Landuse Change Effect on Water Discharge in Panjshir Watershed/Afghanistan

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Abstract: This study employ GIS and Arc SWAT (Soil and Water Assessment Tool) model to estimate daily water discharge and assess the landuse change impacts on runoff generation in Panjshir watershed. Two processing were performed in this research. Processing 1 (Landuse 1993) performed first. Subsequently the model calibrated and validated using SWAT-CUP. Then processing 2 (Landuse 2010) processed same by Arc SWAT and calibrated. The results of both processing were compared to analyses the difference for discharge. Average annual surface flow decreased from by 10.24% to 7.2%, whereas the average annual ground water flow increased by 70.07% to 73.48% in Processing 2. The average annual total water yield decreased from 253.37mm to 227.76mm.

Keywords: Landuse/Landcover Change, SWAT, GIS, Surface Runoff, Panjshir Watershed

1. Introduction

Surface runoff is usually affected by many natural factors such as soil types and texture, geomorphologic condition, temperature, precipitation as well as humans activities such as presence of reservoirs, dams and other irrigation canal, landuse/ landcover (LULC) changes etc. Due to development in a catchment, the impervious area and deforestation continuously increases which results in increased velocity and quantity of runoff. Also increasing in scarcity of water resources, hydrological impacts of LULC change has drawn attention among hydrological researchers, decision and policy makers throughout the world. These problems can be addressed by using a Geographic Information System (GIS) that is efficient for spatial and temporal data analysis and SWAT model. In the previous paper (Ayoubi[1] and Dongshik[2], 2016) the monthly surface runoff investigated by SWAT and GIS in Panjshir watershed which the model showed good performance. Now the LULC change with respect to population growth is needed to sustainably manage the water scarcity and water resources at watershed level. Therefore, the purpose of the study is to assess the LULC changes on Shukhi station in Panjshir watershed and daily runoff modelling using Soil and Water Assessment Tool (SWAT).

2. Study Area

Panjshir River originates from a mountainous range of Hindu Kush which reaches over 6000*m* above mean sea level (A.M.S.L) in north part of the Kabul River Basin. The watershed covers an area of 12,752.942 km^2. Topography of the study area is alpine with the highest elevation 5669m and lowest 1053m (A.M.S.L) DEM based. The mountains are rocky with sharp peaks, and steep slopes. Some of the peaks have permanent snowcaps and glaciers. The main LULC classes includes irrigated and rainfed agriculture lands, fruit trees, vineyards, barren lands, sand cover, forest & shrubs, rangeland, snow & water and urbanization. In this study the watershed divided to sub-basin and Hydrological Response Units (HRUs), Figure 1.

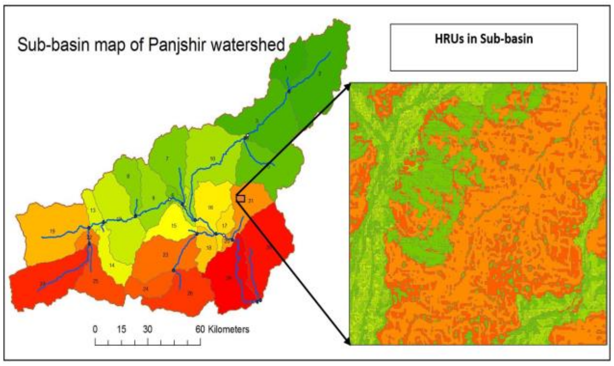

Figure 1. 29 Sub-basin and 492 HRUs of Panjshir watershed.

3. Methodology

For this study first all required input data arranged as Digital Elevation Model (DEM), landuse maps, soil type map, climate data and stations location using ArcGIS version 10.2.2. Afterward SWAT model 2012 was applied to simulate daily water discharge. Subsequently the model calibrated and validated using SWAT-CUP software. After achieving a satisfactory result landuse 1993 was replaced by landuse 2010 to evaluate and assess the impact of land use change on discharge hydrograph and total water flow. Figure 2 shows the method for this research.

3.1 Brief Description of SWAT Model

SWAT is abbreviation for Soil and Water Assessment Tool. A comprehensive, semi-distributed, continuous long period, hydrologic quality and quantity river basin model developed by USDA Agricultural Research Service (USDA-ARS) Arnold et al. (1998). This model operates on a daily time step and is designed to predict the impact of land use and land management on water resources, sediment, and agricultural chemical yields in ungauged watersheds. In SWAT the basin can be divided in to many sub-basins and each sub-basin sub divides into HRUs (Hydrologic Response Units) by using the soil types, land use and slope classes that have homogeneous hydrologic properties. The model needs calibration and validation for evaluation of its efficiency.

4. Data Processing

Collecting and processing of the required data for SWAT is the first main important part and sometimes can be tedious and time consuming. For this study data Collected from national and global sources that includes DEM, Soil, Landuse, and Hydro-meteorological data.

DEM with 30m resolution gained from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) GDEM and classified into five classes of the elevation. Soil map was collected from soil map of the world and is based on Food and Agriculture Organization (FAO-UNESCO). Soil map classified into four classes: Lithosols (1), Lithisols (2), Calcaric Flurisols, and Gleysols. The soil texture is mainly Loam and UWD (Unweathered bedrock). Land use data in 1993 and 2010 were collected from MAIL/AFG (Ministry of Agriculture and Life Stock in Afghanistan). Both land uses reclassified into eight classes (Figures 3 and 4). Hydro-meteorological data inside the study area collected from the Ministry of Energy and Water in Afghanistan (MEW/AF). Nine local meteorological stations utilized by the model. Beside that thirteen global stations also collected from Climate Forecast System Reanalysis (CFSR) and used in this study.

