 5 is showing the simulated daily discharge for Asan watershed before calibration.

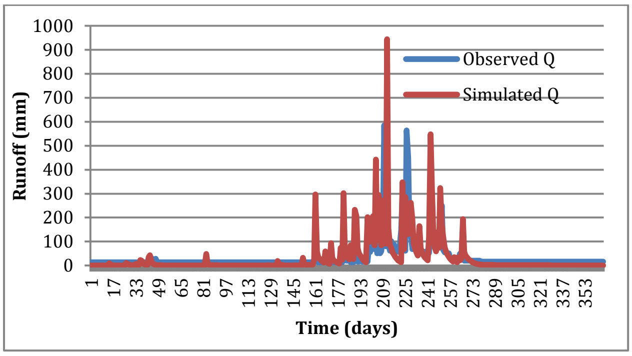

Fig.5 SWAT simulated daily discharge for Asan watershed for year 2000 before calibration

The results obtained for daily discharge by SWAT model were not satisfactory. Therefore, SWAT- CUP software was calibrated by few sensitive parameters for hydrological modeling. The calibration parameters for year 2000 were CN2 (relative 0.045), ALPHA_BF (relative 0.6575), GW_DELAY (replaced 37.35) and GWQMN (absolute 1.885).

4.2.2 Model Validation

The calibrated model was again run with the new set of parameters in the swat database file for monsoon of year 2000 with the LULC map of year 2000 and year 2013. As shown in above figures, after calibration and validation, the figure 6 presents matching between precipitation and runoff values for 2000. The plot below clearly shows a resembling trend between rainfall and runoff for the monsoon of year 2000.

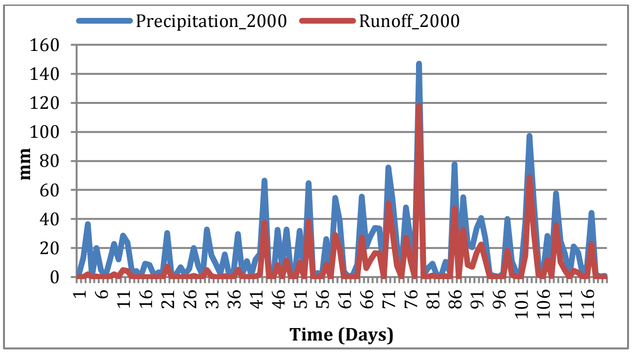

Fig.6 Comparing between precipitation and runoff, 2000

4.2.3 Calibration assessment

The figure 7 shows validated runoff and simulated runoff for the year 2000. Besides, the plot of simulation and validation for 2000 showed the coefficient of determination (R^2) and the Nash-Sutcliffe coefficient 0.9904 and 94%, respectively. The result indicates a good correlation between simulation and validation of 2000.

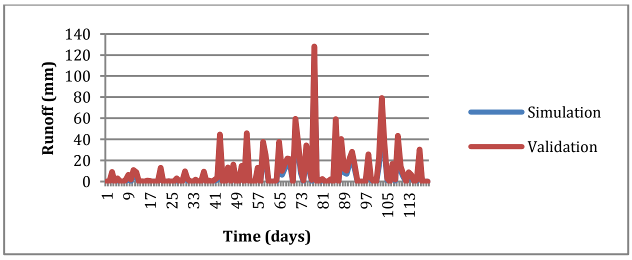

Fig.7 Simulation and validation for the year 2000

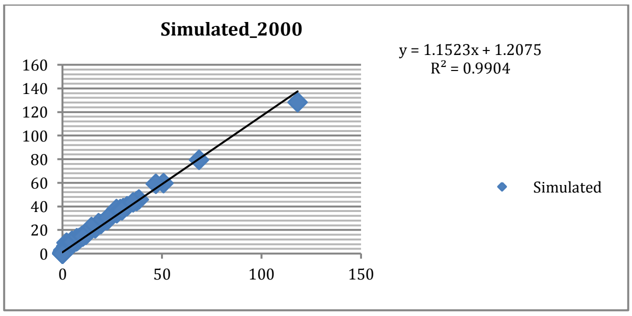

Fig.8 The plot of simulation and validation, 2000

4.3 Runoff Maps of 2000 and 2013

The figure 9 and 10 represent the runoff maps for year 2000 and 2013. In 2000, the subbasins, which is 14, 15, 16, 17, 21, 22, 23, 24, 25, have high value of runoff, which are more than 10 m. However, these values changed at 2013 when there is more contribution from subbasin 20, which is around 13 m because of increase in industrial area.

