Impact of Land Use and Climate Change on Surface Runoff Using GIS and SWAT Model: A Case Study

Aakriti Chauhan, Suman Kumari*, Md Umerjan Deva and Vijay Shankar
[1,] National Institute of Technology Hamirpur, Himachal Pradesh, India
**Corresponding author e-mail id: kumarisuman1993@gmail.com*

Abstract: Surface runoff is a noteworthy component of the hydrological cycle and is a prime source to fulfil the water requirements of human beings. Thus, dealing with the surface runoff turns out to be significant and is conceivable through the protection of soil and water on a definite scale, for example, a watershed. In India, information accessibility on surface runoff is extremely restricted. Hence, there is a need to gauge the surface runoff at the selected area on the watershed. The Distributed Hydrological Model SWAT (Soil and Water Assessment Tool) is frequently used to gauge the surface runoff. The paper presents a case study of Kunah Khad watershed in Hamirpur, Himachal Pradesh, to estimate the effect of land use/cover and climate changes on monthly stream flow of the watershed using SWAT model. The study aims to exhibit the estimation of the monthly discharge values for the point selected on the Kunah Khad stream utilizing SWAT model. LAND-sat images obtained from USGS earth explorer were processed in ArcGIS using digital image classification tool to determine the land use map and land cover changes. Climate data for the past decade consisting of rainfall, maximum and minimum temperature, wind speed, relative humidity and solar radiations were acquired from Global Weather Data (GWD). Land use maps, soil map and climatic data have been used as inputs to the SWAT model and the output provided by SWAT was Surface Runoff on monthly time set-up. The performance of the model was evaluated on the basis of Coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) which were found to be 0.82 and 0.78 for calibration period and 0.88 and 0.80 for validation period, respectively. On the basis of the results obtained in this study, the digital image classification was found to be a satisfactory methodology for visual explanation at high precision, as it takes less time and effort than conventional algorithms. The maps obtained from image classification were of a high accuracy and were reasonable as an input into the SWAT model. The outcomes of the study specified that the land cover and land use patterns have varied and resulted in an increment in the settlement, agricultural, vegetation and forest land, whereas, decrement in water bodies and barren land. This shows augmentation in surface runoff, though, the variation has not occurred notably.

Keywords: SWAT model; Land use; Climate change; ArcGIS; Surface Runoff

1. Introduction

The area of land where precipitation falls, gathers and depletes off in a typical outlet like into a waterway or other water bodies is known as a watershed (Black, 1996). A watershed is isolated by a high rise of land called edge line. The various characteristics of water (distribution and circulation) regarding the watershed can be described in terms of a cycle known as the hydrologic cycle. Negative changes in atmosphere parameters like precipitation, temperature of biological system impact the hydrological cycle in a watershed. Land use and land cover variation is a widespread process chiefly driven by natural processes and man-made activities due to which there are changes that affect the natural ecosystems (Urich, 2002). Natural or anthropogenic exercises confer such changes that may cause over mugginess, intemperate aridity, increase in overflow, immaterial precipitation, disintegration, floods and dry seasons. Quantifying the effects of changes in land use, soil misfortune, quality and amount of water on watershed are critical discourses in water asset building. There might be changes in hydrological cycle due to land use, changes in base stream (Wang et.al 2003) and yearly normal release of bowls (Costa et al 2003). Type and level of land spread effects the overflow, penetration and the surface spillover release and all over sediment load rate moved from a watershed.

The present investigation is an endeavour to clarify the impact that land use changes superficially have on the spillover of a watershed utilizing ArcGIS programming and SWAT model. ArcGIS programming helps in the planning of information maps like land use maps and soil maps. Arnold et al. (2010b) describes developments in SWAT to route water flows that simulate the impacts of spatial land use and cover changes and land management on various landscapes. The predominant point of the investigation is to give depiction of Kunah Khad watershed in the Indian state of Himachal Pradesh, and to determine land use, land spread changes in the previous decade and assess the impact of land use and changing climatic parameters on surface overflow changes using the Soil and Water Assessment Tool (SWAT).

