Quantifying the impacts of decadal landuse change on the water balance components using soil and water assessment tool in Ghaggar river basin

Nitin Chauhan¹ · Vipin Kumar¹ · Rakesh Paliwal²

Received: 12 June 2020 / Accepted: 29 September 2020 / Published online: 6 October 2020
© Springer Nature Switzerland AG 2020

Abstract

The landuse and landcover change is considered as one of the most vital components of the global environmental change responsible for influencing the quantity, seasonal patterns and durations of the water flow within basins around the world. The aim of this study is to assess the impacts of changes in landuse landcover on the various hydrological components for Ghaggar river basin for a period of 1985–2015 using Soil and Water Assessment Tool model. The landuse landcover maps have been prepared using various Landsat satellite images for the year 1985, 1995, 2005 and 2015. The fixing changing method has been employed to quantify the impacts of landuse changes on hydrological components by changing the landuse maps of different year and keeping rest of the inputs same. The correlation and Partial Least square regression are used to examine the impacts of change in landuse on the hydrological components. The results unveiled that the increase in agriculture and built-up area and decrease in area of evergreen, deciduous and mixed forest. During the period 1985–2015 there is increase in annual stream flow (0.20%), wet season streamflow (1.55%), surface runoff (12.23%) and water yield (0.22%) on the contrary there is decrease in dry season streamflow (2.1%), Evapotranspiration (0.08%), groundwater flow (8.62%), Percolation (8.02%) and lateral flow (3.92%) owing to changes in landuse landcover. There is an urgent need to adopt soil and water conservation practices in the area to avert these deleterious effects of landuse landcover changes.

Keywords Landuse landcover · Water balance · Hydrological modelling · SWAT · PLSR

1 Introduction

The most vital component of the global environmental change is the landuse and landcover (LULC) change. It is considered as the prime driver responsible for influencing the quantity, seasonal patterns and durations of the water flow within basins around the world but the situation has become more critical with climate change [1–3]. The hydrological characteristics of a river basin are substantially influenced by the spatial patterns of LULC changes which are attributed to the anthropogenic activities, vegetation alterations and modifications in the

landuse practices [1]. The hydrological cycle and the water resources availability is significantly affected by the LULC changes [1, 4–6]. The transactions of landcover to urban and agriculture classes severely alter the water hydrology of a basin by altering interception, infiltration and evapotranspiration properties which has a confounding impact on the runoff timing and volume [5, 7].

Apart from extensively affecting the river flows, LULC changes has a profounding effects on other components of the hydrological cycle such as groundwater and evapotranspiration as well. The groundwater recharge is reduced in the dry season as a result of reduction in infiltration

✉ Nitin Chauhan, nitinharsac@gmail.com | ¹School of Earth Sciences, Banasthali Vidyapith, Banasthali, Rajasthan, India. ²Regional Remote Sensing Centre–West, ISRO, Jodhpur, Rajasthan, India.

volume. [8, 9] conducted studies revealing reductions in the ground water recharge and infiltration owing to effect of increase in surface runoff. Similarly, the evapotranspiration also get reduces due to transaction of landuse from forest to grasslands. Therefore, for sustainable water resource management, understanding the impacts of the LULC changes on the hydrological cycle of a basin is very much required [10]. Therefore, the water resources management and planning demands formulating a pivotal strategy of comprehending the impacts of Landuse change on hydrological response of a catchment [11].

Several studies have been conducted by various researchers in past to assess the LULC impact on various hydrological parameters in different environmental and climatic regimes at different spatial and temporal scale [12–18]. The results of a study conducted in Ethiopia revealed that the change in LULC from forest to agricultural land resulted in an increase in runoff [19]. Several studies have shown that on keeping the infiltration properties of the soil undisturbed vegetation loss can lead to increased baseflow [1, 20]. However, it contradicts with various studies revealing that loss of vegetation makes the soil, erosion prone and reduces the water percolation to groundwater [21]. Several deforestation related studies have revealed that flooding is mostly associated with decrease in forest cover [22, 23]. The major changes in the LULC around the world are attributed to urbanizations resulting in increase in impervious surface which in turn decreases the infiltration of water into the soil [24, 25]. Rapid urbanization also leads to frequent flooding events as the water in the streamflow increases owing to decrease in baseflow [26]. The quantification of the impacts of landuse change on hydrological response specially streamflow is challenging and doesn't always reflect a strong interrelationship [1, 6, 7, 27]. The reason for this is lack of comprehension attributed to quantification of watershed heterogeneity, landuse configuration, hydrological processes behavior and climate [28].

Researchers around the world have been assessing the LULC change impacts on runoff using the pair catchment experiments and hydrological modelling. The pair catchment experiments are easy to implement for smaller catchment but requires extensive temporal hydrological data analysis and might require a lots of time for adequate data collection [4, 15, 29–31]. On the contrary, the hydrological models are either empirical, physical or conceptual based on model structure or can be classified as lumped, semi distributed and distributed based on spatial processes. The spatial variations of the hydrological processes are extensively accounted by the physically based and spatially distributed models. Various models employed for assessing the impacts of LULC change on hydrological processes e.g. SWAT [1, 2, 11, 32], HBV [33–35], MIKESHE [36]. For

assessing the impacts of landuse changes on hydrological parameters a fixing-changing method is used wherein model is simulated with different static landuse map for a given common time frame [32, 37–39].

The Soil and Water Assessment tool is one of the most widely used model for simulating the impacts of landuse changes on watershed hydrology and has established its significance for hydrological impact studies. A study conducted on Upper Du watershed in China using SWAT model for the assessing the impacts of decadal landuse of 1978–2007 on streamflow and sediment yield revealed positive correlation with farmland and a negative correlation forest [32]. The SWAT model was employed for assessing the landuse change impacts on hydrological regime of Andassa watershed of Ethiopia with the landuse of period 1985–2015 and Cellular Automata Markov based predicted landuse of 2030 and 2045 resulting in increase in annual flow, surface runoff and water yield and decrease in lateral flow, groundwater flow and evapotranspiration which was reflected in future scenarios also [2]. An increase in streamflow and decrease in baseflow was inferred for River Njoro watershed due to landuse change using the SWAT model [40].

The current study area is the Ghaggar river basin which is part of lower Shivaliks and is considered as the flimsiest ecosystem of India. The area has witnessed a lot of landuse change due to rapid urbanization leading to water scarcity in the area. Although work has been done for Ganga basin as a whole [1] but still a lot of understanding has to be built for accurately assessing the impacts of landuse changes in this area. With this consideration in thoughts, this study was conducted using calibrated and validated SWAT model for fulfilling the specific objectives of this study i.e. (1) to determine the landuse landcover changes from 1985 to 2015 using 4 satellite images (2) assessing the impacts of LULC changes on water balance components (3) assessing the impacts of individual LULC changes on hydrological parameters at sub-basin scale using PLSR analysis.

