IMPACTS OF LANDUSE CHANGES ON RUNOFF GENERATION IN SIMLY WATERSHED

*Tanveer Abbas[1], Ghulam Nabi[2], Muhammad Waseem Boota[1]
Fiaz Hussain[1], Muhammad Faisal[1] and Haseeb Ahsan[1]
[1] Centre of Excellence in Water Resources Engineering, University Of Engineering and Technology Lahore
[2] Centre of Excellence in Water Resources Engineering, University Of Engineering and Technology Lahore
*Corresponding Author's email: tanveer.abbas14@yahoo.com, tanveer_abbas14@hotmail.com

ABSTRACT: *Landuse change has significant impacts on hydrologic processes in a watershed. Assessment of the impacts of landuse changes is essential for watershed management and sustainable development. In this study, a soil and water assessment tool (SWAT) model was used to assess the landuse changes impacts on runoff generation in Simly dam watershed located 30 km east of Islamabad, Pakistan with a catchment area of 156 km^2.The simulation was performed for three time periods 1991-92, 2000-01, 2009-10 on a monthly time step. The model was calibrated using the auto-calibration tool SWAT-CUP. Model predicted surface runoff volumes with Nash Sutcliffe Efficiency (NSE) ranges from 0.81 to 0.83. The results of the scenarios revealed that expansion of urban areas from 5% to 10% indicated 1.2% and 0.2% increase in the surface runoff and water yield respectively, expansion of forests areas from 46% to 66% indicated 9.3% and 2.5% decrease in the surface runoff and water yield respectively and deforestation of the catchment from 46% to 36% indicated 6.7% and 2.2% increase in the surface runoff and water yield respectively. The study has presented that the Soil and Water Assessment Tool (SWAT) model can be a suitable tool for evaluating the impacts of landuse changes in Simly watershed.*

Keywords: SWAT, Hydrological modeling, SWAT-CUP, Landuse changes, Landuse Scenarios

INTRODUCTION

A Landuse change within any catchment is important because of its impacts on hydrology and ecology of the area. Landuse changes such as decreased forest area and urbanization implies impacts on the hydrological response of the watershed. Due to development in a catchment, the impervious area and deforestation continuously increases which results in increased velocity and quantity of runoff [1].Many techniques have been developed for accurately estimation of runoff which includes rational method, SCS method, Tabular Method (TR-55) etc. Additionally, the dependable estimations of many hydrological parameters including runoff are time taking by traditional methods. So it's necessary that some appropriate methods and approaches should be used for computing the hydrological response of a watersheds. Use of mathematical models for hydrologic assessment of watersheds using remote sensing and geographical information system (GIS) are the supporting tools and methods for it [2]. Different models approaches are used for rainfall-runoff modelling such as lumped, semi-distributed and distributed models. In lumped models no account taken of variations within the catchment of precipitation, vegetation, soils and topology. In distributed hydrological models the spatial variability of the input variables is taken. Semi-distributed hydrological models are between the lumped and the fully distributed physically-based models. SWAT is a physically based distributed, continuous time [3] hydrologic model. It was developed to predict the impact of catchment practices on water, sediment, water quality and agriculture chemical yields in complex watersheds with changing soils, landuse, and management conditions over a long period of time [4]. The model has been tested in different watersheds and was able to well explain watershed hydrologic processes. To benefit from its good Modelling capability, testing this model for the Simly Dam Watershed is quite necessary. Due to rapid development in watershed, the massive deforestation has cleared vast mountainous terrains in Murree district [5]. This caused high discharges and sediment deposition in the reservoir. Present storage capacity of Simly Dam Lake is 32219 acre-feet. Comparing it with actual storage capacity 33000 acre-feet, 2.36 % storage capacity of Simly Dam is lost within 1994-2005 [6]. For the proper watershed management there is need to assess the landuse changes and their impacts on runoff generation. Therefore, the objective of the study is to assess the landuse changes on the catchment of Simly dam and rainfall-runoff modelling using Soil and Water Assessment Tool.

