Long-term hydrological effects of climate change and land-use change in the Upper Part of Dong Nai river basin

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ABSTRACT

Climate change coupled with land-use change has posed distinctive challenges in the management practices of surface water resources in terms of hydrological conditions and water balance. Climate change has significantly affected the hydrological conditions while the changing in land-use and land-cover (LULC) for social demands has continuously skewed the water balance. The Upper Part of Dong Nai (UPDN) River Basin has a crucial role for the socio-economic development of provinces in the Southeast region of Vietnam. However, the potential hydrological impacts of climate change and LULC on this area have not been well examined yet. Therefore, there is a need for assessment of long-term impacts from climate change and changes in LULC in order to derive the sustainability of watershed management and planning. This study used Landsat images and SWAT (Soil and Water Assessment Tool) model to evaluate water yield and sediment load in the UPDN river basin in the period of 1984 - 2014. Three distinct Landsat images in 1994, 2004 and 2014 were used to specify the changes in LULC maps with seven classes (water bodies, built-up residential area, evergreen forest, coniferous forest, mixed forest, perennial orchard, and annual agricultural). The LULC maps were combined with the soil map, DEM map, temperature and precipitation data to set up inputs for SWAT model. Observed stream flow in 1984 – 2014 has applied to calibrate and validate the model. The simulated result shows that formation and operation of cascade hydroelectric reservoirs are the dominant factors causing for the changes in hydrological conditions of the UPDN river basin. These findings contribute a comprehensive approach to empirical information for the sustainable practices of watershed management in the UPND river basin.

Keywords: SWAT, Landsat, water yield, sediment load, total discharge, Upper Part of Dong Nai Basin.

1. INTRODUCTION

The Dong Nai (ND) river basin, a river originates in the Central Highland region of Vietnam, is the largest national river basin and the most country's dynamic economic development region. The basin covers with an area of 48,471 km^2 with 10 provinces included Ho Chi Minh City which form the southern focal economic zone, a highly populous and economic development region, with a relatively high income per capita compared with other regions in Vietnam. Water source of the Dong Nai river basin is a dispensable resource for the development of more than 60 industrial parks and export processing zones at the downstream part (Ringler and Huy, 2004).

It was reported that during the period 1990-2000 tropical forests in South-East Asian countries had been decreased from 53.9% in 1990 to 48.6% in 2000 (UN, 2005). In the same manner, for a long time, land use/land cover (LULC) of the UPND river basin has been significantly changed because of conversion of forests into intensive agricultural land and large hydropower projects in the upstream part. The changes in LULC have altered the hydrologic system and have potentially large effects on the surface water quality (rivers and lakes) due to increases or decreases in soil erosion or other pollutants within the river basin (Can et al., 2015; Wagner et al., 2013). Additionally, the impacts of LULC change on watershed hydrology are interlinked with impacts of climate change (Mango et al., 2011).

In a context of climate change in Vietnam, on average for the whole country, annual rainfall had tended to increase slightly, but have increased by approximately from 6.9% to 19.8% over the past 57 years (from 1958 to 2014) in the Southern regions. At the same time, annual temperature has increased by 0.42°C. Among seven climatic zones, the Central Highlands of Vietnam was the area with the highest temperature increase and annual rainfall of this region had increased by 8.6% over the past 57 years (MONRE, 2016).

The effects of climate variation and change on the hydrological cycle have been coincident with those of change in land use, so that it is difficult to separate these two sets of effects in analysis and synthesis (Dam, 2003). In recent years, hydrological models have been developed to assess long-term hydrological effects of climate change and land use change. The rainfall-runoff models, such as VIC, TOPMODEL, HBV, MIKESHE, and SWAT (Soil and Water Assessment Tool) model, are the standard tools used for investigating hydrological processes under the climate change and change in LULC. Each model has gotten its own unique characteristics and respective applications and each model has various drawbacks like lack of user friendliness (Devi et al., 2015). Borah and Bera, (2003) have compared SWAT with other models, found 17 applications of SWAT, and concluded that it can be applied for continuous simulations of flow, soil erosion, nutrient and sediment transport etc.

SWAT, a model with the wide range applications, has gained international acceptance as a very flexible and robust interdisciplinary tool that can be used to simulate a variety of watershed problems. The distinct advantages of SWAT model were already testified by various scientific platforms in the literature (Gassman et al., 2007; Huang and Lo, 2015). Moreover, with development of GIS-based interfaces, which provide a straightforward means of translating digital topographic, soil and land use data into model inputs, the process of configuring SWAT for a given watershed has also been greatly facilitated (Gassman et al., 2007). With the Arc-SWAT 2012 Version, the input lup.dat file is particularly useful to initialize mid-simulation conservation measures because it allows HRU (hydrologic response unit) fraction updating during a simulation run (Gassman et al., 2007). Additionally, the fast evolution of Remote Sensing (RS) and Geographic Information Systems (GIS) techniques facilitated derivation of the topographic factor from digital elevation map (DEM) data, while RS data helped to identify land use change and land cover classification (Ozcan et al., 2007).

There have been many cases where SWAT models have been deployed to predict simultaneous impacts of climate change and change in land use on hydrological conditions (Khoury et al., 2015; Mango et al., 2011; Zhu and Li, 2014). To provide quantitative information that would allow stakeholders and decision makers to make better choices regarding land and water resources management, determination contributions of LULC change and climate conditions to change in stream-flow and sediment yield is necessary. The objectives of this study are: (i) to create LC maps for three Landsat images (1994, 2004, and 2014), and to observe LC changes in 20 years (1994 – 2014); (ii) to evaluate the impacts of land use changes on stream-flow and sediment yield; and (iii) to provide invaluable evidence for future formulation of appropriate government land development policies.

2. MATERIALS AND METHODS

2.1 Study area

The study area is located in the Upper Part of the Dong Nai river basin (Figure 1), which covers an area of 972,460 ha and belongs to Lam Dong, Dak Nong, and Dong Nai provinces.