2 Material and methods

2.1 Study area

The Ghaggar river basin up to its confluence with the Medkhali river is the study area for this research. This study area forms the part of the flimsiest ecosystem in India i.e. lower Shivaliks owing to its highly erodible soil structure. The study area covers the parts of Solan and Sirmaur districts in Himachal Pradesh, Panchkula in Haryana and Union Territory of Chandigarh. The geological structure of the Shivaliks is majorly composed of sandstones

and conglomerate rocks. The basin area extends from 76°51'45.06" and 30°36'46.50" to 77°12'45.30" and 30°54'27.18" and covers an area of 559.14 km² (Fig. 1). The Ghaggar river basin has a hilly topography with the elevation ranging from 249 to 1869 m. The Ghaggar river is the most prominent ephemeral stream draining the Shivaliks and Himalayas. The Dagshai village near Shimla, Himachal Pradesh in the foothills of the Shivaliks is the origin of Ghaggar river. The Ghaggar is a non-perennial river, which carries its optimum flow throughout the year in the upstream part only. The Markanda, Saraswati, Tangri and Chotang River are the main tributaries of the Ghaggar river. The area has witnessed the extensive urban growth specially in Panchkula since 1985 and terrace farming is the predominant activity in the study area.

2.2 Landuse/landcover change assessment

The LULU change analysis was carried out using the classified outputs of 1985, 1995, 2005 and 2015 satellite images for demonstrating the patterns of LULC change. The rate of change [41] change [42] statistics were used for explicating

the extent of changes experienced between the subsequent periods (1985–1995, 1995–2005 and 2005–2015). The formulae for calculating Percent of Change and Rate of Change are given in Eqs. 1 and 2

$$\text{Percentage of Change} = \frac{T_2 - T_1}{T_1} \times 100 \quad (1)$$

$$\text{Rate of Change} = \frac{T_2 - T_1}{Z} \quad (2)$$

where T_2 is area of LULC in hectares in time 2, T_1 is area of LULC in time 1 and Z is the time interval between T_2 and T_1 .

2.3 SWAT mode overview, data inputs and analysis

2.3.1 SWAT model overview

SWAT is a hydrological model with acronym standing for soil and water assessment tool. It is a physically based river basin, or watershed scale model which requires the

Fig. 1 The location map of the study area

input information of weather, soil, topography, landuse and management practices prevalent within a watershed in order to model the physical processes associated with movement of water and sediment as well as crop growth. SWAT facilitates the subdivision of the watershed into smaller units such as subbasins for effective modelling purposes. The areas within the subbasin having a unique combination of landuse/landcover, soil and management practices are known as Hydrological Response Units. The water balance equations are the main driving force working behind the SWAT model for a watershed. The surface runoff volumes and peak runoff are simulated by SWAT for each HRU. The surface runoff volume is computed using modified SCS (Soil Conservation Service) curve number method or Green and Ampt infiltration method [43].

ArcSWAT is graphical user interface developed by SWAT developers to be integrated into various version of ESRI ArcGIS. It is a freely available software which can be downloaded from <https://swat.tamu.edu/software/arcs SWAT/>. In this present study ArcSWAT 2012 is used which is integrated with ArcGIS 10.5 version. ArcSWAT requires landuse, soil, weather data, management practices, water quality data and simulation period for ensuring optimum simulation results. ArcSWAT interface requires raster grids, vector shapefile/feature classes and database files to create SWAT model inputs.

2.3.2 SWAT data inputs

The different data input required for SWAT analysis includes Digital Elevation Model, Landuse Landcover (LULC) data, Soil, Weather data and discharge data and the details of their generation is given in below section.

2.3.2.1 Digital elevation model Sentinel 1A and B microwave data has been used for the generating the DEM (Digital Elevation Model) having the spatial resolution of 13.96 m. The interferometrically prepared DEM in ESRI Grid format is used for watershed delineation. This process resulted in 60 third order and 32 fourth order subbasins for which subbasin parameters are calculated.

2.3.2.2 Landuse landcover data The landuse data for 1985, 1995 and 2005 was downloaded from Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) which is prepared using the satellite data from Landsat 4 Multispectral Scanner System (MSS) and Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) respectively while the landuse data for 2015 has been prepared using Landsat 8 Operational Land Imager (OLI) through visual interpretation and unsupervised classification using ISODATA algorithm. An overall mapping accuracy of 82.67% and

the Kappa accuracy of 0.82 for 2015 satellite data was achieved. The overall accuracies of 1985, 1995 and 2005 were 94.46% and Kappa accuracy of 0.9445 respectively as per the Decadal Land Use and Land Cover Classifications done across India [44]. The eight LULC classes were identified in the study area based on LULC classification schema described in International Geosphere–Biosphere Programme (IGBP) [45] i.e. Agriculture, Barren Land, Deciduous Forest, Evergreen Forest, Mixed Forest, Shrubland, Built-Up and waterbodies (Fig. 2).

2.3.2.3 Soil data The soil data as per the soil classification given by Food and Agriculture Organization (FAO) is used in ArcSWAT. The soils of the Ghaggar river basin can be classified into 3 classes i.e. Eutric Cambisols (54.98%), Eutric Regosols (33.15%) and Eutric Fluvisols (11.88%). It has a spatial resolution of about 1 km i.e. equivalent to 30 arc seconds and it consists of a 30-cm topsoil layer, and a 70-cm subsoil layer information.

2.3.2.4 Meteorological data In current study re-analyzed and re-gridded weather data created by Indian Meteorological Department (IMD) [46, 47] for the entire India is used. The minimum and maximum temperature is available from IMD with a spatial resolution of $1^{\circ} \times 1^{\circ}$ for the period 1951–2015 while the rainfall data is available with spatial resolution of $0.25^{\circ} \times 0.25^{\circ}$ for a period from 1901 to 2016. For current study nine grids of rainfall and four grids of temperature nearby the study area with a time period from 1969 to 2015 have been used. The Rainfall and Temperature data has been converted into the SWAT ingestible formats. The Mean monthly rainfall and temperature (1969–2015) of the grids in the Ghaggar River Basin are shown in Fig. 3.

2.3.2.5 Streamflow data The hydrological discharge measuring site is available in subbasin number 92. The discharge data was collected for site 4A available on Ghaggar river near Chandigarh for periods 1999–2015 and was used for calibration and validation of the SWAT model for landuse of 2015. The data was collected from Irrigation department, Panchkula, Haryana.

2.3.3 Sensitivity analysis

The first step in the process of calibration and validation is the identification of the utmost sensitive parameters for a given hydrological unit. The process of identifying the changes in the output according to changes in input model parameters is known as sensitivity analysis. The sensitivity analysis can be performed in two ways i.e. local and global both of which may yield different results. In current study the Sequential Uncertainty Fitting Algorithm

Fig. 2 Decadal landuse land-cover maps of Ghaggar river basin **Fig. 3** Mean monthly rainfall and temperature (1969–2015) characteristics of the stations in the Ghaggar river basin. (where X-Rainfall grid code, Tmin—Minimum Temperature grid code and Tmax—Maximum Temperature grid code)

Version 2 (SUFI-2) within the SWAT Calibration and Uncertainty Programs (SWAT-CUP) software with Modified Nash-Sutcliffe (MNS) objective function is used for performing the sensitivity analysis of SWAT parameters and initially 8 parameters were selected to identify the most important

parameters as given in Table 1. The global sensitivity is applied to eliminate the non-sensitive parameters [48]. The t-stat and *p*-value were used as a measure of sensitivity and sensitivity rank are assigned to the most sensitive parameters.