2. Materials and Methodology

Study Area

The examination area is Kunah Khad, a left bank tributary of Beas waterway located in Hamirpur district of Himachal Pradesh, India. Topographically it stretches out from 31^0 35'18"N to 31^0 47'35"N and 76^0 22'58"E to 763^0 9'32"E. It streams in the East-West course at certain areas and South-West heading towards the end and streams North-West way before it joins Beas waterway. Kunah Khad watershed stretches out over a region of 355.54 km^2. Kunah Khad additionally has its very own tributaries like Hathli Khad, Sukar Khad, Gosoti Khad.

The majority of the territory has an altitude of 700-900 meters above mean sea level (MSL). About 26.230% of the watershed region is between the statures of 800-900 meters and approximately 21.41 % in the midst of the altitude 700 to 800 meters. In Kunah Khad, the most predominant soil in the watershed is well drained loamy skeletal soil. Climate of the Kunah Khad watershed is sub-tropical in nature. (Sarkar, 2013). Around 84% of the annual rainfall in the watershed is received in summer monsoon between June and September whereas around twelve percent (12%) rainfall is received in winter season and in other months rainfall is very less and sporadic.

Data Set for SWAT Model

The data sets required for SWAT model include relief maps, soil data, land use maps, maximum and minimum temperature, daily precipitation, relative humidity, wind speed and sunshine hours. The present study is performed by preparing the Land Use and Land Cover maps after obtaining open source Digital Elevation Model (DEM) for the area under consideration. Variables used and climate data required for the study are shown in Table 1.

Soil and Water Assessment Tool (SWAT)

SWAT is a watershed scale model and it has been created to assess the long-term effects of land use and land spread practices in enormous watersheds. SWAT model works at bowl scale on day by day time setup (Arnold et al., 1997, 2001). This is a model with ArcGIS interface created by the USDA-Horticulture Exploration Administration (Arnold et al., 1999). This is a hydrology model with segments like climate, return stream, spillover, evapotranspiration, permeation, groundwater stream, reach steering, transmission misfortunes, penetration, supplement and pesticide stacking and water exchange. In this model, the basin is divided into sub-basins based on geology criteria and is additionally partitioned in number of hydrological response units in view of soil type, land use and incline mixes. It helps in re-enactment of segments of hydrological cycles, surface overflow, silt limit and supplement cycles utilizing SWAT-CUP tool. In this examination, ArcGIS was used to break down DEM of study area and arrange the shapefile utilizing Hydrology device in the software. On shapefile of the investigation zone, we discover stream bearing, stream amassing of the watershed. Supervised classification was performed on the examination territory DEMs so as to create land use maps for the year 2003 and 2013 separately. Also, soil maps of the examination zone were obtained which characterized the soil present in the investigation zone after which the meteorological information records were arranged in the word position. Land Use maps, soil map and climatic parameters were given as contributions to SWAT model, which on subsequent handling in the model delivered surface overflow as output. An overview about climatic inputs, cropping, flow, pollutants and hydrologic balance is discussed by Gassman et al. (2007).

Table 1. Variables used in the SWAT model and data sources

S. No.	Variables	Data Sources and Methodology
1.	Remote sensing data	SRTM (DEM)
2.	Land use/ land cover mapping	Earth Site Explorer -USGS Digitally LULC map has been prepared by using image classification tool in ArcGIS.
3.	Soil map	It has been obtained from National Bureau of soil survey and land use planning.
4.	Climate data	Rainfall, temperature, relative humidity, wind speed and sunshine hours have been collected from Land Records Department, Hamirpur and Global Weather Data.