STUDY AREA

The study area for this research is Simly Dam watershed, 30 kilometers (19 mi) east of Islamabad and Rawalpindi in Rawalpindi District, Punjab, Pakistan. Its coordinates are 33°43'8"N Latitude and 73°20'26"E Longitude The catchment area of Simly dam is 156 km^2. The area is bounded by range of hilly uplands ranging from 693-2261 m from sea level. Annual precipitation of the catchment area is 1776 mm (PMD, Pakistan). Five major tributaries contribute to Simly dam which are Soan, Khad, Mangal, Basant and Bissa. Soan River at Simly has a catchment area of 59 km^2 which rises from within a few kilometers of Murree Hills. Simly dam watershed contains three hill divisions of Murree Hills. Eastern side of Murree, western side of Chrihan give rise to Soan tributary and western side of Puphundi and eastern side of Chrihan give rise to Khad tributary, which join each other at village Chhaka few kilometers above Simly dam [7].

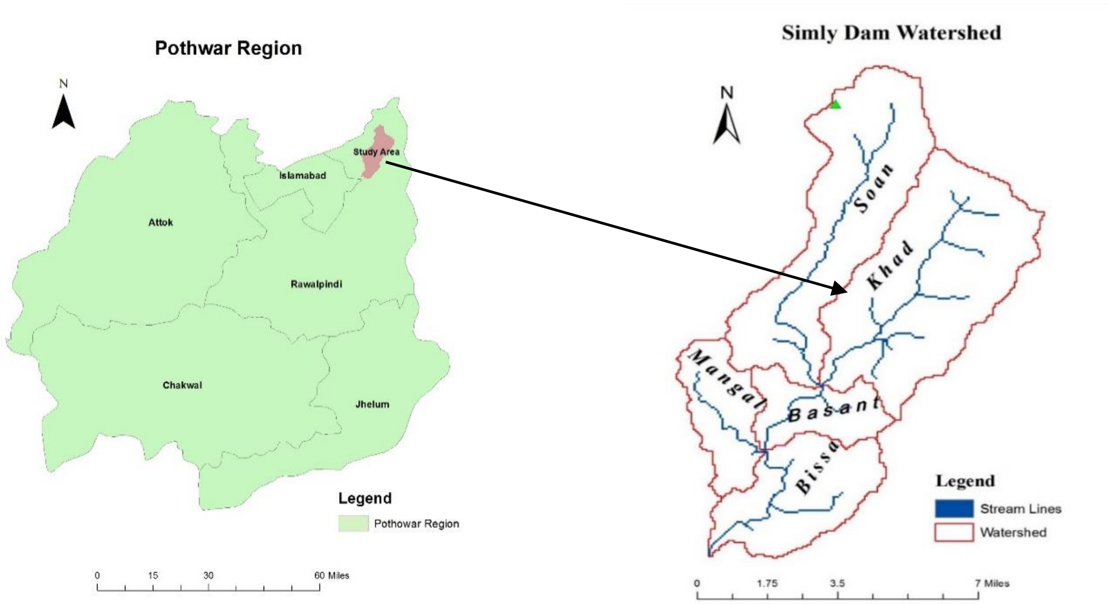

Figure 1 Location of Study Area

MATERIALS AND METHODS

Data Collection

The following set of data is used in SWAT model.

Digital Elevation Model (DEM)

The DEM for the Simly Dam watershed **(Fig.2)** was extracted from Digital Elevation model (DEM) was downloaded from http://srtm.csi.cgiar.org/ with a spatial resolution of 90 m. The Digital Elevation model (DEM) was delineated **(Fig.1)** to acquire sub-basins, stream network and longest flow path. Channel parameters like slope and reach length were extracted from DEM.