Table 1 Selected parameters of the SWAT model for uncertainty analysis

Sr. no.	Parameters	Description	Initial range
1	r_CN2.mgt	Initial SCS CNII value	− 0.02 – 0.2
2	v_ESCO.hru	Soil evaporation compensation factor	0.85 – 1
3	r_GWQMN.gw	Threshold water depth in the shallow aquifer for flow	− 0.2 – 2
4	v_ALPHA_BF.gw	Baseflow alpha factor	0 – 0.2
5	r_GW_REVAP.gw	Groundwater 'revap' coefficient	− 0.01 – 0.1
6	v_GW_DELAY.gw	Groundwater delay time (days)	0 – 100
7	r_SOL_K.sol	Saturated hydraulic conductivity	− 0.2 – 0.2
8	r_OV_N.hru	Manning's "n" value for overland flow	− 0.01 – 0.1

V implies replacement of the parameter with the fitted value; R indicate multiplying the parameter with (1 + fitted value)

2.3.4 SWAT calibration and validation using SWAT-CUP

The calibration is the process of parameterizing of a model in order to reduce the uncertainty prediction for a given set of local conditions. On the other hand, validation is the process of running the model based on the finalized parameters during the calibration and the comparative analysis between model outputs with the observed data which were not used during calibration. In present study the observed discharge from 1999 to 2009 was used for calibration while the 2010–2015 was used for validation. In present study Sequential Uncertainty Fitting (SUFI-2) method available in SWAT CUP v5.2.1 is used to quantify the uncertainties using the sequential and fitting process. SUFI-2 supports the usage of ten different types of objective functions such as Coefficient of Determination (R^2), Chi2, Nash-Sutcliffe (NS), bR2, SSQR, Percentage Bias (PBIAS), King Gupta Efficiency (KGE), RSR, Modified Nash-Sutcliffe (MNS). In this study MNS objective function was used for discharge at monthly time step as there was a lack of daily data. As compared to normal Nash-Sutcliffe this method is more sensitive to over and under prediction.

2.3.5 Performance evaluation of SWAT model

In the current study the evaluation of the SWAT hydrological predications was done by the use of extensive array of statistical techniques such as coefficient of determination (r^2), Nash-Sutcliffe efficiency (NSE; [49], RMSE-Observation Standard Deviation Ratio (RSR) [50] and Percent bias (PBIAS) [51] to highlight the correlation and bias between the calibrated and observed datasets. These are standard criteria referred in many studies to compare the reliability of modeling outcomes with respect to the observed datasets and are recommended by [52]. The squared value of coefficient of correlation as given by Pearson is defined as coefficient of determination r^2 . The value of r^2 ranges from 0 to 1. While 1 represents perfect correlation and 0 represents

no correlation providing an estimate of variance replicated by the model outputs against the observed values. The NSE is basically ratio of squared difference between observed and predicted values to that of variance of observed values for the given time period. The values of NSE lies between 1 being the perfect fit of the predicted data against the observed data to $-\infty$. Percent bias (PBIAS) measures the average estimation of bias between the simulated and observed data. The positive and negative values of PBIAS indicates underestimation and overestimation bias. The low values of PBIAS indicates accurate simulation with 0 has the optimal value. The value of RSR varies from 0 to a large positive value. A zero value represents a perfect simulation with zero RMSE.

In SWAT the uncertainties are quantified by a P-factor which is defined as percentage of observed data covered by the 95% prediction uncertainty (95PPU). The output variables used to calculate the 95PPU are obtained through Latin hypercube sampling having the cumulative distribution levels of 2.5% and 97.5%. R-factor is another measure which quantifies the strengthens of uncertainty analysis. It is basically the relative width of the 95PPU calculated as average width of 95PPU divided by standard deviation of measured data. The theoretical ranges of P-factor and R-factor are between 0–100% and 0–infinity respectively. The P-factor value of 1 and R-factor value of 0 refers to a situation where measured data exactly corresponds to simulated data [48]. In present study SUFI-2 method available in SWAT CUP v5.2.1 is used to quantify the uncertainties using the sequential and fitting process. The parameter sensitivity of the SUFI-2 accounts for all the sources of uncertainties such as model input, structures, parameters, and measured data.

2.3.6 Evaluating the impacts of LULC changes on water balance components

For assessing the impacts of landuse changes on hydrological parameters a fixing-changing method was used

[38]. The calibrated model was run for period 1969–2015 (47 years) with change in each landuse map (1985, 1995, 2005 and 2015) keeping the Digital Elevation Model (DEM) and soil data constant. The simulated results were used to assess the impacts of LULC changes on variation in surface water hydrology at basin scale. The impacts of the LULC changes on the annual and monthly means of surface runoff, water yield, lateral flow, groundwater flow (base-flow) and Evapotranspiration were evaluated. The pairwise Pearson Correlation coefficient between the water balance components and the decadal changes in the landuse land-cover classes was computed [32, 38].

The partial Least Square Regression (PLSR) model has been used additionally to understand the impacts of LULC changes on hydrological components. PLSR offers the advantage of dimensionality reduction such as Principal Component Analysis and Multiple regressions and acts as an extension of Multivariate analysis [53]. The prediction of the set of dependent variable(s) from the set of independent variable(s) also known as predictors becomes very easy with PLSR [53–55]. The PLSR develops latent factors and provide weights for the independent variables which help in assessing a particular response against an influencing variable. In current study the predictors were the different LULC classes while the dependent variables were annual streamflow, dry streamflow, wet streamflow, evapotranspiration, surface runoff, base flow, water yield, percolation and lateral flow. All the variables should not be included into a single PLSR model since the presence of reductant variable can lead to models with low statistical significance [56]. For the current study five PLSR models were created Annual streamflow, dry streamflow and wet streamflow (PLSR1), lateral flow, percolation and baseflow (PLSR2), Surface runoff (PLSR3), Water Yield (PLSR4) and Evapotranspiration (PLSR5) in SPSS software. The goodness of fit (R^2) was used for assessing appropriate number of

independent variables in order to overcome the overfitting data problem. The importance of both predictors and response variables in the PLSR modelling is given by the variable importance for the projection (VIP) [56, 57]. The larger VIP values are associated with variables having higher importance. The impact strength and direction of each variable is revealed by regression coefficients in the PLSR model.

3 Results and discussion

3.1 Landuse landcover change analysis

The details of the area in sq.km/hectares and percentage of area spatially distributed under different landuse is given in Table 2. The percentage-based distribution of different landuse landcover categories within the Ghaggar river basin are shown in Fig. 4. The landuse landcover change analysis of Ghaggar river basin based on rate of change and percentage of change of different landuse is given in Figs. 5, 6 and Tables 3, 4, respectively. The result of this analysis revealed that the built-up, shrubland and barren land have exhibited an increment of 157.5 ha/year, 131.5 ha/year and 10.77 ha/year respectively in last 30 years (1985–2015). These incremental changes were due to reduction in deciduous forest, evergreen forest and agriculture at a rate of 167.4 ha/year, 46 ha/year and 66 ha/year respectively. Further the land degradation is aggravated due to encroachment and cultivation activities done by farmers on sloppy and marginal areas. Although the figures show there is a decrease in agriculture over a period of 30 years but the reality is that agriculture land has been converted to built-up while the forest has been converted to agriculture land.