Hydrologic water balance

The hydrological cycle in a basin consist of water stage and land stage and for its simulation a balance equation like water balance equation is required and estimation is individually done on every hydrologic response units (HRU). Following equation was used in SWAT model for calculation of soil moisture content in the soil (Setegn et al. 2008):

$$SWf = SWi + \sum_{1}^{t} t\,(Rd - Qr - Ee - Wsp - Qgw) \qquad (1)$$

Where:

SWf= Final moisture content in soil (mm)*; SWi*= Initial moisture content in soil on i^{th} day (mm)*; Rd*= Precipitation on i^{th} day (mm*); Qr*= Runoff on i^{th} day (mm)*; Ee*= Evapo-transpiration on i^{th} day (mm)*; WSp* = Volume of water in vadose zone from soil profile on i^{th} day (mm) *and Qgw*= Return flow on i^{th} day (mm)

Surface Runoff

The surface overflow from each HRU is assessed exclusively and is consolidated for deciding the gathered yield for watershed separately in SWAT model so as to expand the exactness and improving the portrayal of water balance. The model equations have been discussed in detail in the theoretical documentation of SWAT and by Arnold et al. (1998). In this examination, SWAT model utilized Soil Conservation Service-Curve Number (SCS-CN) technique. The land use and soil characteristics are incorporated into one variable in SCS-CN technique which is being used for various land uses and climate conditions (Adornado and Yoshida, 2010). Soils are grouped into high, moderate, low and extremely low classes based on penetration rate and Natural Resources Conservation Services (NRCS) soil order is utilized. There are a few components which impact the hydrological arrangement of soils like mud content, invasion limit, profundity of soil and water powered conductivity. In SWAT model the Antecedent Moisture Content is characterized based on Curve number (CN). Antecedent Moisture Content (AMC) might be characterized as the dampness content which is available in soil toward the start of precipitation spillover occasion. Antecedent Moisture Content (AMC) clarifies the penetration and deliberation.

Curve Number (CN) is the most extreme potential maintenance parameter and depends on the soil, vegetation, land use complex of the watershed. It is an observational parameter proficiently utilized for foreseeing direct runoff or penetrations from precipitation overabundance, and the rough overflow from precipitation occasion in a specific territory. Utilizing the everyday CN esteem, the maintenance parameter S is also determined.

CNI and CNII can be changed into the other two dampness conditions with the assistance of following conditions:

$$CNI = CNII - (20(100 - CNII))/((100 - CNII) + e^{[2.54 - 0.064(100 - CNII)]} \quad (2)$$

$$CNIII = CNII - e^{[0.00673.(100 - CNII)]} \quad (3)$$

Utilizing the everyday CN esteem the maintenance parameter S is then determined by following condition:

$$S = 25.49 \left[\frac{1000}{CN - 10}\right] \quad (4)$$

Estimated CN has a value somewhere in the range of 0 and 100. At the point when the estimation of Curve number is 100, it describes a condition which has a zero-maintenance potential (S=0) implies impenetrable bowl/catchment and when the estimation of CN is 0 it compares to endlessly abstracting catchment with maintenance parameter $S=\infty$.

Model Framework

The SWAT clubbed with ArcSWAT tool in ArcGIS software has been widely used (Olivera et al., 2006). The layout comprised of input data, watershed delineation with the help of Digital Elevation Model (DEM), HRU definition using land use, soil and weather data and trial of the model, followed by simulation of the considered data.

Model Simulation

The whole simulation process consists of set up of the SWAT project, delineation of watershed, analysis of HRU, input tables and simulation by SWAT which are described below:

(i) Watershed Delineation- Delineation means creation of boundary of study area for a particular control point or outlet. In ArcSWAT interface a user is provided watershed delineator with the help of which delineation of watershed becomes easy from the digital elevation model (DEM). From DEM data ArcSWAT creates stream network, outlets, flow direction and flow accumulation.

(ii) Hydrological Response Unit - It may be defined as integration of many soil classes, land cover classes and slope classes. HRU present in the ArcSWAT interface helps in hundred percent (%) superimposing of soil map and land use map with corresponding delineated watershed and slope classes creating twenty-five sub-basins in the Kunah Khad watershed.