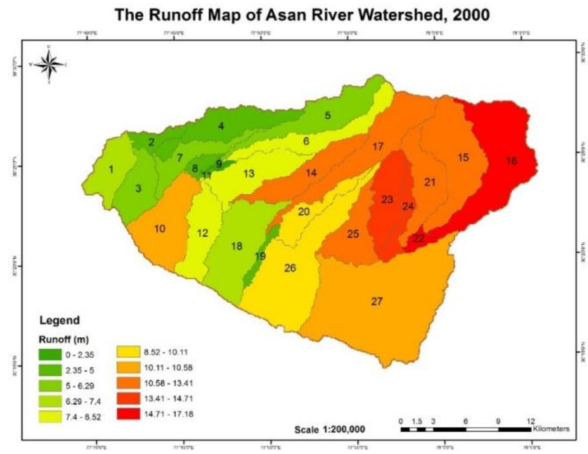

Fig.9 The runoff map of Asan River watershed, 2000

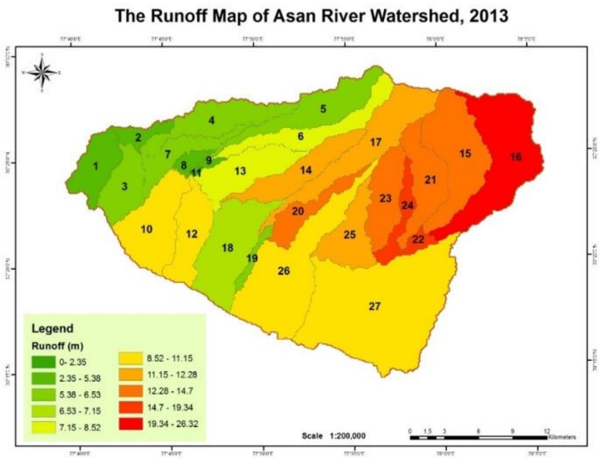

Fig.10 The runoff map of Asan River watershed, 2013

4.4 LULC and Surface Runoff Relation

The interaction between LULC and hydrological response is a complex phenomenon. In this study, SWAT model was used to illustrate LULC change impact on water resource in Asan River watershed. Distributed hydrological modeling can reveal the spatial distribution of hydrological parameters. Combining with spatial distribution of LULC change, the relation between LULC and hydrological process was described in more detail.

The figure 4 revealed that build up area is increased significantly, while crop/fallow and forest are declined from 2000 to 2013. As shown in the figure 5.13, the runoff of 2013 surge than 2000 in most of sub basins. Particularly, it is a rise to 70% and 64.5% at sub-basin 20 and sub basin 16, respectively. These sub-basins has transformed considerably from crop/fallow and forest to build up in the study period. In addition, the figure showed that the run off is no change the forest without change in sub basin 6. The results indicated that the relationship between LULC change and surface runoff is close-fitting.

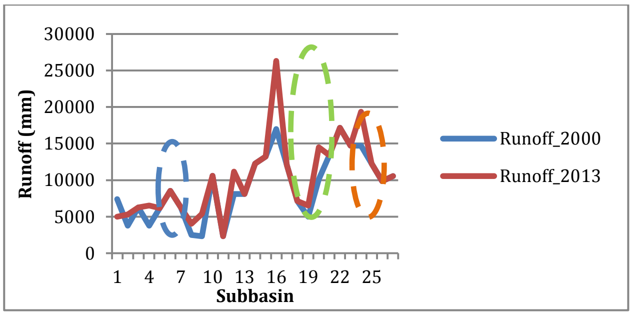

Fig.11 Comparing Runoff of 2000 and 2013 in each sub-basin

Conclusions

Using semi-distributed hydrological model (SWAT) combined with Remote Sensing and GIS technique, the effect of Land use/Land cover change on the water resource (focusing surface runoff) in Asan River watershed was analyzed in this study. The statistical method was also used to analyze the effect of LULC change in 13 years. The key findings are summarized as follows.

5.1 Land use/Land cover change in Asan River watershed

During 2000 to 2013 periods, considering the total change of LULC, build up was increased dramatically by 88.65%, crop/fallow and forest area decreased by 6.6%, 0.25%, respectively. The change of other categories at Asan River watershed is insignificant in the study period for the surface runoff generation processes.

5.2 SWAT modeling results and relation with LULC change

The SWAT model was applied for 2000 and 2013 which were corresponding to period of prepared LULC maps in the study area. A drastic change in build-up area has been observed for sub-basin no. 20 and 16. Analysis of the hydrological modeling results for that sub-basin states that there was an average increase of 70% (Selaqui town) and 65% surface runoff during 13 years due to the rapid growth of urbanization/industrialization in the areas.

In conclusion, the results presented that the increase of build up or the urbanization has effected dramatically on water resource, particularly, in this study is surface runoff.

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