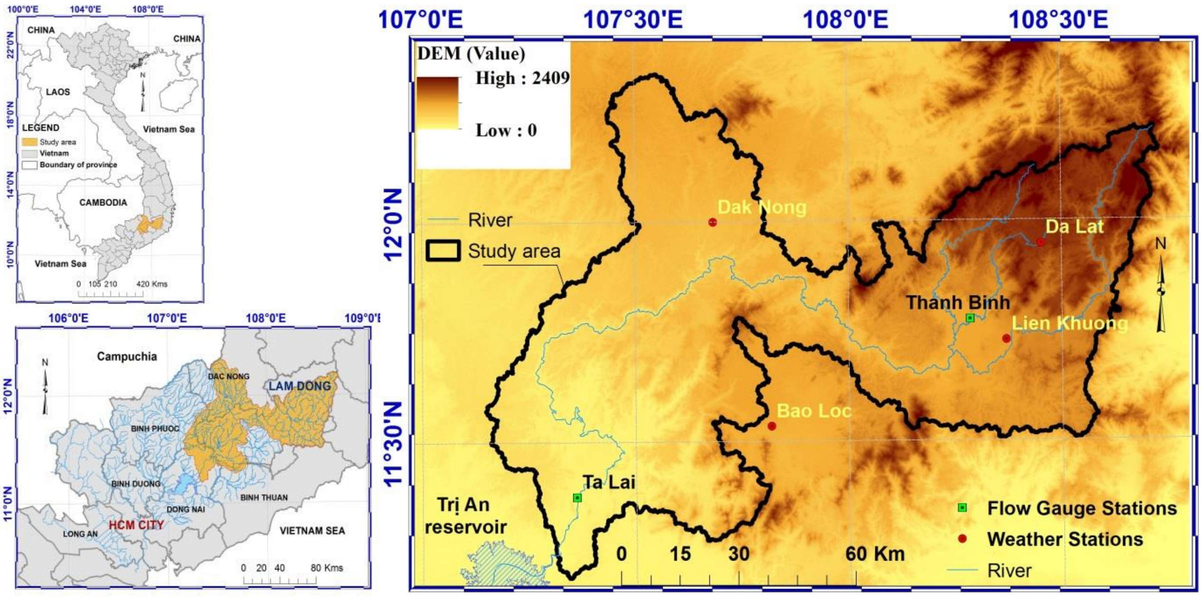

Figure 1. Location of the Study Area and its elevation (m) pattern

The UPDN river basin is an environmentally sensitive mountain area, the altitude of the study area ranges from 100m to 2,409m on level sea. The topographical stratification is clearly from North to South. Topographical features influence climate factors, soils, vegetation of the UPDN basin. This area has been affected by the tropical monsoon climate regime with altitude. There are two seasons, the rainy season lasts from May to November and the dry season is from December to April of the following year. The average annual temperature was 22^{0}C, precipitation was 2,500 mm, and humidity was 83% over the past 33 years, from 1981 – 2014 (Statistical Bureau of Lam Dong province, 2015).

2.2 The SWAT model

Soil and Water Assessment Tool (SWAT) is a physically-based distributed hydrological model developed by Jeff Arnold for the USDA-Agricultural Research Service (USDA-ARS) and designed to estimate impacts of land management practices on water quantity and quality in complex watersheds with varying soil, land use, and management conditions over long periods of time. SWAT partitions a watershed into sub-basins or sub-watersheds connected by a stream network and further delineates each sub-watershed into Hydrological Response Units (HRUs) consisting of unique combinations of land use, soils, and management combinations. SWAT simulates the hydrology of a watershed into two phases. The first phase, the land phase of the hydrologic cycle, calculates the amount of water, sediment, nutrient and pesticide loads from each HRU and sums up to the level of sub-basins. The second phase, the routing phase of the hydrologic cycle, defines the movement of water, sediment and other non-point sources of pollution through the channel network to an outlet of the watershed (Huang and Lo, 2015; Neitsch et al., 2011). The hydrological cycle is simulated in SWAT model based on the water balance equation (Neitsch et al., 2011):

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_a - Q_{gw}) \quad (1)$$

where SW_t is the final soil water content. SW_0 is the initial soil water content on day I. t is the time (days). R_{day} is the amount of precipitation on day I. Q_{surf} is the amount of surface runoff on day i (mm H_2O). E_a is the amount of evapotranspiration on day I. w_{seep} is the amount of water entering the vadose zone from the soil profile on day I. Q_{lat} is the water percolation past bottom of soil profile in the watershed for day I. Q_{gw} is the amount of return flow on day i. All water units are in mm H_2O.

SWAT computes erosion caused by rainfall and runoff from each sub-basin to the basin outlet based on Modified Universal Soil Loss Equation (MUSLE) at a HRU level, the equation is: (Huang and Lo, 2015; Neitsch et al., 2011)

$$sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \quad (2)$$

where sed is the sediment yield on a given day (t). Q_{surf} is the surface runoff volume (mm.ha^{-1}). q_{peak} is the peak runoff rate (m^3.s^{-1}). $area_{HRU}$ is the area of the HRU (ha). K_{USLE} is the USLE soil erodibility factor. C_{USLE} is the USLE cover and management factor. P_{USLE} is the USLE support practice factor. LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor.

In the present study, SWAT in version 2012 was used to estimate water yield and sediment load in the UPDN river basin in the long term of 1984 – 2014 under conditions of climate change coupled with land-use change. The input data of the model includes digital elevation model (DEM), soil, meteorological, and stream-flow data.