(iii) Input Tables- Input tables include rainfall data, minimum and maximum temperature data, wind speed data, relative humidity data and solar radiations data which were arranged in SWAT files and integrated with the model. SWAT model was run on monthly time setup.

(iv) Simulation- So as to boost the efficiencies of model, calibration and validation was done. In the present examination adjustment, approval and affectability investigation were performed with the assistance of Soil Water Assessment Tool –Calibration and Uncertainty Procedures (CUP). SWAT Alignment and Vulnerability Systems is a program created to coordinate numerous vulnerability investigation and adjustment programs utilizing same interface. In the present investigation SUFI2 - Sequential Uncertainty Fitting 2 has been utilized to perform alignment and examine the adjusted and approved outcomes (Kumar et al., 2017).

Model Performance

The precision and flexibility execution of the model must be checked (Goswami et al., 2005) for which coefficients like coefficient of determination (R^2) (Legates and McCabe 1999) and model efficiency coefficient (NSE) (Nash and Sutcliffe 1970) can be figured out (Coffey et al., 2004). NSE is calculated by:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right] \quad (5)$$

Where Y_i^{obs} is the measured value, Y_i^{sim} is the simulated value, Y_i^{mean} is the average of the measured value, and n ($i = 1, 2, \ldots, n$) is the total simulation period. There is an extent of R^2 and NSE within which these quantities lie, such that the point model execution is viewed as tasteful and worthy: $R^2 \geq 0.65$ and NSE ≥ 0.5 (Moriasi et al., 2007). In the present investigation we determined the estimations of referenced coefficients and checked the proficiency of our model.

(i) Coefficient of Determination (R^2) - R^2 decides how well an information fits in factual model. Estimation of R^2 is between 0 to1. When the value of R^2 is equivalent to 1 it means the information fits relapse line splendidly yet when R^2 is equivalent to 0 it implies that line does not fit the information.

(ii) Nash -Sutcliffe efficiency (NSE) - NSE is a coefficient which helps in estimating the effectiveness and precision of the model. NSE has an attractive criterion as NSE ≥0.5, however, the range lies between short unendingness to solidarity (- ∞ to 1). At the point when the estimation of NSE is equivalent to unity it implies there is an ideal match between evaluated esteem and watched esteem.

3. Results and Discussion

LAND-SAT images obtained from USGS earth explorer were processed in ArcGIS using image classification tool to obtain land use maps of Kunah Khad watershed in 2003 and 2013 respectively as shown in figures 1 and 2. The figures represent land use in the watershed categorized as water bodies, urbanization, vegetation, barren land and agricultural land.

Table 2 and 3 shows land use change in the past decade and runoff variation in the past decade respectively. The table compares the land use of 2003 with the 2013 land use, showing the relative change in land use in the watershed in past decade. It conveys how land has been used by the people in the past decade. As a result of SWAT analysis, it is inferred that the areas of urbanization, agriculture, vegetation, forest cover land runoff in the study area shows increasing trend. There is decrement in water bodies and barren land as per the outputs provided by ArcGIS software. In this study monthly runoff has been taken into consideration and how land use and climatic parameters impact the monthly runoff has been studied.