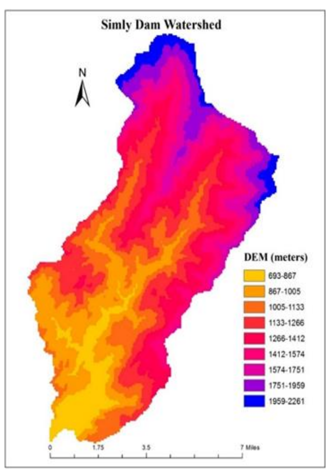

Figure 2 DEM of Study Area

Landuse

The landuse maps were prepared by the processing of Landsat images TM with spatial resolution of 30 m downloaded from http://earthexplorer.usgs.gov/. Supervised classification was achieved in Erdas Imagine Software to identify the major landuse classes in the watershed. Six major classes were identified **(Fig.3)**. The landuse changes were assessed for the Simly dam watershed for different years.

Soil Data

The soil Map was acquired from IPCC Global soil classes developed by the UNO agency Food and Agriculture Organization (FAO). Only one soil class loam type was Identified in the Simly Dam watershed. Additional information about soil texture was obtained from literature and reports [7].

Weather and Flows Data

Simly watershed has only one weather station in the Murree district installed by Pakistan Meteorological Department (PMD). Climatic data i.e. Daily rainfall, minimum and maximum temperature, wind speed, humidity data for the years 1990-2010 was collected from PMD. The Flows data for the years 1990-2012 was collected from Capital Development Authority (CDA) Islamabad.

Description of SWAT Model

The SWAT is a physically based continuous time distributed hydrological model with ArcGIS interface [8]. SWAT has eight main components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The model requires data such as climatic data, soil data, topographic maps, agriculture and land managing practices to simulate physical processes related to water flow, sediment transport, crop growth, nutrient cycling etc.[9] SWAT model is applicable for modeling the ungauged catchments, prediction of land management and climate changes impacts on runoff, sediment and water quality [9]. The hydrological cycle simulated by SWAT is based on following equation:

$$SW_t = SW_0 + \sum_{i=1}^{n}\left(R_d - Q_{surf} - E_a - W_{sep} - Q_{gw}\right) \quad (1)$$

Where, SW_t is the final water content (mm), SW_0 is the initial water content (mm), t is the time (days), R_d is the rainfall on some specific i day (mm), Q_{surf} is the runoff on day i (mm),