2.2 Model setup

2.1.1 *Land use/land cover data*

Land use/land cover (LULC) maps in a 10-year temporal interval were generated from 30-meter resolution Landsat images downloaded from USGS (website: http://earthexplorer.usug.gov). Based on actual conditions of the area, maximum likelihood classification (MLC) method, a commonly used method on Landsat images (Phiri and Morgenroth, 2017), was applied to classify for Landsat 5 TM images (1994, 2004) with 6 bands (1, 2, 3, 4, 5, and 7) and Landsat-8 OLI/TIRS (2014) with 6 bands (2, 3, 4, 5, 6, and 7). The LULC maps with 7 main classes were classified for the study area are (1) water bodies, (2) broadleaf evergreen forest, (3) mixed forest, (4) coniferous forest, (5) built-up residential areas, (6) annual agriculture land, and (7) perennial agriculture land. The accuracy assessment of the LULC maps is reflected by overall accuracy and Kappa coefficient. The results of overall accuracies were good with 84.3%, 87.0% and 77.7% for 2014, 2004, and 1994. Kappa coefficients were 0.81, 0.85, and 0.74 for 2014, 2004, and 1994. Seven LULC classes were then refined, reclassified, and updated to the SWAT land use/land cover type, that was made possible using data from field survey and locally statistic references in order to better represent the land cover in the study area (Mango et al., 2011). These LULC classes were translated to SWAT-Land-use type that (1) water bodies, (2) broadleaf evergreen forest, (3) mixed forest, (4) coniferous forest, (5) built-up residential areas, (6) annual agriculture land, and (7) perennial agriculture land is coded (1) WATR, (2) FRSE, (3) FRST, (4) PINE, (5) URML, (6) AGRR, (7) AGRC, respectively, see Figure 2 (a), (b), and (c).

2.1.2 *Digital Elevation Model*

Digital Elevation Model (DEM) of the study area with 12.5-meter resolution downloaded from the website of the American National Aeronautics and Space Administration (NASA): ttps://urs.earthdata.nasa.gov/users/new. The DEM was used to delineate the basin boundary, along with 36 sub-basins as presented on Figure 2 (f).

2.1.3 *Climate data*

Climate data used in the SWAT model consists of daily rainfall, temperature, wind speed, humidity and evapotranspiration data. The daily precipitation and the maximum and minimum temperatures from 1984 to 2014 were obtained from 4 weather stations (Da Lat, Lien Khuong, Bao Loc, and Dak Nong), the location of these stations is shown on Figure 2 (d) and (f). The missing data in daily solar radiation, wind speed, and relative humidity were generated automatically by SWAT (Jha et al., 2007; Mango et al., 2011). The spatial location of these stations could be sufficiently representative for the rainfall and temperature across the entire watershed area.

2.1.4 *Soil data*

The SWAT model requires soil property data such as the texture, chemical composition, physical properties, available moisture content, hydraulic conductivity, bulk density and organic carbon content for the different layers of each soil type (Setegn et al., 2010). Soil data were obtained from the 1:100,000 soil map of Department of Natural Resources and Environment (DONRE) Lam Dong province and the available soil analysis data from Department of Science and Technology (DOST) Lam Dong province and the third Governmental Highland Program in 2012 (Dang et al., 2013; Dinh, 2012; Institute of Agriculture and Soil Vietnam, 2017). The study area has 22 land units belonging to two major soil groups: Ferrasol (formed from acidic volcanic rock) and Acrisol (formed from clay and degenerated stone), the spatial distribution of classes is shown in Figure 2 (e).

2.1.5 *River discharge*

Daily and monthly water discharge data from 1984 to 2014 were derived from the Thanh Binh and Ta Lai gauge station located at the upstream and downstream of the basin, see Figure 1. The discharge values were used for calibration and validation of the model (Mango et al., 2011).

2.2 Model validation

In this study, the coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (E_{NS}) index were used to evaluate the simulated results of SWAT model. The R^2 ranges from zero to one. If the R^2 value is one, it indicates a perfect alignment between simulated and observed values. If the R^2 value is zero, it indicates no alignment between simulated and observed values. Meanwhile, values for E_{NS} ranges from $-\infty$ to one. The model results are satisfactory as E_{NS} values should be greater than 0.5. Further, E_{NS} values between 0.5-0.65, 0.65-0.75, and exceed 0.75 are acceptable, good, and very good, respectively, for model results (Can et al., 2015; Moriasi et al., 2007).

2.3 Evaluation of the Long-term hydrological impacts of LULC change

After calibration and validation, Arc-SWAT 2012 version model was run using each LULC map in 1994, 2004, and 2014 as the input to simulate stream-flow and sediment yield from 1984 to 2014. The simulated output for the LULC pattern of year 2004 was used as the baseline to examine stream-flow and sediment yield variations in LULC scenarios of other years.