Table 2 The landuse landcover area statistics of different categories for Ghaggar basin (Year wise)

LULC classes	Area (1985) km ²	% of Area covered (1985)	Area (1995) km ²	% of Area covered (1995)	Area (2005) km ²	% of Area covered (2005)	Area (2015) km ²	% of Area covered (2015)
Agriculture	206.37	36.91	189.58	33.91	157.27	28.13	186.53	33.36
Barren land	0.00	0.00	0.00	0.00	0.82	0.15	3.23	0.58
Deciduous forest	213.99	38.27	213.92	38.26	214.99	38.45	163.76	29.29
Evergreen forest	47.57	8.51	42.86	7.66	44.76	8.00	33.77	6.04
Mixed forest	34.42	6.16	36.46	6.52	49.40	8.84	35.44	6.34
Shrubland	13.73	2.45	27.07	4.84	41.66	7.45	53.12	9.50
Built-up	5.19	0.93	12.09	2.16	25.70	4.60	52.44	9.38
Waterbodies	37.87	6.77	37.16	6.65	24.54	4.39	30.85	5.52
	559.14	100.00	559.14	100.00	559.14	100.00	559.14	100.00

Fig. 4 Landuse landcover area (%) based distribution for Ghaggar basin (Year wise)

Fig. 5 The landuse landcover change analysis (Rate of change) for Ghaggar basin

3.2 Sensitive parameters for SWAT model

Initially 8 parameters were selected to identify the most important SWAT parameters as given in Table 1. The t-stat and *p*-value were used as a measure of sensitivity and sensitivity rank are assigned to the most sensitive parameters. The high sensitivity of the parameters is defined by higher t-stat absolute values while the 0 *p*-values are more significant. The sensitive parameters along with their sensitivity ranking are given in Table 5. It is clear that CN2.mgt, ESCO.hru and GWQMN.gw are more sensitive as compared to rest of the parameters.

3.3 SWAT model calibration, validation and uncertainty analysis

The graphical representation of the comparative chart between the observed and the simulated flow for the calibration (1999–2009) and validation (2010–2015) are shown in Figs 7 and 8 respectively. A good match was achieved between the observed and the simulated discharge values for calibration (01/1999–12/2009) and validation period (01/2010–12/2015) as shown in Figs. 7 and 8, respectively. The Coefficient of Determination (R^2), Nash-Sutcliffe efficiency (NSE), Percent bias (PBIAS) and

Fig. 6 The landuse landcover change analysis (Percentage of change) for Ghaggar basin

Table 3 Landuse landcover rate of change (hectares/year) analysis of Ghaggar basin (Year wise)

LULC classes	Area hectares-1985	Area hectares-1995	Area hectares-2005	Area hectares-2015	Rate of change (Ha/Year)			
					1995–1985	2005–1995	2015–2005	2015–1985
Agriculture	20,637.26	18,958.14	15,726.66	18,652.94	–167.91	–323.15	292.63	–66.14
Barren land	0.00	0.00	82.25	323.16	0.00	8.23	24.09	10.77
Deciduous forest	21,399.23	21,391.91	21,499.02	16,376.48	–0.73	10.71	–512.25	–167.43
Evergreen forest	4757.22	4285.62	4475.9	3377.17	–47.16	19.03	–109.87	–46.00
Mixed forest	3442.39	3645.63	4940.24	3543.91	20.32	129.46	–139.63	3.38
Shrubland	1372.53	2707.36	4166.06	5311.78	133.48	145.87	114.57	131.31
Built-up	518.82	1209.44	2570.16	5244.07	69.06	136.07	267.39	157.51
Waterbodies	3786.65	3716.02	2453.83	3084.59	–7.06	–126.22	63.08	–23.40

Table 4 Landuse landcover percentage of change (%) analysis of Ghaggar basin (Year wise)

LULC classes	Area (Ha) 1985	Area (Ha) 1995	Area (Ha) 2005	Area (Ha) 2015	Percentage of change (%)			
					1995–1985	2005–1995	2015–2005	2015–1985
Agriculture	20,637.26	18,958.14	15,726.66	18,652.94	–0.08	–0.17	0.19	–0.10
Barren land	0.00	0.00	82.25	323.16	0.00	0.00	2.93	0.00
Deciduous forest	21,399.23	21,391.91	21,499.02	16,376.48	0.00	0.01	–0.24	–0.23
Evergreen forest	4757.22	4285.62	4475.9	3377.17	–0.1	0.04	–0.25	–0.29
Mixed forest	3442.39	3645.63	4940.24	3543.91	0.06	0.36	–0.28	0.03
Shrubland	1372.53	2707.36	4166.06	5311.78	0.97	0.54	0.28	2.87
Built-up	518.82	1209.44	2570.16	5244.07	1.33	1.13	1.04	9.11
Waterbodies	3786.65	3716.02	2453.83	3084.59	–0.02	–0.34	0.26	–0.19

RMSE- Observation Standard Deviation Ratio (RSR) for the monthly calibration and validation are given in Table 6. The overall performance ratings of the results of the statistics is satisfactory as per the criteria given in Table 7 by [1, 52, 58]. The r-factor for calibration and validation were 0.68

and 0.38, respectively while the p-factor for calibration and validation were 0.64 and 0.51, respectively. Although the performance of the model was satisfactory still a large difference was detected. The limitation of the SCS curve number method may be the possible reason for this difference

Table 5 Sensitive flow parameters and their rank

Sr. no.	Parameters	t-stat	p-value	Rank of sensitivity	Fitted value	New min	New max
1	r_CN2.mgt	37.07	0.00	1	-0.1916	-0.388	0.004
2	v_ESCO.hru	1.25	0.21	2	0.91675	0.875	0.958
3	r_GWQMN.gw	1.02	0.31	3	0.5106	-0.234	1.256
4	r_SOL_K.sol	0.96	0.34	4	-0.1748	-0.362	0.013
5	r_OV_N.hru	0.95	0.34	5	0.04863	0.019	0.078
6	v_ALPHA_BF.gw	0.85	0.40	6	0.1622	0.081	0.243
7	v_GW_DELAY.gw	0.59	0.55	7	64.5	32.240	96.760
8	r_GW_REVAP.gw	0.38	0.70	8	0.06513	0.028	0.103

Fig. 7 The monthly average discharge during Calibration of SWAT model (1999–2009) **Fig. 8** The monthly average discharge during validation of SWAT model (2010–2015)

Table 6 Model performance statistics for the calibration and validation periods

Sr. no.	Performance evaluator	Calibration	Validation
1	R ²	0.65	0.57
2	NSE	0.61	0.54
3	PBIAS	− 18.0	19.2
4	RSR	0.63	0.68
5	p-factor	0.64	0.51
6	r-factor	0.68	0.38

between the observed and simulated discharge. The duration and intensity of the precipitation is not considered by the SCS-Curve number method used in SWAT model. The optimal parameters calculated during calibration were used to setup the SWAT model for evaluating the hydrological responses to LULC changes.