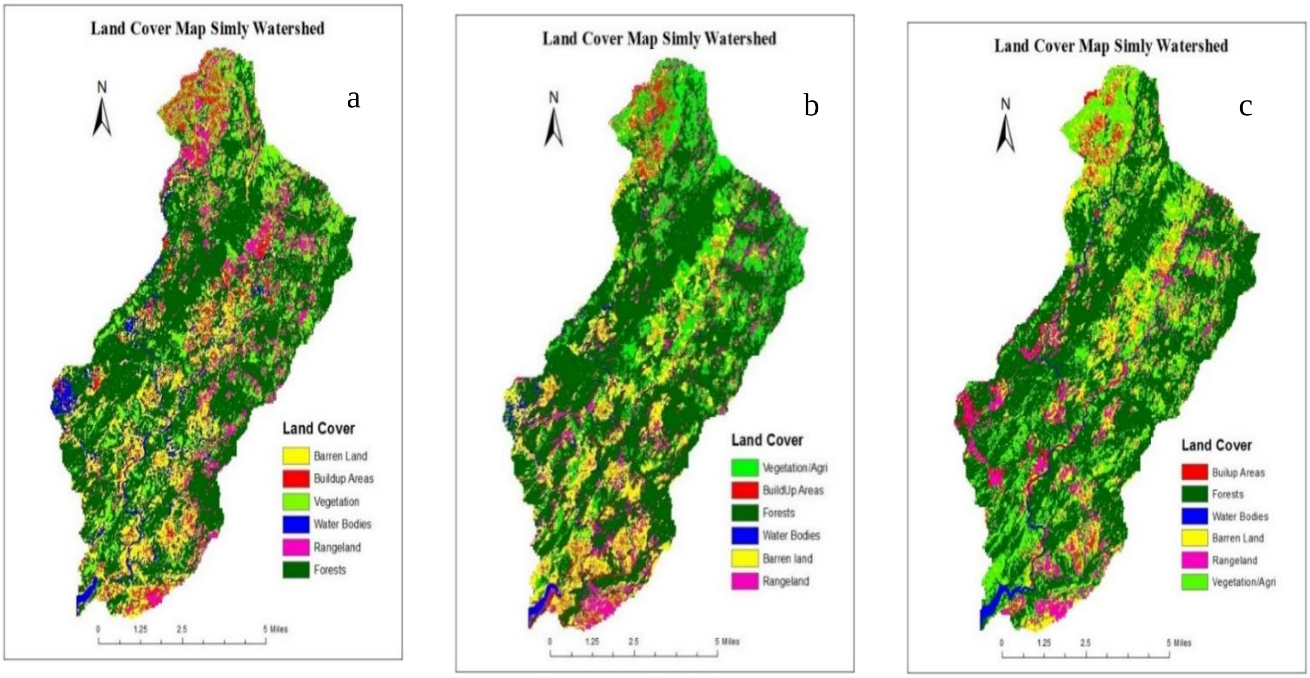

Figure 3 Landuse Maps of Study Area (a) 2010 (b) 2000 (c) 1992

E_a is the amount of evapotranspiration on a day i (mm), W_{sep} is the amount of percolation in the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

MODEL SETUP

Hydrological modeling of Simly Dam watershed was carried out using the ArcSWAT2012. SWAT delineates the basin into sub-basins on the basis of digital elevation model (DEM). Digital Elevation model (DEM) was imported into the model and with help of polygon the study area was extracted. Digital Elevation model (DEM) of the study area was delineated to extract sub-basins, stream network, reaches and longest flow paths. The study area was divided into 5 sub-basins **(Fig.1).** Landuse, Soil map and slope were classified by the Arc SWAT. A user look up table was formed for the for the landuse and soil map to identify the SWAT code. In this study 85 HRUs were created after the combination of landuse, soil data and slope layers based on dominant landuse, soil, and slope using 2%, 4% and 6% as threshold values for landuse, soil and slope respectively. About 26 parameters can be used for model calibration. Manual calibration and sensitivity analysis option is available in model but automatic model calibration and sensitivity analysis option is also available. In this study auto-calibration and sensitivity analysis tool SWAT-CUP was used. SWAT-CUP uses 5 different algorithms for the calibration and sensitivity analysis, i.e. The Sequential Uncertainty Fitting ver. 2 (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (PARASOL). SUFI-2 was used in this study. The degree of uncertainty is accessed by P-factor which is percentage of data covered by 95PPU which is calculated at 2.5% and 97.5% of the output Variable. Another is the r-factor which is relative width of 95% probability band. The goodness of calibration and prediction uncertainty is decided on the basis of the nearness of the p-factor to 100% and the r-factor to 1. Other factors to assess the goodness of fit are the coefficient of determination (R^2) and Nash Sutcliff efficiency (NSE) between the observed and simulated values. R^2 and NSE are determined by the following equations.

$$R^2 = \frac{[\sum(Q_{m,i} - \bar{Q}_m)(Q_{s,j} - \bar{Q}_s)]^2}{\sum(Q_{m,j} - \bar{Q}_m)^2 \sum(Q_{s,i} - \bar{Q}_s)^2} \qquad (2)$$

$$NSE = 1 - \frac{\sum_i (Q_m - Q_s)^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \qquad (3)$$

Where Q_m, Q_s, $\bar{Q}_m$ $\bar{Q}_s$ are the measured, simulated, average measured discharge and average simulated Discharge respectively. After the model was set up, the simulation for the years 1991-1992, 2000-2001 and 2009-2010 to analyze the impacts of landuse on runoff. Model was initially calibrated manually for the years 1991-1992, 2000-2001 and 2009-2010 and then the model output was exported to SWAT-CUP for automatic calibration and sensitivity analysis. Similarly model was validated for 2011-2012 using calibrated parameters of 2009-2010. About 100 iterations were performed to calibrate the model and to identify the sensitive parameters. Nineteen parameters were calibrated for the Simly dam watershed whose values are given in (**Table.1**).