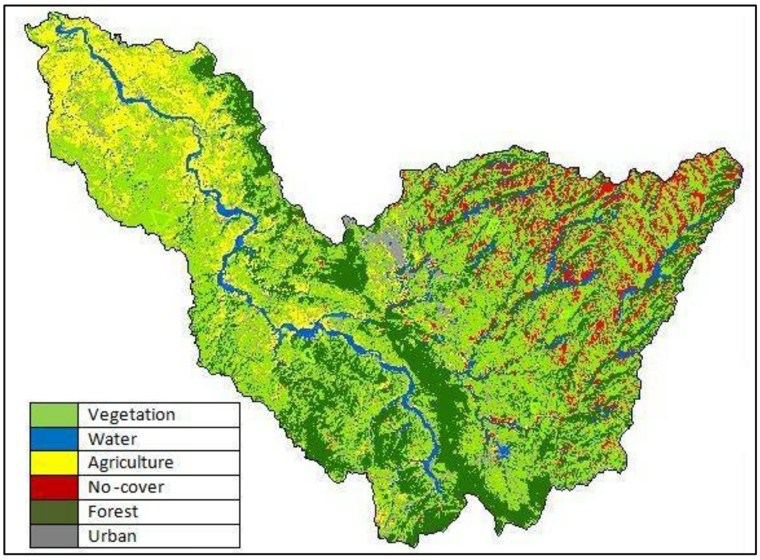

Fig. 1: Landuse map of Kunah Khad watershed 2003

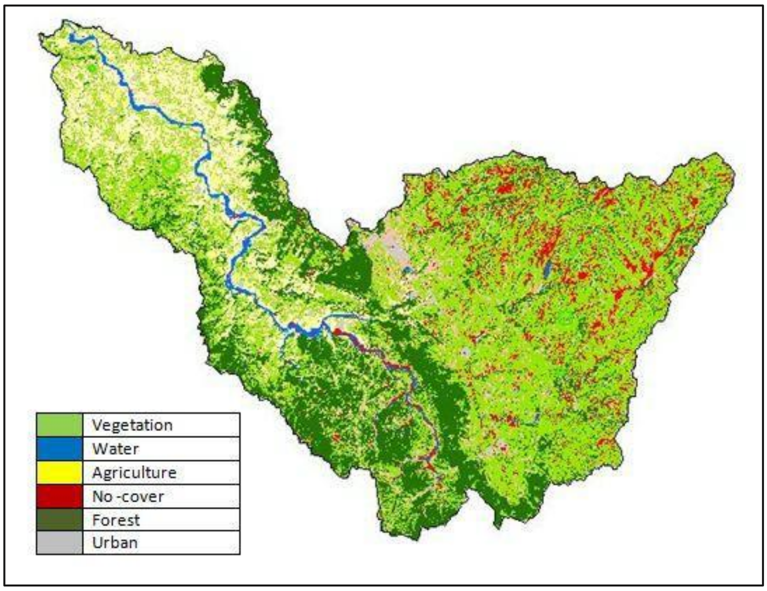

Fig. 2: Landuse map of Kunah Khad watershed 2013

Table 2. Land use change in 2003 and 2013

Land use/ Land cover	**2003**		**2013**		**% change**
	km²	**%**	**km²**	**%**	
Forest	64.57	22.41	67.30	23.36	4.23
Water bodies	20.41	7.08	6.61	2.29	-67.6
Urban	19.92	6.91	27.42	9.52	37.65
Vegetation	128.13	44.48	131.39	45.61	37.65
No cover	17.67	6.13	15.75	5.47	-10.8
Agriculture	37.38	12.98	39.61	13.75	5.97

Table 3. Variation of runoff in 2003 and 2013

MONTH	RUNOFF (cumecs) 2003	RUNOFF (cumecs) 2013
January	1.874	4.318
February	5.60	5.317
March	0.110	2.658
April	0.006	0.112
May	0.000	0.002
June	0.0047	18.547
July	16.522	53.98
August	21.273	91.149
September	1.559	8.676
October	0.001	17.172
November	0.0079	1.410
December	0.00018	1.738

Sensitivity Analysis

The procedure used to decide how free factor esteems will affect a specific ward variable under a given arrangement of presumptions is defined as sensitivity analysis. In this study, the identification of most sensitive parameters was done using sensitivity analysis. The sensitive variables were altered to perform more calibration and the limit of calibration parameters were taken after analysing literature reviews of different studies and SWAT-CUP manual. From all the considered parameters for calibration, five were found to me most sensitive and they include hydraulic conductivity, threshold water depth, base flow, soil evaporation compensation factor and slope steepness.