3.4 Assessing the impacts of LULC changes on hydrological parameters at basin and sub basin scale

The impacts of the LULC changes on the water balance components in the Ghaggar river basin are calculated on annual basis and are summarized in Table 8. The Ghaggar river basin has seen increase in built-up,

scrubland and agricultural area with reduction in deciduous and evergreen forest which resulted in increase in mean annual discharge from 1113.76 mm in 1985 to 1114.42 mm in 1995, 1113.89 mm in 2005 to 1115.96 mm in 2015. As a result of the continuous LULC changes a similar increased response was observed in wet season discharge (June–September) throughout 1985–2015 (2099.32 mm, 2105.85 mm, 2108.69 mm and 2131.88 mm in 1985, 1995, 2005, 2015 respectively). On the contrary the reduction in vegetative covers and increment in agriculture and built-up areas the dry season discharge has been reduced from 1985 to 2015 (620.98 mm, 618.70 mm, 616.48 mm, 608.00 mm in 1985, 1995, 2005 and 2015 respectively). The Ghaggar river basin has seen increase in built-up, scrubland and agricultural area with reduction in deciduous and evergreen forest which resulted in increase in mean annual surface runoff from 255.97 mm in 1985 to 269.62 mm in 1995, 282.70 mm in 2005 to 287.28 mm in 2015. Similarly, water yield has increased from 1985 to 2005 periods and then reduced in 2015 (629.92 mm in 1985, 631.92 mm in 1995, 647.57 mm in 2005 and 631.30 mm in 2015). In contrast, groundwater flow has reduced through the 1985 (309.99 mm), 1995 (300.26 mm) increased in 2005 (302.29 mm) and again decreased in 2015 (283.28 mm) periods. Similarly, lateral flow has reduced from 46.53 mm in 1985 to 45.10 mm in 1995 and, will continue its reduction to 45.50 mm in 2005

Table 7 General performance ratings for recommended statistics for a monthly timestep [1]

Performance rating	R ²	NSE	PBIAS	RSR
Very good	0.75 < R ² < 1.00	0.75 < NSE < 1.00	PBIAS < ± 10	0.00 < RSR < 0.50
Good	0.65 < R ² < 0.75	0.65 < NSE < 0.75	± 10 < PBIAS < ± 15	0.50 < RSR < 0.60
Satisfactory	0.50 < R ² < 0.65	0.50 < NSE < 0.65	± 15 < PBIAS < ± 25	0.60 < RSR < 0.70
Unsatisfactory	R ² < 0.50	NSE < 0.50	PBIAS > ± 25	RSR > 0.70

Table 8 Mean annuals of hydrological components during different LULC periods in the Ghaggar river basin

Study period	Streamflow			Other hydrological component (mm)					
	Annual	Wet (June–September)	Dry (October–May)	ET	Surface runoff	Baseflow	Water yield	Percolation	Lateral flow
1985	1113.76	2099.32	620.98	643.58	255.97	309.99	629.92	346.58	46.53
1995	1114.42	2105.85	618.70	640.89	269.62	300.26	631.92	336.67	45.10
2005	1113.89	2108.69	616.48	622.83	282.70	302.29	647.57	339.43	45.50
2015	1115.96	2131.88	608.00	643.06	287.28	283.28	631.30	318.78	44.70
Percentage change (%)									
1995–1985	0.06	0.31	− 0.37	− 0.42	5.33	− 3.14	0.32	− 2.86	− 3.07
2005–1995	− 0.05	0.14	− 0.36	− 2.82	4.85	0.67	2.48	0.82	0.89
2015–2005	0.19	1.10	− 1.38	3.25	1.62	− 6.29	− 2.51	− 6.08	− 1.75
2015–1985	0.20	1.55	− 2.09	− 0.08	12.23	− 8.62	0.22	− 8.02	− 3.92

and to 44.70 mm in 2015 LULC. The reduction of ET has also been observed through 1985 to 2015 periods (643.58 mm, 640.89 mm, 622.83 mm and 643.06 mm in 1985, 1995, 2005 and 2015, respectively). The impacts of the LULC changes on the monthly means of surface runoff, water yield, lateral flow, groundwater flow (base-flow) and Evapotranspiration in form of percentage changes are provided in Fig. 9.

3.5 Assessing the contribution of individual LULC change on hydrological parameters

The Spatial distribution of the changes for the LULCs i.e. agriculture, Evergreen Forest, Deciduous Forest, Mixed Forest, Scrubland, and Built-Up Area between the period 1985 and 2015 are shown in Fig. 10. The Spatial distribution of the changes for the hydrological components i.e. Evapotranspiration, Lateral Flow, Surface Runoff and Water

Fig. 9 Percentage change in monthly average (1985–2015) **a** streamflow, **b** Evapotranspiration, **c** surface runoff, **d** groundwater flow, **e** water yield, **f** Percolation and **g** Lateral flow response in the different LULC periods of the Ghaggar river basin

Fig. 10 Spatial distribution of the changes for the different LULCs between the period 1985 and 2015

Yield for the period 1985–2015 are shown in Fig. 11. The increase in Built-up area (70.69–98.17% in subbasin number 16, 23, 32, 44, 53 and 81) is mainly concentrated in the southern and western part of the Ghaggar river basin near Panchkula city. The Evergreen Forest area has reduced in Subbasin No 7, 8, 9, 12, 16, 20, 24, 25, 28 and 34 from 3.60 to 66%. The deciduous Forest area has reduced in subbasin number 17, 28, 49, 57, 65, 66, 69, 75, 76 and 80 significantly 29–57.16% and has been converted into agriculture land. The Mixed forest has reduced in subbasin 40, 56, 58, 61, 71, 82, 84, 85 and 86 significantly 3.30–21.26% and are converted into agriculture land. The scrubland has increased in subbasin number 3, 4, 30, 88, 90 and 91 26.77–64.27%.

The pairwise Pearson's correlation of the landuse landcover classes with the hydrological components for the Ghaggar river basin are shown in Table 9. A strong

association between the LULC classes and hydrological components is evident from the results. A significant higher negative correlation was demonstrated by the Evergreen, Deciduous and Mixed forest with the annual streamflow, wet season streamflow and surface runoff. A positive correlation was found between Evergreen, Deciduous and Mixed forest with dry season streamflow, Percolation, lateral flow, water yield and Evapotranspiration. The agricultural land showed a significantly positive correlation with Evapotranspiration. The barren land, Scrubland and Built-Up areas showed a positive correlation with the annual streamflow, wet season streamflow and surface runoff while a negative correlation was shown with Dry season streamflow, Groundwater Flow, Lateral flow and Percolation. The correlation results displayed in Table 9 suggests that all the Landuse landcover classes

Fig. 11 Spatial distribution of the changes for the different hydrological components between the period 1985 and 2015

plays a significant role to the changes in the hydrological components.

The hydrological components in similar fashion to that of LULC classes demonstrated significant correlation among themselves within the Ghaggar river basin. The annual streamflow showed a significant positive correlation with wet season streamflow, surface runoff and Evapotranspiration while it has negative correlation with dry season streamflow, groundwater flow, lateral flow and percolation. The wet season streamflow is positively correlated with the surface runoff while it is negatively correlated with the dry season streamflow, percolation, groundwater flow and lateral flow. The existence of a significant correlation among various hydrological components within the Ghaggar river basin is demonstrated revealing

the facts that increment or decrement in one component results in decrement or increment of other components.