LANDUSE SCENARIOS DEVELOPMENT

In order to develop management practices for protecting the Catchment and to assess the impacts of landuse changes

Table 1 *Calibrated Parameter Values of the SWAT Model on the Simly Watershed in Different Periods*

Parameter	**Physical meaning**	1991-1992	2000-2001	2009-2010
CN2	Moisture condition II curve number	-6.25	-7.25	-7.19
ALPHA_BF	Base-flow recession constant	0.043	0.075	0.044
GW_DELAY	Delay time for aquifer recharge (day)	8.509	7.512	9.375
GWQMN	Threshold water level in shallow aquifer for base flow	312	362	365
ESCO	Soil evaporation compensation coefficient	0.625	0.925	0.919
EPCO	Plant uptake compensation factor	0.188	0.125	0.181
CANMX	Maximum canopy storage (mm)	12.5	7.5	10.63
SOL_AWC	Available water capacity (m/m)	0.375	0.325	0.431
SURLAG	Surface runoff lag coefficient (day)	5.421	6.20	5.850
SHALLST	Initial depth of water in the shallow aquifer (mm)	625	675	618.8
GW_SPYLD	Specific yield of shallow aquifer (m3/m3)	0.250	0.310	0.328
GWHT	Initial ground water height (m)	11.88	10.63	8.844
SLSUBBSN	Average slope length (m)	Changes for HRU	Changes for HRU	Changes for HRU
CH_N2	Manning 's n value for main channel	0.230	0.122	0.167
RCHRG_DP	Deep aquifer percolation factor	0.375	0.575	0.494
REVAPMN	Threshold water level in shallow aquifer for "revap"	265.3	262.5	262.5
GW_REVAP	Ground water evaporation coefficient	0.019	0.097	0.097
CH_K2	Effective channel hydraulic conductivity, mm/hr	61.63	64.38	64.38
OV_N	Manning 's n value for overland flow	0.03	0.04	0.04

Specifically on runoff generation and water yield three scenarios were developed. Landuse maps were developed for different scenarios and model simulation. Three landuse scenarios, Scenario A: expansion of urban areas from 5% to 21, Scenario B: expansion of forests areas from 46% to 61%, Scenario C: deforestation of the catchment from 46% to 34% were developed keeping the rainfall pattern same for all the scenarios of base year (2010) to assess the landuse Impacts on runoff generation in Simly Dam watershed.

RESULT AND DISCUSSION

Landuse Changes Assessment

Complete information on the distribution of landuse is vital for estimating hydrological changes in a watershed. The landuse changes for the watershed were estimated for three different periods i.e. 1992, 2000 and 2010 (**Fig.3)**. Major Landuse changes was observed in the forest and vegetation/agriculture class which indicated a reduction of about 14.6 km^2 (9.35%) and 5.8 km^2 (3.73%) respectively during the period 1992-2010 (**Table. 2**). Wood is the only source of energy due to Non-availability of other energy sources [11]. Major part of the forest has been transformed into barren land and built-up land, while some of it has

Table 2 Landuse Changes for the period 1992-2010

	1992		2000		2010		1992-2010	Change
Land-use	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Change (km^2)**	**%**
Forests	85.9	55	78.7	50	71.3	46	-14.6	-9.35
Vegetation	30.9	20	26.2	17	25.1	16	-5.8	-3.73
Buildup Areas	3.6	2	6.3	4	7.8	5	4.2	2.67
Water Bodies	3.9	3	4.2	3	4.7	3	0.8	0.51
Rangeland	13.2	8	14.5	9	17.0	12	3.8	2.46
Barren Land	18.5	12	26.1	17	27.3	18	8.8	5.67
Total	156.0	100	156.0	100	156.0	100	-	-