Simulation and validation of the SWAT model against monthly surface runoff flow was performed using Sequential Uncertainty Fitting-2 algorithm. Calibration and simulation of the model were performed for the time period of 2005 to 2011 which comprised the warm up period of two years i.e. from 2003 to 2005. Calibration was performed by using SWAT-CUP tool (Abbaspour et al. (2007) Calibration was done in order to increase the accuracy and efficiency of the model and to obtain good values of coefficient of determination and Nash-Sutcliffe Efficiency so that performance of the model will increase. After calibration values of R^2 and NSE were 0.82 and 0.78 respectively. Validation was performed to check the accuracy of the results and the performance of the model. The value of R^2 and NSE is found to be 0.88 and 0.80 respectively for the validated data. Calibrated model was validated for the period 2012 to 2013. Validation was performed using SWAT-CUP tool in the SWAT model after calibration in order to validate the results obtained. Values of R^2 and NSE increased from 0.82 to 0.88 and 0.78 to 0.80 respectively. Since values of R^2 and NSE are greater than the satisfactory criteria hence the results provided by model are good.

Table 4. Performance evaluation of the model

Data sets	R^2	NSE
Calibrated period (2003-2011)	0.82	0.78
Validated period (2011-2013)	0.88	0.80

The changes in yearly surface runoff discharge for the Kunah Khad watershed in the past decade has been presented in Table-5 from which we can infer that there has been an increase in the surface runoff. It has been observed that the model has effectively showed the change in surface runoff to a great extent. The SWAT model was run on monthly time step showing the changes in runoff with good accuracy.

Table 5. Observed vs Simulated Discharge for monthly time step

Year	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)
2005	93.056	111.036
2013	412.0253	790.6712

This significant augmentation in runoff of the watershed can be considered to the increase in settlement, vegetation, agricultural land and forest cover and decrease in barren land in past decade. Though the surface runoff discharge has shown changes comparable with the land use changes, however, there is not significant change in some land use parameters. Therefore, climatic changes in rainfall, solar radiations, temperature and relative humidity may be held accountable for such type of variations. The unusual change in precipitation pattern in the last few years could also be the cause for increase in surface runoff discharge.

4. **Conclusions**

The study has been conducted on Kunah Khad, a tributary of Beas River flowing in Hamirpur, Himachal Pradesh, India. Soil and Water Assessment Tool (SWAT) model combined with ArcGIS interface has been used in order to provide surface runoff for watershed and to determine the land use and land cover changes. Land use maps, soil map and climate data has been used as inputs to the SWAT model and the output provided by SWAT was Surface Runoff on monthly time set-up.

The juxtaposition between observed and calibrated results showed the Nash-Sutcliffe Efficiency (NSE) and Coefficient of determination (R^2) values to be 0.78 and 0.82 respectively and similarly for observed and validated data to be 0.80 and 0.88 respectively for monthly time step. Increase in number of days with high rainfall intensity during the past decade is also a noticeable factor for contribution in the tremendous augmentation of surface runoff in the watershed. On the basis of the results obtained in this study, it can be concluded that the digital image classification is a satisfactory methodology for visual explanation and precision map of a highly changeable area taking less time and efforts as compared to conventional algorithms. The maps obtained from land cover classification was used satisfactorily as an input into SWAT model. The results obtained shows that there is increase in urbanization, agriculture, vegetation and forest area and decrease in water bodies, no cover area in the watershed. Increase in vegetation, urbanization, agriculture in the watershed results in increased infiltration and reduced losses therefore, justifying the increment in the runoff.

Acknowledgements

The authors would like to acknowledge the MoES (India) – NERC (UK) funded collaborative research project titled "Sustaining Himalayan Water Resources in a changing Climate (SusHi-Wat)" and DBT funded research project titled "Social-economic-environmental trade-offs in managing Land-River interface".