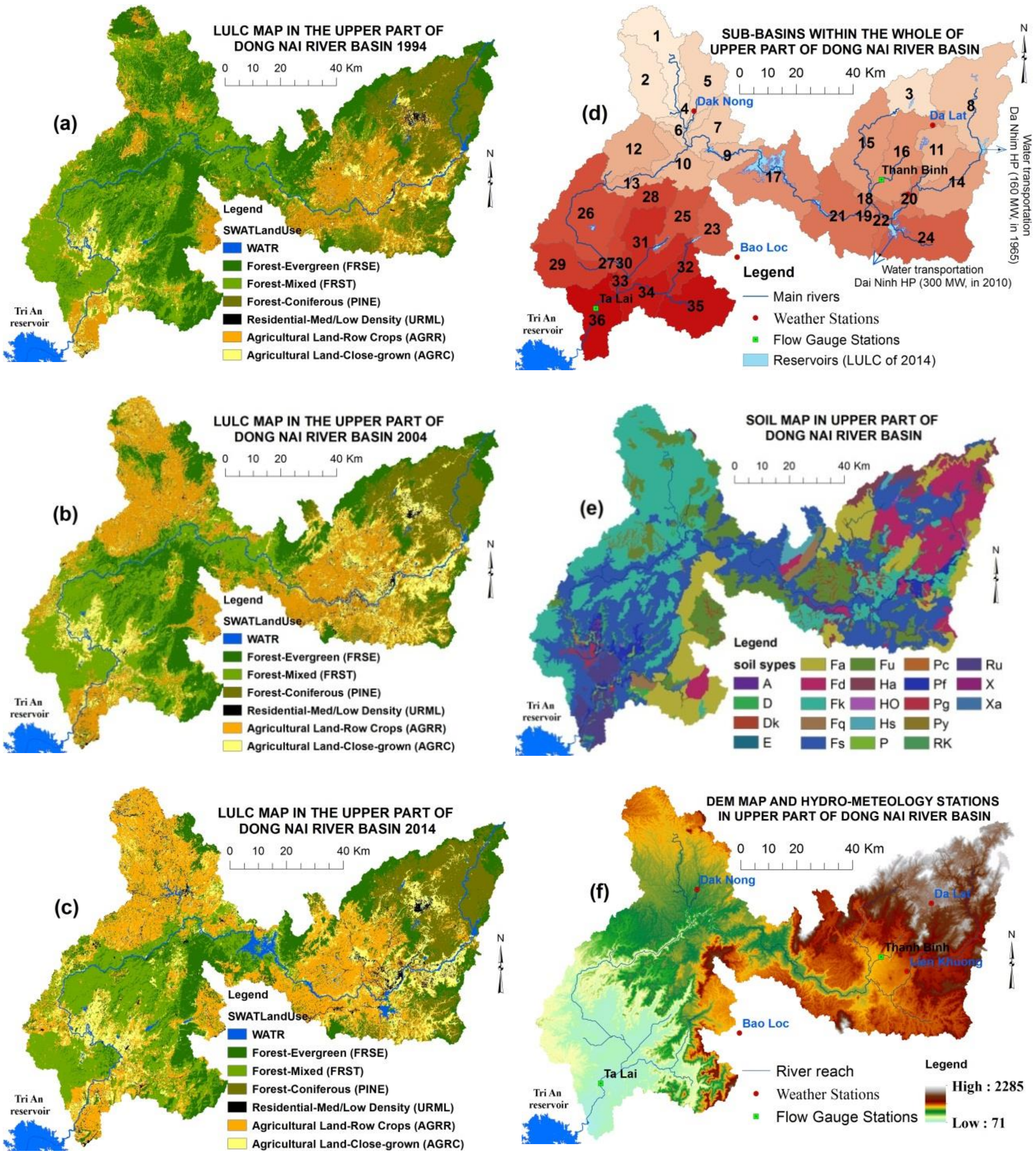

Figure 2. (a), (b), and (c) LULC classification of year 1994, 2004, and 2014; (d) 27 Sub-basins within the whole basin; The distribution of soil types within the basin; (e) DEM and hydro-meteorology stations in the basin

3. RESULTS AND DISCUSSION

3.1 SWAT calibration and validation

The model calibration and validation were conducted according to two local stream-flow gauge stations (Thanh Binh and Ta Lai gauge) from the upper and lower stream sections respectively. Simulated and observed stream-flow data from January of 2000 to December of 2010 were used for model calibration, based on the LULC map of 2004. The summed simulated and observed stream flows during the calibration period achieved relatively good results with R^2 of 0.811 and E_{ns} of 0.809, R^2 of 0.771 and E_{ns} of 0.765 for the upper and lower stream, respectively, see Figure 3. The simulated and observed stream-flows during the validation period of 1984 – 2014 were with an E_{ns} of 0.712 and R^2 of 0.713, E_{ns} of 0.712 and R^2 of 0.713 for the upper and lower stream, respectively.