transformed into rangeland due to deforestation. [11] Also reported that there has been decrease in the forest area during the last 30 years especially 1997-2006 in Rawalpindi-Islamabad areas. Whereas according to [10] deforestation is increasing at the rate of about 1.5 % annually due to development. Build up areas also increased 3.6 km^2 (2%) in 1992 to 7.8 km2 (5%) in year 2010. The vegetation class indicated decrease in coverage during 1992-2010 period i.e. 30.9 km2 (20%) in 1991 and 25.1 km2 (16%) in 2010. This situation indicates intense deforestation and rapid urban development in the catchment area of Simly Dam.

Hydrological modelling

Rainfall-runoff simulation was performed for the different periods i.e. 1991-1992, 2000-2010 and 2009-2010 and compared with the measured runoff at outlet and their validation period was 2011 –2012. Model was calibrated for 19 different parameters (**Table. 1**). Model was calibrated and validated using observed runoff data. The calibration periods were 1991 –1992, 2000 –2001 and 2009-2010. Analysis by SUFI-2 method and previous studies by [12, 13] nine sensitive parameters for the runoff simulation were determined. (**Table.1**), including two evapotranspiration parameters (EPCO, ESCO), four surface-flow parameters (CN2, SOL_AWC and OV_N, SULAG), and three ground water parameters (GW_REVAP, GW_ALPHA and GWQMN). The criteria used for the assessment of the model performance is given in (**Table.3).** Three time spans were selected for the rainfall-runoff modelling and three years 1992, 2000 and 2010 with annual rainfall of 1711mm, 1498 mm and 1681mm were selected to assess the land-use impacts on runoff generation. For this purpose surface discharge and water yield was computed for the selected years and was compared for the increase or decrease in the runoff generation over the entire catchment. The annual hydrological parameter summery is shown in the (**Table.4**). Tabular results indicate increase in surface discharge and water yield over the entire catchment. On an average there is 10-12% increment in surface runoff and water yield. Higher stream flow as a result of decreased forest areas and vegetation was observed.

Table.3 *Criteria for examining the accuracy of calibration and validation period*

	1991-92	2000-01	2009-10
Index		Calibration Period	
R2	0.83	0.81	0.80
NSE	0.77	0.78	0.76
r-factor	1.2	1.6	1.3
p-factor	0.76	0.71	0.71
		2011-12	
Index		Validation Period	
R2		0.75	
NSE		0.67	
r-factor		1.2	
p-factor		0.80	