A detailed summary of the five PLSR models constructed for Ghaggar river basin area are given in Table 10. For all the five PLSR models i.e. Annual streamflow, dry streamflow and wet streamflow (PLSR1), lateral flow, percolation and baseflow (PLSR2), Surface runoff (PLSR3), Water Yield (PLSR4) and Evapotranspiration (PLSR5) the obtained R^2 values are above 0.5 which suggests good prediction capabilities of the model. In PLSR1 model (Annual, Wet and Dry Streamflow) the first component/latent factor explains the 94.2% of the variance (Table 10). The PLSR1 is dominated by barren land, shrubland and built-up on positive side while Deciduous forest and evergreen forest on negative side. The relative importance of the predictors

Table 9 Pair-wise pearson correlation for changes in eight LULC types and hydrological components between the 1985 and 2015 periods

	AGRL	BARR	FODB	FOEB	FOMI	SHRB	URBN	WATR	A _{STQ}	W _{STQ}	D _{STQ}	ET	SURQ	GWQ	WYD	PERC	LATQ
AGRL	1																
BARR	-0.188	1															
FODB	-0.070	-0.962	1														
FOEB	0.093	-0.924	0.945	1													
FOMI	-0.937	-0.083	0.349	0.241	1												
SHRB	-0.617	0.871	-0.736	-0.830	0.337	1											
URBN	-0.360	0.981	-0.905	-0.921	0.074	0.950	1										
WATR	0.928	-0.431	0.169	0.228	-0.862	-0.728	-0.556	1									
A _{STQ}	0.048	0.904	-0.961	-0.990	-0.373	0.747	0.876	-0.101	1								
W _{STQ}	-0.204	0.981	-0.957	-0.977	-0.106	0.896	0.981	-0.388	0.953	1							
D _{STQ}	0.268	-0.986	0.941	0.958	0.033	-0.922	-0.993	0.459	-0.925	-0.997	1						
ET	0.924	0.122	-0.386	-0.279	-0.999	-0.299	-0.034	0.842	0.410	0.146	-0.073	1					
SURQ	-0.726	0.781	-0.621	-0.750	0.460	0.987	0.888	-0.790	0.651	0.818	-0.850	-0.425	1				
GWQ	0.182	-0.928	0.926	0.996	0.154	-0.875	-0.941	0.307	-0.973	-0.982	0.969	-0.193	-0.806	1			
WYD	-0.938	-0.061	0.329	0.229	1.000	0.351	0.093	-0.873	-0.360	-0.089	0.014	-0.998	0.471	0.142	1		
PERC	0.149	-0.927	0.934	0.998	0.187	-0.859	-0.934	0.278	-0.980	-0.981	0.966	-0.226	-0.786	0.999	0.174	1	
LATQ	0.394	-0.667	0.637	0.853	-0.052	-0.824	-0.757	0.339	-0.795	-0.793	0.780	0.020	-0.825	0.879	-0.052	0.870	1

AGRL Agriculture, BARR Barren, FODB Deciduous Forest, FOEB Evergreen Forest, FOMI Mixed Forest, SHRB Scrubland, URBN Built-up, WATR Water, A Annual, W Wet, D Dry, STQ Streamflow, ET Evapotranspiration, SURQ Surface Runoff, GWQ Groundwater flow, WYD Water yield, PERC Percolation, LATQ Latent Flow. Significant value at $P=0.05$ are shown in Bold

Table 10 Summary of PLSR models of the hydrological components in the Ghaggar river basin

PLSR model	Response variable	Components	R ²	% of explained variability in Y	%Cumulative Y variance (R-square)	Adjusted R-square
1	Annual, wet and dry streamflow	1	0.942	94.22	94.22	0.913
		2		4.77	98.99	0.970
		3		1.01	100.00	
2	Percolation, lateral flow, baseflow	1	0.818	81.78	81.78	0.727
		2		2.76	84.53	0.536
		3		15.47	100.00	
3	Surface runoff	1	0.952	95.19	95.19	0.928
		2		1.74	96.93	0.908
		3		3.07	100.00	
4	Water yield	1	0.97	97.03	97.03	0.955
		2		2.70	99.72	0.992
		3		0.28	100.00	
5	ET	1	0.983	98.27	98.27	0.974
		2		1.63	99.90	0.997
		3		0.10	100.00	

Table 11 VIP (Variable importance for projection) values and PLSR weights of hydrological components in the Ghaggar river basin

Variables	Annual, wet and dry streamflow		Percolation, lateral flow, baseflow		Surface runoff		Water yield		Evapo-transpiration	
	VIP	w*1	VIP	w*1	VIP	w*1	VIP	w*1	VIP	w*1
Agriculture	0.194	−0.069	0.327	0.116	0.949	−0.335	1.548	−0.547	1.537	0.543
Barren Land	1.268	0.448	1.201	−0.425	1.021	0.361	0.101	−0.036	0.203	0.072
Deciduous Forest	1.260	−0.446	1.191	0.421	0.811	−0.287	0.543	0.192	0.641	−0.227
Evergreen Forest	1.289	−0.456	1.347	0.476	0.981	−0.347	0.377	0.133	0.464	−0.164
Mixed Forest	0.218	−0.077	0.149	0.053	0.601	0.213	1.649	0.583	1.661	−0.587
Shrubland	1.135	0.401	1.205	−0.426	1.290	0.456	0.579	0.205	0.498	−0.176
Built-up	1.260	0.445	1.248	−0.441	1.160	0.410	0.154	0.054	0.057	−0.020
Waterbodies	0.426	−0.151	0.432	0.153	1.033	−0.365	1.441	−0.510	1.399	0.495

in model is defined by $VIP > 1$ and therefore Barren Land, Deciduous Forest, Evergreen Forest, Shrubland and Built-up have more significance in PLSR1 model (Table 11).

In PLSR2 (Percolation, Baseflow and Lateral flow) the first component/latent factor explains the 81% of the variance (Table 10). The PLSR2 is dominated by barren land, shrubland and built-up on negative side while Deciduous forest and evergreen forest on positive side. The relative importance of the predictors in model is defined by $VIP > 1$ and therefore Barren Land, Deciduous Forest, Evergreen Forest, Shrubland and Built-up have more significance in PLSR2 model (Table 11). In PLSR3 model (Surface Runoff) the first component/latent factor explains the 95% of the variance (Table 10). The PLSR3 is dominated by barren land, shrubland and built-up on positive side while Deciduous forest, evergreen forest and agriculture on negative side. The relative importance of the predictors

in model is defined by $VIP > 1$ and therefore Barren Land, Shrubland and Built-up have more significance in PLSR3 model (Table 11). In PLSR4 model (Water Yield) the first component/latent factor explains the 97% of the variance (Table 10). The PLSR4 is dominated by Deciduous Forest, Evergreen Forest, Mixed Forest, Shrubland on positive side while barren land and agriculture on negative side. The relative importance of the predictors in model is defined by $VIP > 1$ and therefore agriculture and mixed forest have more significance in PLSR4 model (Table 11). In PLSR5 model (Evapotranspiration) the first component/latent factor explains the 98% of the variance (Table 10). The PLSR5 is dominated by agriculture on positive side while Deciduous Forest, Evergreen Forest and Mixed Forest on negative side. The relative importance of the predictors in model is defined by $VIP > 1$ and therefore agriculture and mixed forest have more significance in PLSR5 model (Table 11).