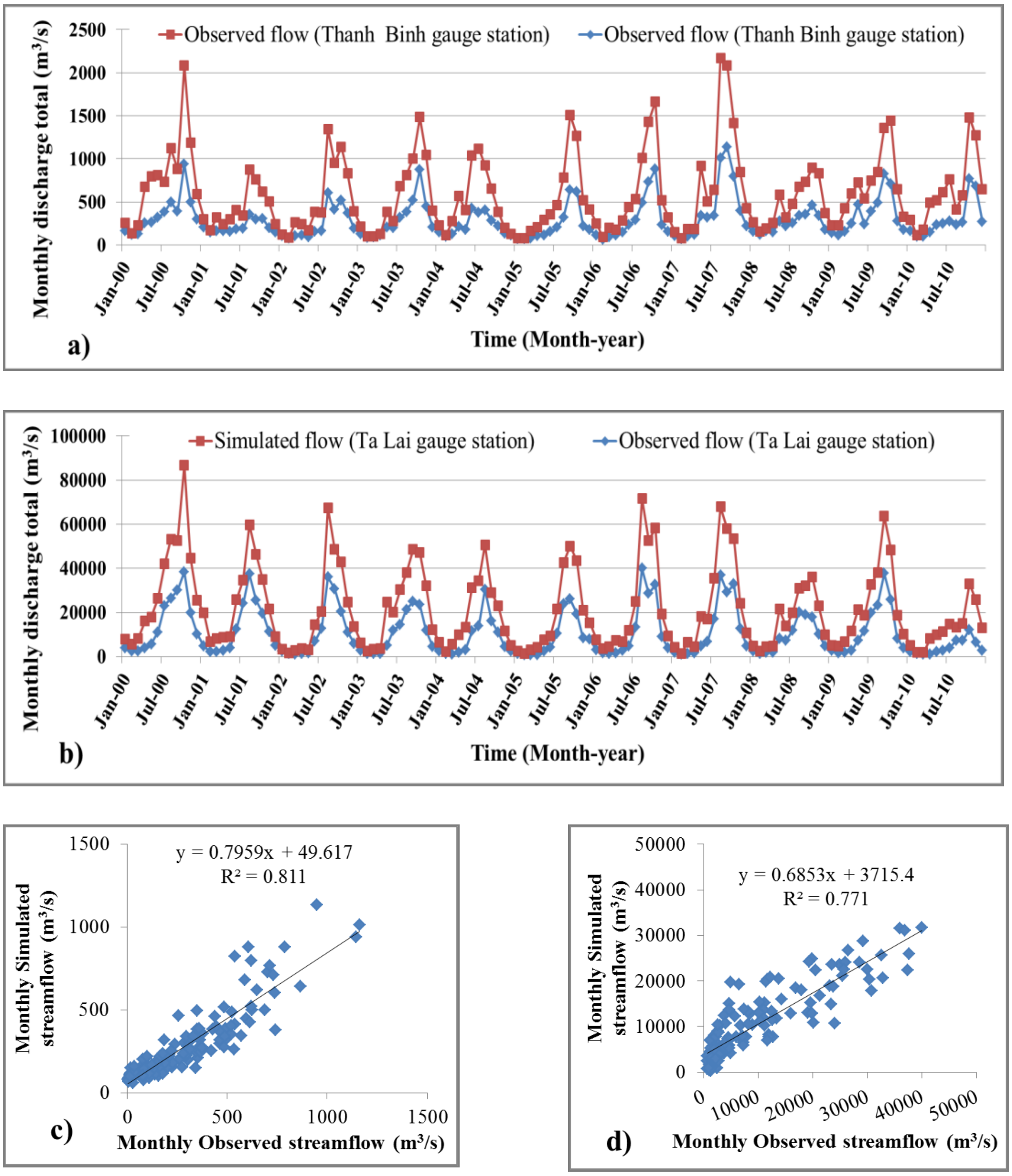

Figure 3. Comparison between simulated and observed monthly stream-flow in the calibration period of model: (a) and (c) Thanh Binh gauge; (b) and (d) Ta Lai gauge.

Because there have not daily sediment load observation, the study used monitoring data of intermittent Total Suspended Solid (TSS) in surface water at Thanh Binh gauge from DONRE of Lam Dong province to assess the accuracy of simulation sediment load. Based on observation TSS (mg/L) data in the middle of the dry season (February and March) and the rainy season (August and September) collected from 2007 to 2014. The rate of fitness of the simulation got the value of $R^2 = 0.803$ and Ens = 0.682, see Figure 6. According to Moriasi et al. (2007), the match between the simulation value and the observed value is acceptable.

The high R^2 and E_{ns} values indicated that the SWAT model can be used to simulate the stream-flow and sediment load for assessing the long-term hydrological impacts of the climate change coupled with land-use change in the UPDN river basin.

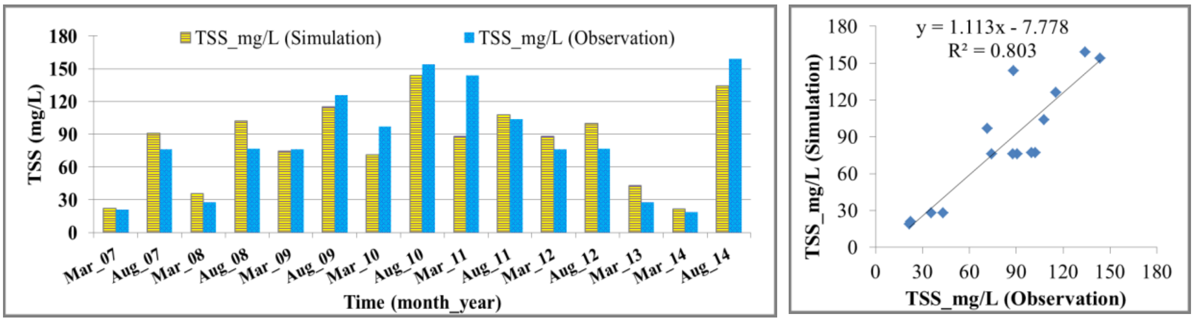

Figure 4. Comparison between simulated and observed TSS at the point of surface water monitoring at Thanh Binh gauge

3.2 Climate change

The analysis results indicate that annual precipitation has increased by approximately 1.6% over the past 30 years (1984 – 2014), on the entire basin. At the same time, Figure 5 indicates that an increase in annual min-temperature was similar to an increase in annual rainfall. However, the variation of rainfall and Min_temperature is different via the temporal and spatial. The rate of annual min-temperature increases in Bao Loc, located on 800m above sea level, which is greater than Da Lat, located on 1.500m above sea level. Similarly, the rate of annual rainfall increases in Bao Loc station, is greater than Da Lat station.

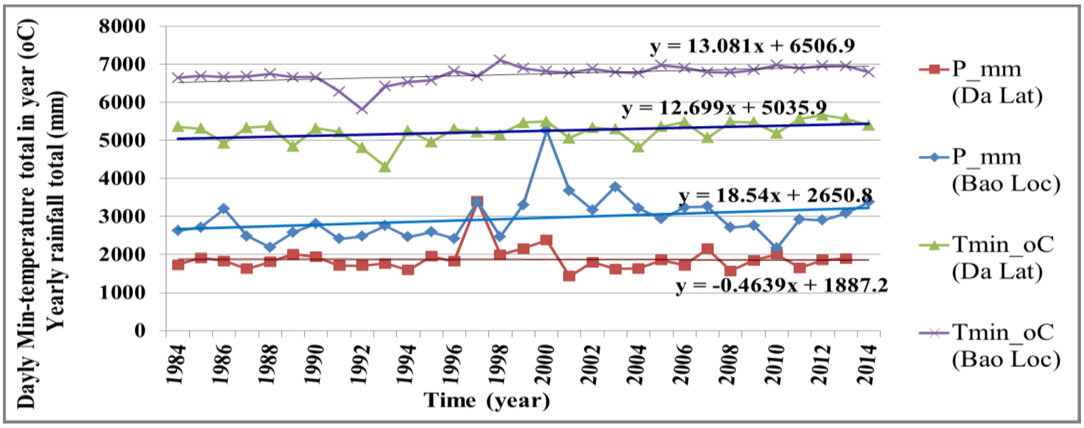

Figure 5. Trend of change in min-temperature and annual rainfall from 1984 – 2014