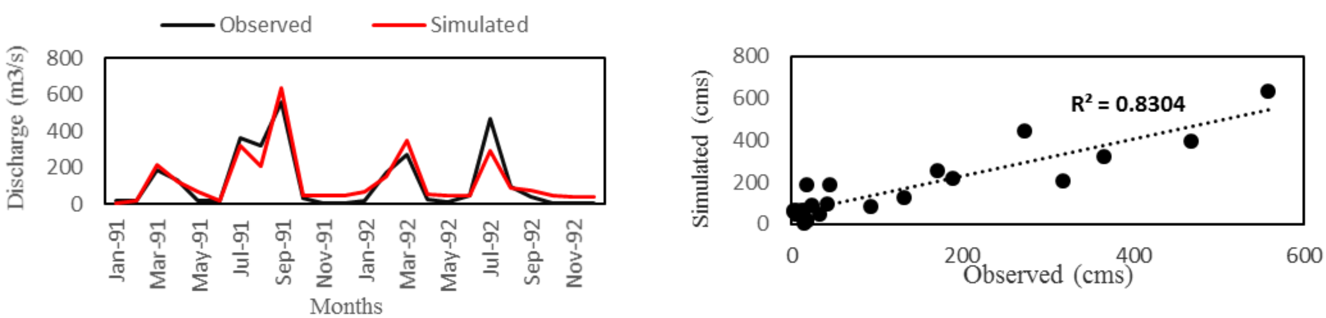

Figure 4 *Calibration Period (1991-1992)*

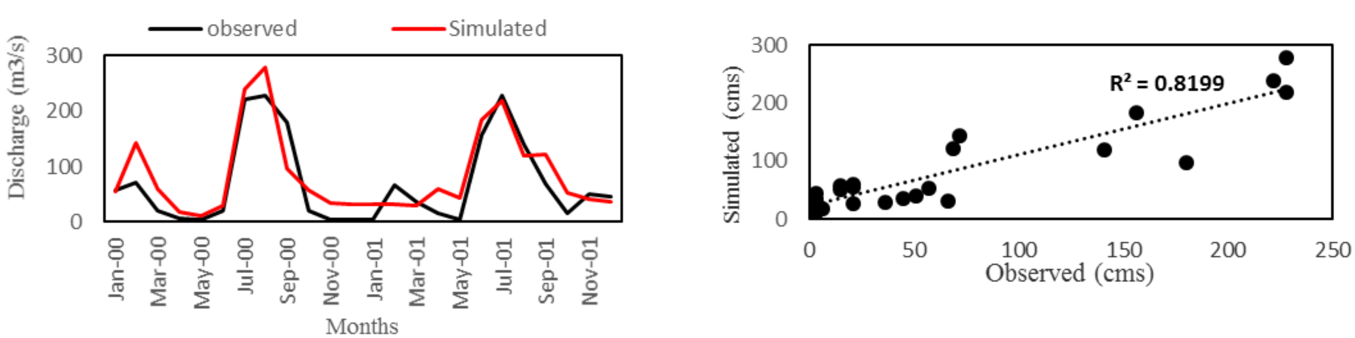

Figure 5 *Calibration Period (2000-2001)*

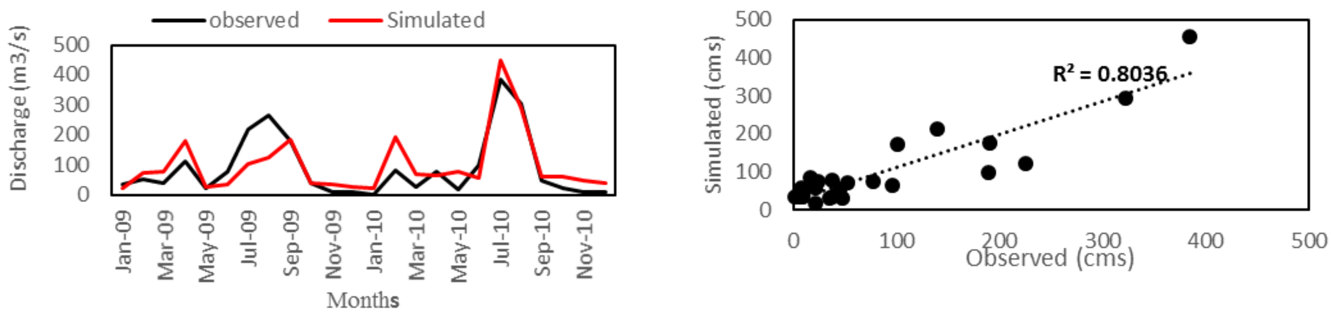

Figure 6 *Calibration Period (2009-2010)*

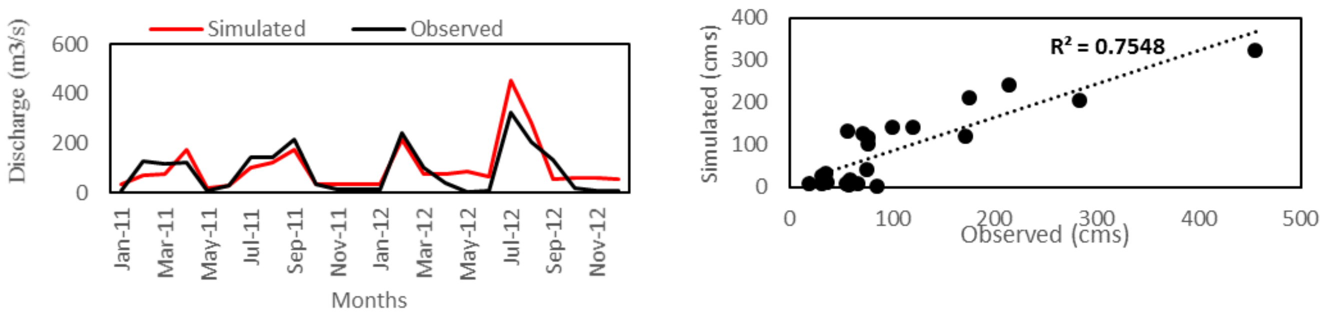

Figure 7 *Validation Period (2011-2012)*

Table 4 *Annual hydrological parameter summaries for the watershed*

Year	Precipitation (mm)	SURQ (cms)	WYL (cms)
1992	1711.5	1296.5	1352.3
2000	1498.4	1051.6	1183.4
2010	1681.4	1428.4	1466.2

Notes: SURQ: Amount of surface runoff contribution from stream flow from HRU during simulation, WYLD; Water yield (mm).

EFFECTS OF LANDUSE CHANGE ON THE RUNOFF GENERATION

Landuse Change Scenarios

The response of various hydrological parameters was studied using probable changes in different landuse in the watershed in future. Landuse changes within 1992-2010 period formed the basis for developing these scenarios. The scenarios 2 and 3 are related to different cases of afforestation and deforestation respectively while scenario 1 pertains to increased urbanization. Landuse maps were developed (on the basis of previous land use changes) for different scenarios and model simulation. Using the already determined parameters the model was calibrated. Results of the different landuse scenarios are described as under;

Scenario A: Expansion of Urban Areas

In scenario-A, all the agriculture land is assumed to be converted into built-up land (built-up land increases from 5% to 10%) keeping other land-use conditions same as of the base year 2010. The scenario indicates an increase of about 1.2% in the surface runoff and 0.2% increase in the water yield respectively from that of the base year 2010.

Scenario B: Expansion of the Forests Areas

In scenario-2, all the barren is converted into forests (forests area increased from 46% to 66%) keeping other landuse Conditions same as the base year 2010.The scenario results Indicate that there is decrease in 9.3% decrease in the surface runoff and 2.5% decrease in the water yield respectively.