References

Abbaspour K. C., Vejdani, M. and Haghighat, S. (2007). SWATCUP calibration and uncertainty programs for SWAT. *In Proc. Intl. Congress on Modelling and Simulation (MODSIM'07)*, 1603-1609. L. Oxley and D. Kulasiri, eds. Melbourne, Australia: Modelling and Simulation Society of Australia and New Zealand.

Adornado, H. A. and Yoshida, M. (2010). GIS-based watershed analysis and surface run-off estimation using curve number (CN) value, *J. Environ. Hydrol*., 18, 1–10, 2010.

Arnold, J. G., Allen, P.M. and D. S. Morgan, D.S. (2001). Hydrologic model for design and constructed wetlands. *Wetlands* 21(2): 167-178

Arnold, J. G., Gassman, P. W. and White, M. J. (2010b). New developments in the SWAT ecohydrology model. *In Proc. 21st Watershed Technology Conf.: Improving Water Quality and Environment.* ASABE Publication No. 701P0210cd. St. Joseph, Mich.: ASABE.

Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. (1998). Large-area hydrologic modeling and assessment: Part I. Model development. *J. American Water Resour. Assoc.* 34(1): 73-89.

Black, P. E. (1996). *Watershed hydrology*. CRC Press.

Coffey, M. E., Workman, S. R., Taraba, J. L. and A. W. Fogle. (2004). Statistical procedures for evaluating daily and monthly hydrologic model predictions. Trans. ASAE 47(1): 59-68.

Costa et al. (2003). Effects of large-scale changes in land cover on the discharge of the Tocantins River, southeastern Amazonia. *J. Hydrol., 283 (2003),* pp. 206-217, 10.1016/S0022-1694(03)00267-1

Gassman, P. W., M. Reyes, C. H. Green, and J. G. Arnold. (2007). The Soil and Water Assessment Tool: Historical development, applications, and future directions. Trans. ASABE 50(4): 1211- 1250.

Kumar, N., Singh, S.K., Srivastava, P.K. and Narsimlu, B. (2017). SWAT Model calibration and uncertainty analysis for streamflow prediction of the Tons River Basin, India, using Sequential Uncertainty Fitting (SUFI-2) algorithm. *Modeling Earth Systems and Environment*, **3**, 1.

Legates, D.R. and McCabe, G.J. (1999). Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation. *Water Resources Research*, 35, 233–241. doi:10.1029/1998WR900018

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Binger, R. D. Harmel, and T. Veith. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE 50(3): 885-900.

Nash, J.E. and Sutcliffe, J.V. (1970). River flow forecasting through conceptual models part I — A discussion of principles. *Journal of Hydrology*, 10 (3), 282–290. doi:10.1016/0022-1694(70)90255-6

Olivera, F., M. Valenzuela, R. Srinivasn, J. Choi, H. Cho, S. Koka, and A. Agrawal. (2006). ArcGIS-SWAT: A geodata model and GIS interface for SWAT. *J. American Water Resources Assoc.* 42(2): 295-309.

Sarkar, A. (2013) Study of Climate Responsive Passive Design Features in Traditional Hill Architecture of Khyah Village in Hamirpur, Himachal Pradesh, India for Indoor Thermal Comfort. *J. Inst. Eng. India Ser*. A 94, 59–72 (2013) doi: 10.1007/s40030-013-0033-z

Setegn, S. G., Srinivasan, R., & Dargahi, B. (2008). Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model. *The Open Hydrology Journal*, 2(1).

Urich, P. B. (2002). Land use in karst terrain: review of impacts of primary activities on temperate karst ecosystems (pp. 60-p). *Wellington: Department of Conservation*.

Wang, Z., Changming, L., Youbo, H. (2003). The theory of SWAT model and its application in Heihe Basin. *Progress in Geography*, 22(1): 79–86.