3.3 Changes in LULC

The LULC changes in the basin are shown in Table 2. The rate of forest cover of 1994, 2004, and 2014 is 706,803 ha (72.68%), 520,359 ha (53.51%), and 485,908ha (49.97%), respectively. The forest area has been reduced 186,444 ha (19.17%) in the period of 1994 – 2004 and 34,451 ha (3.82%) in the period of 2004 - 2014. This shows that the area of forest has been lost in the period of 1994-2004, which is greater than the period of 2004-2014. In contrast to reduction in forest area, there have been increased 181,642 ha (18.68%) of agricultural land; 16,231ha (1.67%) of water bodies areas; and 25,824ha (2.66%) of built-up residential areas. This means the primary cause of the loss of 223,576 ha (22.99 %.) over the past 20 years (1994- 2014) was conversion of forests into agriculture land.

Table 2. LULC changes between 1994, 2004, and 2007 in the UPDN river basin

Land Use Type	1994		2004		2014		Change (20 years)	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
WATR	8505	0.87	8,557	0.88	21,590	2.22	+16,231	+1.67
FOREST	706,803	72.68	520,359	53.51	485,908	49.97	**-223,576**	-22.99
URML	7,922	0.81	19,305	1.99	24,274	2.50	+25,824	+2.66
AGRR	177,033	18.20	292,927	30.12	304,231	31.28	+101,913	+10.48
AGRC	72,197	7.42	132,312	13.61	136,457	14.03	+ 79,730	+8.20
Total	972,460	100	972,460	100	972,460	100		

Figure 6 shows that the forest has been dominant land cover types of the UPDN river basin and the rests were perennial agriculture land, annual agriculture land, built-up residential area, and water bodies.

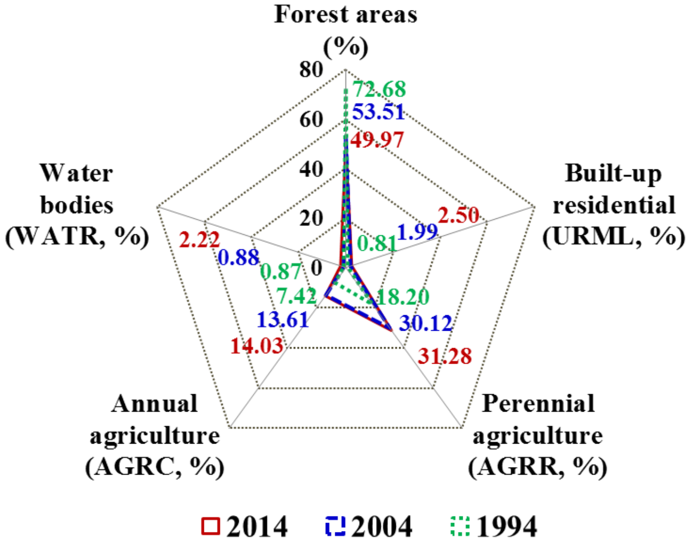

Figure 6. Percentage of area of LULC classes in 1994, 2004, and 2014

3.4 Hydrologic response to climate change and change in land use/land cover

SWAT model simulated the hydrological responses to 1994, 2004, and 2014's weather data on different land use in 1994, 2004, and 2014. The simulated results of monthly stream-flow from 1984 to 2014 based on scenarios of the LULC of 1994, 2004, and 2014 are shown in Table 3. Water yield (mm) and sediment yield (tons/ha) from HRUs in watershed for the year had changed 1215.67 and 2.15, 1314.02 and 11.7, 1549.33 and 11.7, respectively, in 1994, 2004, and 2014. This evidences that change in climate condition and land use has affected the hydrological responses.

Table 3. Annual hydrological summaries for the watershed

Year	PREC *	SURQ	LATQ	GWQ	LATE	ET	PET	WATER YIELD	SED YIELD
1994	1888.5	591.7	77.7	518.3	549.1	137.5	692.3	1215.7	2.2
2004	1955.8	723.9	83.0	477.4	498.5	112.0	670.0	1314.0	11.7
2014	2230.1	848.9	90.1	578.8	643.3	124.1	671.6	1549.3	11.7
Change (1994 – 2014)	+341.6	+257.2	+12.5	+60.5	+94.2	-13.4	-20.7	+333.7	+9.6

*Notes: * PREC is average amount of precipitation in watershed for the year (mm). SURQ is amount of surface runoff contribution from stream-flow from HRU during simulation. LATQ is lateral flow contribution to stream-flow in watershed for the year (mm). GWQ is groundwater contribution to stream in watershed on year (mm). LATE is water percolation past bottom of soil profile in watershed for the year (mm). SW is amount of water stored in soil profile in watershed for the year (mm). ET is actual evapotranspiration in watershed for the year (mm). WATER YIELD is water yield to stream-flow from HRUs in watershed for the year (mm). SED YIELD is sediment yield from HRUs in watershed for the year (t/ha).*

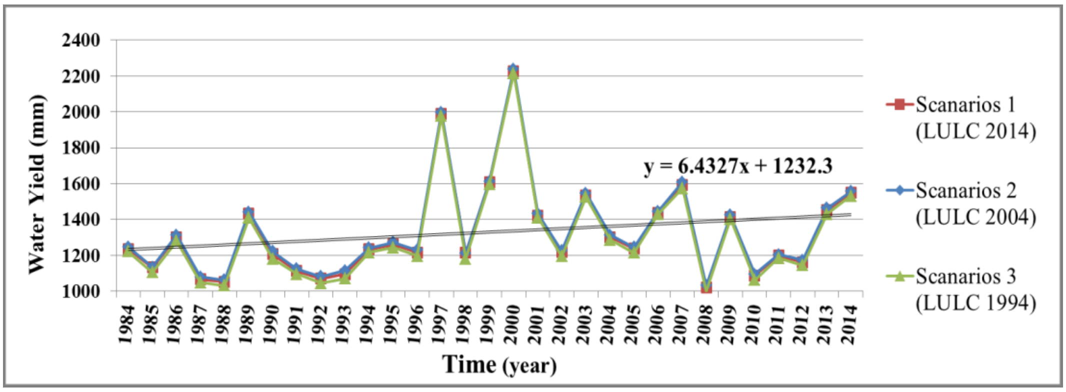

Figure 7. Hydrographs for the yearly sediment yield estimated by the SWAT for the simulation in the period of 1984–2014 in the study area