Scenario C: Deforestation of the Catchment

In scenario-3, forest area is decreased (forests area decreases from 46% to 36%) and agriculture/vegetation was increased (agriculture/vegetation increases from 16 to 21%) from the base year 2010. The scenario results indicated 6.7% increase in the surface runoff and 2.2% increase in the water yield respectively from the base year 2010.

CONCLUSION

This paper investigated the effects of land-use change on the runoff generation characteristics in the Simly dam Watershed. The changes in landuse over the period 1992–2010, have been substantial and have contributed to increase in runoff. The forest area has decreased from 55 to 46%, whereas the vegetation/agricultural area have decreased from about 20 to 16%. The model simulated runoff increased by 10-12% during the period 1992-2010. The SWAT model can be used to assess the impacts of landuse changes on runoff generation characteristics in Simly dam watershed with satisfactory accuracy. Three different landuse scenarios were applied to the study area to assess the impacts the landuse changes on runoff. Two scenarios gave increase in the runoff while third one gave decrease in the runoff. By expanding the urban areas indicated 1.2% and 0.2% increase in the surface runoff and water yield respectively, expansion of forests areas indicated 9.3% and 2.5% decrease in the surface runoff and water yield respectively, deforestation of the catchment indicated 6.7% and 2.2% increase in the surface runoff and water yield respectively. Scenario results indicated that forests class is most sensitive for the Simly Dam watershed. The outputs could provide important situations for water preservation and river health protection in Simly dam watershed.

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