4 Conclusions

This study is an attempt to reveal how the land use changes in the past several decades have impacted the hydrology of Ghaggar river basin using the fixing changing method, calibrated SWAT model and PLSR analysis. The land use change within the Ghaggar river basin is mainly attributed to transformation of agricultural land into built-up areas. The deleterious impact of the land cover due to deforestation and increased anthropogenic activities on the hydrological components is clearly evident. There was a great consistency in the results to the other studies conducted around the world [1, 2, 34, 38].

The inferences deduced from the study clearly exhibit that the increase in surface runoff is a negative impact on the Ghaggar river basin which further intensifies the environmental stress of erosion and sediment yield. The increased urbanization and agricultural activities are the main contributors for controlling the annual streamflow, wet streamflow, surface runoff, and water yield in Ghaggar river basin. The chances of flooding get enlarged due to increase in annual and wet season streamflow. Similarly, the reduction in dry streamflow may affect the agriculture practices within the basin by affecting the irrigation. A decline in the percolation is also exerting a negative impact on the study area by reducing the recharge of aquifers. The deforestation of the evergreen and deciduous forest is yet another factor responsible for stressing the water resource availability in the Ghaggar river basin.

This study offers quantitative information related to impact of LULC change on hydrological components such as water yield and ET to the decision makers and various stakeholders for formulating policies related to water resource management. This attempt is a comprehensive example for integrating remotely sensed LULC, hydrological modeling and partial least square regression analysis to quantify the potential impacts of LULC changes on water provisioning. The enormous alterations of LULC changes in the past 30 years if are continued at the same pace than the assessment of its impact on hydrological components which is attempted through this study can be very beneficial to the water resource planners.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Anand J, Gosain AK, Khosa R (2018) Prediction of land use changes based on land change modeler and attribution of changes in the water balance of Ganga basin to land use change using the SWAT model. *Sci Total Environ* 644:503–519
2. Gashawa T, Tulu T, Argawa M, Worqlul AW (2018) Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. *Sci Total Environ* 619–620:1394–1408
3. Serpa D, Nunes JP, Santos J, Sampaio E, Jacinto R, Veiga S, Lima JC, Moreira M, Cortereal J, Keizer JJ, Abrantes N (2015) Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. *Sci Total Environ* 538:64–77
4. Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *J Hydrol* 310:28–61
5. Romanowicz RJ, Booij MJ (2011) Impact of land use and water management on hydrological processes under varying climatic conditions. *Phys Chem Earth* 36(13):613–614
6. Kindu M, Schneider T, Döllerer M, Teketay D, Knoke T (2018) Scenario modelling of land use/land cover changes in Munessa-Shashemene landscape of the Ethiopian highlands. *Sci Total Environ* 622–623(1):534–546
7. Li Z, Liu W, Zhang X, Zheng F (2009) Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *J Hydrol* 377:35–42
8. Bewket W, Sterk G (2005) Dynamics in land cover and its effect on stream flow in the Chemoga watershed, Blue Nile Basin, Ethiopia. *Hydrol Process* 19(2):445–458
9. Yun P, Huili G, Demin Z, Xiaojuan L, Nobukazu N (2011) Impact of land use change on groundwater recharge in Guishui River Basin, China. *Chin Geogra Sci* 21(6):734–743
10. Mango LM, Melesse AM, McClain ME, Gann D, Setegn SG (2011) Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. *Hydrol Earth Syst Sci* 15(7):2245–2258
11. Mango M, Melesse AM, McClain ME, Gann D, Setegn SG (2011) Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. *Hydrol Earth Syst Sci* 15(7):2245–2258
12. Van Rompaey AJ, Govers G, Puttemans C (2002) Modelling land use changes and their impact on soil erosion and sediment supply to rivers. *Earth Surf Proc Land* 27(5):481–494
13. Siriwardena L, Finlayson BL, McMahon TA (2006) The impact of land use change on catchment hydrology in large catchments: The Comet River, Central Queensland, Australia. *J Hydrol* 326(1–4):199–214
14. Bakker MM, Govers G, Van Doorn A, Quetier F, Chouvardas D, Rounsevell M (2008) The response of soil erosion and sediment export to land-use change in four areas of Europe: The importance of landscape pattern. *Geomorphology* 98(3–4):213–226
15. Rientjes TH, Haile AT, Kebede E, Mannaerts CM, Habib E, Steenhuis TS (2011) Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile Basin–Ethiopia. *Hydrol Earth Syst Sci* 15(6):1979–1989
16. Wang R, Kalin L, Kuang W, Tian H (2013) Individual and combined effects of land use/cover and climate change on Wolf Bay watershed streamflow in southern Alabama. *Hydrol Process* 28(22):5530–5546