Figure 7 shows that the effects of the LULC change on water yield were not significantly different for LULC scenarios in 1994, 2004, and 2014. These results match with the previous studies (Can et al., 2015), which showed that moderate land use changes could affect minor changes in the water yield. On the other hand, the higher annual precipitation has increased water yield from HRUs in watershed throughout the year over the past 30 years (1984 - 2014). However, the findings show the yearly total discharge in the downstream part of the UPDN river basin (at the Ta Lai gauge station) was not well consistent with an increase in annual rainfall on the entire basin, in the period of 1984 – 2014. The aggregated yearly flow has increased in the period of 1984 – 2006 but it decreased in the period of 2007 - 2014, see Figure 8. The increases in flow can be explained by increases in precipitation and water yield of runoff in the period of 1984 – 2006. In addition, as mentioned above, large conversion of 186,444 ha (19.17%) in the period of 1994 – 2004 to agriculture and other lands has also contributed to increase in the stream-flow. This is similar to the findings in the Be River and Cau River catchment in Vietnam, conducted by Phan et al. (2011) and Khoi and Suetsugi (2014). The present study result is well match with previous findings conducted by Truong et al. (2018), which concluded that the conversion of forests to agricultural land led to an immediate increase in the total discharge.

Further, Figure 8 also indicates that the total yearly water discharge decreased in the period of 2007 - 2014. The primary cause for this decrease is the operation of Dai Ninh hydropower plant, in which water was transported to another watershed fully operated since 2010. The second reason was due to the development of agricultural crops such as coffee, tea and reforestation (Truong et al., 2018). The third reason was an increase in evapotranspiration and consumption of irrigation water in the dry season. The last but not least was water storage in reservoirs of large hydropower projects, including Da Dang 2 (34MW), Dong Nai 3 (180MW), Dong Nai 4 (340MW), Dong Nai 2 (70MW), and Dong Nai 5 (150MW) hydropower plants that came into operated in 2008, 2009, 2010, 2012, 2013 and 2014, respectively.

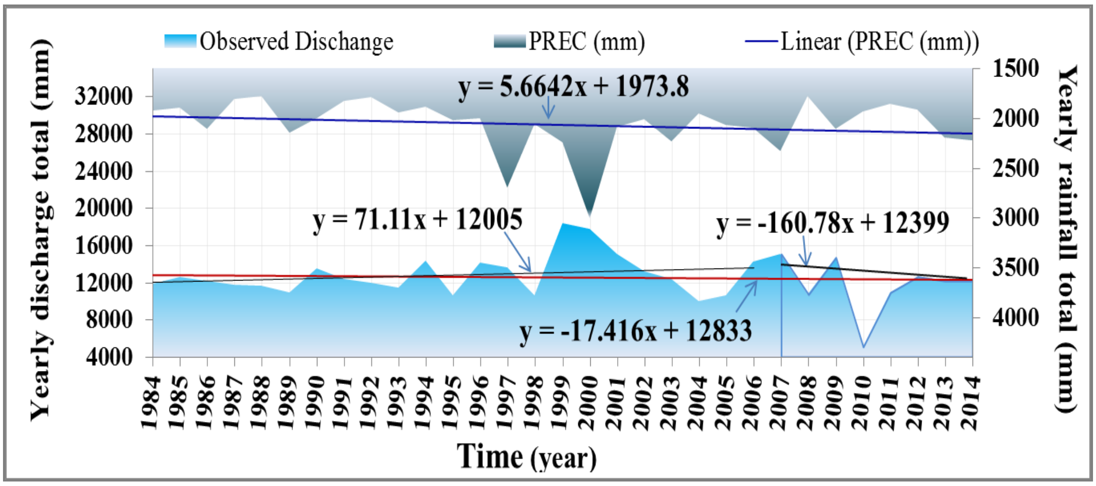

Figure 8. Hydrographs for the yearly rainfall total and the yearly observed discharge total in the period of 1984–2014 at Ta Lai gauge

As can be seen from Figures 7 and 9, the results show that effects of LULC change on sediment load have been more strongly than water yield. This finding is similar to the results from previous authors Khoury et al. (2015); Mango et al. (2011); and Zhu and Li (2014), which indicate that changes in water quantity parameter (stream-flow) have mainly been driven by climate change, whereas changes in water quality parameters (nitrogen species, sediment yield) have mainly been driven by land use changes.

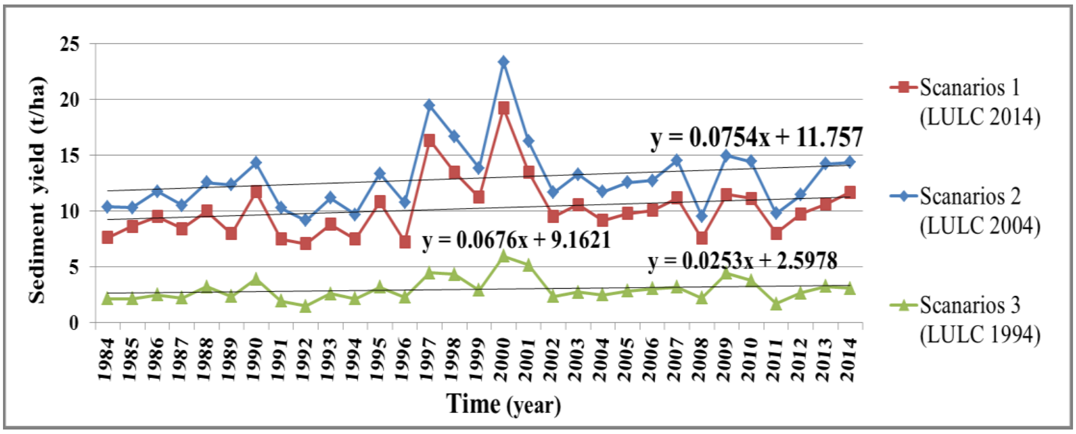

Figure 9. Hydrographs for the sediment yield (t/ha) estimated by the SWAT for the simulation in the period of 1984 – 2014