17. Wagner PD, Kumar S, Schneider K (2013) An assessment of land use change impacts on the water resources of the Mula and Mutha Rivers catchment upstream of Pune, India. *Hydrol Earth Syst Sci* 17(6):2233–2246
18. Eshtawi T, Evers M, Tischbein B (2016) Quantifying the impact of urban area expansion on groundwater recharge and surface runoff. *Hydrol Sci J* 61:826–843
19. Hurni H, Tato K, Zeleke G (2005) The implications of changes in population, land use, and land management for surface runoff in the Upper Nile Basin Area of Ethiopia. *Mt Res Dev* 25(2):147–154
20. Bruijnzeel LA (2004) Hydrological functions of tropical forests: not seeing the soil for the trees? *Agr Ecosyst Environ* 104(1):185–228
21. Bonell M, Purandara BK, Venkatesh B, Krishnaswamy J, Acharya HA, Singh UV, Jayakumar R, Chappell N (2010) The impact of forest use and reforestation on soil hydraulic conductivity in the Western Ghats of India: implications for surface and sub-surface hydrology. *J Hydrol* 391(1–2):47–62
22. Lin Y, Wei X (2008) The impact of large-scale forest harvesting on hydrology in the willow watershed of Central British Columbia. *J Hydrol* 359(1–2):141–149
23. Bradshaw CJ, Sodhi NS, Peh KS, Brook BW (2007) Global evidence that deforestation amplifies flood risk and severity in the developing world. *Glob Change Biol* 13(11):2379–2395
24. Valentin C, Agus F, Alamban R, Boosaner A, Bricquet JP, Chaplot V, de Guzman T, de Rouw A, Janeau JL, Orange D, Phachomphonh K, Phai DD, Podwojewski P, Ribolzi O, Silvera N, Subagyo K, Thiébaux JP, Toan TD, Vadari T (2008) Runoff and sediment losses from 27 upland catchments in Southeast Asia: Impact of rapid land use changes and conservation practices. *Agricu Ecosyst Environ* 128(4):225–238
25. Remondi F, Burlando P, Vollmer D (2016) Exploring the hydrological impact of increasing urbanisation on a tropical river catchment of the metropolitan Jakarta, Indonesia. *Sustain Cities Soc* 20:210–221
26. Rose S, Peters NE (2001) Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. *Hydrol Process* 15(8):1441–1457
27. Defries R, Eshleman KN (2004) Land-use change and hydrologic processes: a major focus for the future. *Hydrol Process* 18(11):2183–2186
28. Wang G, Yang H, Wang L, Xu Z, Xue B (2012) Using the SWAT model to assess impacts of land use changes on runoff generation in headwaters. *Hydrol Process* 28(3):1032–1042
29. Zhang Y, Guan D, Jin C, Wang A, Wu J, Yuan F (2014) Impacts of climate change and land use change on runoff of forest catchment in northeast China. *Hydrol Process* 28(2):186–196
30. Marhaento H, Booji MJ, Rientjes TH, Hoekstra AY (2017) Attribution of changes in the water balance of a tropical catchment to land use change using the SWAT model. *Hydrol Process* 31(11):2029–2040
31. Lorup JK, Refsgaard JC, Mazvimavi D (1998) Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: case studies from Zimbabwe. *J Hydrol* 205(3–4):147–163
32. Yan B, Fang NF, Zhang PC, Shi ZH (2013) Impacts of land use change on watershed streamflow and sediment yield: an assessment using hydrologic modelling and partial least squares regression. *J Hydrol* 484:26–37
33. Akhtar M, Ahmad N, Booji MJ (2008) The impact of climate change on the water resources of Hindukush–Karakorum–Himalaya region under different glacier coverage scenarios. *J Hydrol* 355(1–4):148–163
34. Birhanu A, Masih I, van der Zaag P, Nyssen J, Cai X (2019) Impacts of land use and land cover changes on hydrology of the Gumara catchment, Ethiopia. *Phys Chem Earth* 2019:165–174
35. Guzha AC, Rufino MC, Okoth S, Jacobs S, Nobrega RL (2018) Impacts of land use and land cover change on surface runoff, discharge and low flows: evidence from East Africa. *J Hydrol Re Stud* 15:49–67
36. Im S, Kim H, Kim C, Jang C (2008) Assessing the impacts of land use changes on watershed hydrology using MIKE SHE. *Environ Geol* 57:231–239
37. Wang G, Xia J, Chen J (2009) Quantification of effects of climate variations and human activities on runoff by a monthly water balance model: A case study of the Chaobai River basin in northern China. *Water Resour Res* 45(7):1–12
38. Nie W, Yuan Y, Kepner W, Nash MS, Jackson M, Erickson C (2011) Assessing impacts of Landuse and Landcover changes on hydrology for the upper San Pedro watershed. *J Hydrol* 407:105–114
39. Tang L, Yang D, Hu H, Gao B (2011) Detecting the effect of land-use change on streamflow, sediment and nutrient losses by distributed hydrological simulation. *J Hydrol* 409:172–182
40. Baker TJ, Miller SN (2013) Using the soil and water assessment tool (SWAT) to assess land use impact on water resources in an East African watershed. *J Hydrol* 486:100–111
41. Gashaw T, Bantider A, Mahari A (2014) Evaluations of land Use/Land cover changes and land degradation in Dera District, Ethiopia: GIS and remote sensing based analysis. *Int J Sci Res Environ Sci* 2(6):199–208
42. Haseen EE, Aseen M (2018) Land use/cover dynamics and its drivers in Gelda catchment, Lake Tana watershed, Ethiopia. *Environ Syst Res* 6(4):1–13
43. Green WH, Ampt GA (1911) Studies on Soil Physics. *J Agricultural Phys* 4(1):1–24
44. Roy PS, Roy A, Joshi PK, Kale MP, Srivastava VK, Srivastava SK, Dwevidi RS, Joshi C, Behera MD, Meiyappan P, Sharma Y, Jain AK, Singh JS, Palchowdhuri Y, Ramachandran RM, Pinjarla B, Chakravarthi V, Babu N, Gowsalya MS, Thiruvengadam P, Kotteeswaran M, Priya V, Yelishetty KV, Maithani S, Talukdar G, Mondal I, Rajan KS, Narendra PS, Biswal S, Chakraborty A, Padalia H, Chavan M, Pardeshi SN, Chaudhari SA, Anand A, Vyas A, Reddy MK, Ramalingam M, Manonmani R, Behera P, Das P, Tripathi P, Matin S, Khan ML, Tripathi OP, Deka J, Kumar P, Kushwaha D (2015) Development of Decadal (1985–1995–2005) land use and land cover database for India. *Remote Sens* 7(3):2401–2430
45. Strahler A, Muchoney D, Borak J, Friedl F, Gopal S, Lambin L, Moody A, (1999) MODIS land cover product algorithm theoretical basis document (ATBD) Version 5.0, 1–72
46. Rajeevan M, Pai DS, Sridhar L, Sreejith OP, Satbhai NS, Mukhopadhyay B (2014) Development of a new high spatial resolution (0.25° × 0.25°) long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *Mausam* 65(1):1–18
47. Rajeevan M, Srivastava AK, Kshirsagar SR (2009) Development of a high resolution daily gridded temperature data set (1969–2005) for the Indian region. *Atmos Sci Lett* 10(4):249–254
48. Abbaspour KC, Vejdani M, Haghighat S (2007) SWAT-CUP Calibration and uncertainty programs for SWAT, Jan 2007. [Online]. Available: https://www.mssanz.org.au/MODSIM07/papers/24_s17/SWAT-CUP_s17_Abbaspour_.pdf
49. Nash JE, Sutcliffe JV (1970) River Flow Forecasting through Conceptual Model. Part 1- A Discussion of Principles. *J Hydrol* 10(3):282–290
50. Singh J, Knapp HV, Arnold JG, Demissie M (2004) Hydrologic modeling of the Iroquois River watershed using HSPF and SWAT. *J Am Water Resour Assoc* 41(2):343–360

51. Gupta HV, Sorooshian S, Yapo PO (1999) Status of automatic calibration for hydrologic models: comparison with multilevel expert calibration. *J Hydrol Eng* 4(2):135–143
52. Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Am Soc Agric Biol Eng* 50(3):885–900
53. Abdi H (2007) "Partial least square regression (PLS regression)," in *Encyclopedia of Measurement and Statistics*. Sage Publications, Thousand Oaks, CA
54. Wold S, Sjostroma M, Eriksson L (2001) PLS-regression: a basic tool of chemometrics. *Chemom Intell Lab Syst* 58:109–130
55. Carrascal LM, Galvan I, Gordo O (2009) Partial least squares regression as an alternative to current regression methods used in ecology. *Oikos* 118(5):681–690
56. Shi Z, Ai L, Li X, Wu G, Liao W (2013) Partial least-squares regression for linking land-cover patterns to soil erosion and sediment yield in watersheds. *J Hydrol* 498:165–176
57. SAS Institute Inc., (2017) *JMP® 13 Multivariate Methods*. Second edition, Cary, NC: SAS Institute Inc.,
58. Moriasi DN, Gitau MW, Pai N, Daggupati P (2015) Hydrologic and water quality models: performance measures and evaluation criteria. *Trans ASABE* 58(6):1763–1785

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.