The rate of sediment yield from HRUs in watershed for the year with scenarios 1 (LULC 2014) was significantly higher than scenarios 3 (LULC 1994). Then, the rate of sediment yield of scenarios 1 (LULC 2014) was slightly lower than scenarios 2 (LULC 2004). This is explained that the coverage of vegetation declined in the period 1994 - 2004 in accordance with a decrease of forestland and an increase in agricultural use. The rate of soil erosion with scenarios of LULC 2014 decreased slightly compared to scenarios of LULC 2004 because of growth of perennial crops (coffee and tea), which was converted from forestland. The plants have grown with extensive canopy development and increased leaf area index, protecting soil from erosion by heavy rains.

As above-mentioned, the change in vegetation cover had considerable impacts on the sediment load. However, the rate of soil erosion has been a spatial and temporal change in the sub-basins. The results show that with the same climatic conditions, with land use scenario in 2014, the soil erosion potential in the sub-basins is arranged as shown in Figure 10.

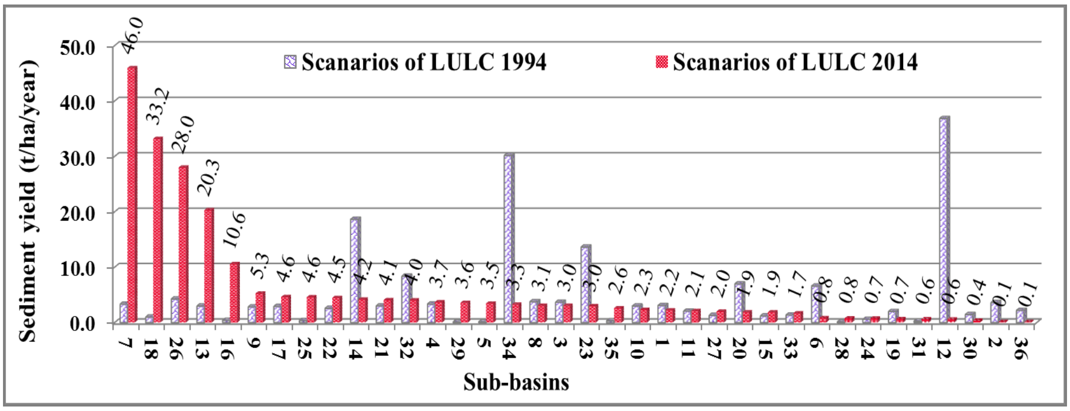

Figure 10. The spatio-temporal changing concentration of TSS at each sub-watershed outlet and the comparison

Similar to Khoury et al. (2015) and Mango et al. (2011), in general, the result found that the changes of flow-stream and sediment load have been strongly nonlinear responses to changes in climate and LULC. The combined effects on water quality/quantity endpoints can be significantly different from the sum of the effect of each stressor/driver.

3.5 Limitations and recommendations

Appling Arc-SWAT 2012 Version model to assess long-term hydrological effects of climate change and land-use change in the Upper Part of Dong Nai river basin had get satisfactory results. However, there are limitations, such as the missing data in solar radiation, wind speed, and relative humidity, the lack of sediment load data, the representativeness of the precipitation data. In addition, other conditions that are not modeled, such as the use of water for irrigation, dam operation. These could decrease the accuracy of the simulated results based on SWAT model. Therefore, for a better estimation of the simulated values, the model needs to be enriched by additional data on rainfall, solar radiation, wind speed, and relative humidity, dam operation, irrigation water, in order to improve the simulation results.

4. CONCLUSIONS

Under the climate change, the annual precipitation on the entire Upper Part of the basin has increased 1.6% in the period 1984 – 2014. The forest area has been reduced more than 223,576 ha (23%) in the past 20 years (1994 – 2014). In contrast, the agricultural area has been increased from 18.2% to 31.3% and water bodies also changed from 0.9% to 2.2% at the same time. This study shown that using Landsat images, SWAT model, and available dataset successfully applied to detect the long-term hydrological impacts of LULC change coupled with climate change in the UPDN river basin from 1984 to 2014.

The model simulation indicated that climate change and change in LULC has fluctuated (increased and decreased) in stream-flow and sediment yield for the whole watershed from 1984 to 2014, but with a distinct spatial and temporal pattern. The results indicated that effects of LULC change on sediment load were more strongly than water yield under the same climate conditions and amount of sediment load has been different from sub-basins. The enormous conversion of forest areas to agricultural land in the period of 1994 – 2004 coupled with a higher amount of rainfall has led to an increase in total discharge and sediment load in the period of 1994 – 2006. Subsequently, a decline of these quantities was due to hydropower reservoir development, vegetation regrowth, the acceleration of evapotranspiration and consumption of irrigation water. The findings indicated the primary cause of the decreasing stream-flow in the downstream of the UPDN river basin since 2006 was due to formation and operation of cascade hydroelectric reservoirs.

Finally, these findings provides useful information for decision-makers in formulating policies and developing counteract measures for minimizing erosion effects, such as alternative crops (crops rotation) and land use optimization to adapt with a trend of the increase in rainfall, temperature, and extreme weather phenomenon as a consequence of climate change, and to achieve sustainable watershed development and management.

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