5. Results and Discussion

Because SWAT model has hundreds of parameters where a suitable range for each parameter is defined, it is difficult for researchers and water managers to find out the fitted parameters which base to spatial characteristics and suit for study area. So the fitting of parameters implemented by automatic calibration Sufi-2 Algorithm in SWAT-CUP.

5.1. Calibration and Validation of Model

SWAT-CUP was set up to calibrate the model with four iterations. Each iteration was 500 simulation. Totally 2000 simulations done. Based on sensitivity analysis which has done on 27 parameters that affects discharge hydrographs and total amount of runoff, 11 Parameters was more effective fitting the hydrograph and estimation of water quantity in Shukhi station.

Table 1.Sensitive parameters and Calibrated Values.

Parameters	Min value	Max value	Fitted Value
R SMFMN.bsn	-3.806	0.479	0.475
R__SMFMX.bsn	-2.563	1.068	-0.635
R SMTMP.bsn	-0.830	5.991	2.260
R SFTMP.bsn	0.517	1.100	0.801
R SOL_AWC.sol	3.908	12.326	4.321
R SLSUBBSN.hru	-1.751	-0.573	-0.753
R HRU_SLP.hru	-0.149	0.227	-0.058
R__CN2.mgt	0.500	0.700	0.529
A__GWQMN.gw	0.000	25.000	21.925
V GW_REVAP.gw	0.000	0.100	0.020
V__REVAPMN.gw	0.000	20.000	11.900

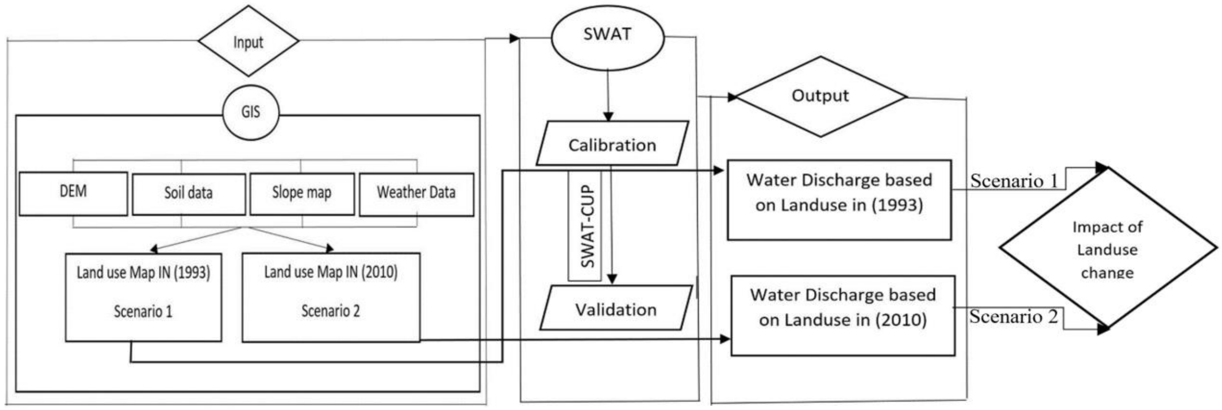

Figure 2. Methodology of the research.

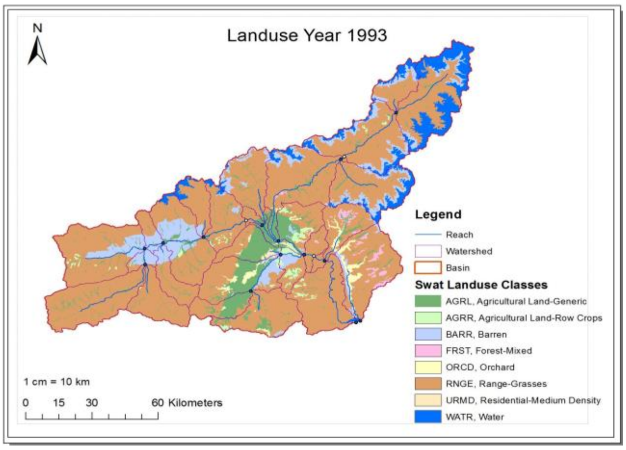

Figure 3. Land use map 1993

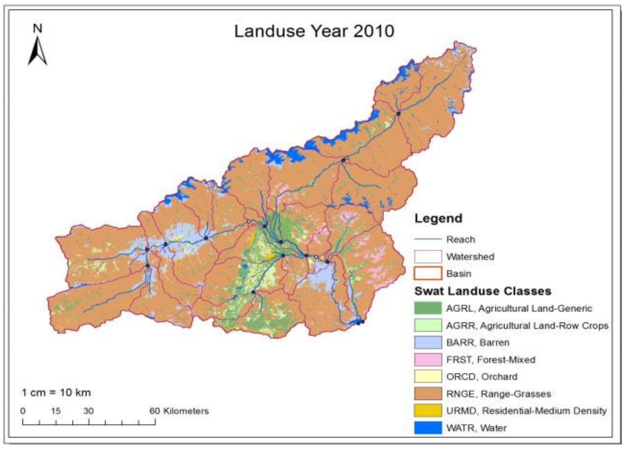

Figure 4. Land use map 2010

For each parameter the fixed values obtained during calibration Table 1. Then the land use in 1993 was replaced by land use 2010 without farther changes of other inputs for processing 2. Shukhi outlet station selected to calibrate with eleven optimized parameters which was calibrated in processing 1. By this method, we could assess the suitability of fixed parameters for both two processing. The statistics results of coefficient of determination R^2 for daily discharge estimation reached at 0.815 for processing 1 and 0.817 for Processing 2 respectively, which showed very good correlation between observed and estimated discharge. Figure 5 represents the daily discharge hydrograph in Shukhi outlet station for both processing. The base flow for all years during dry periods under estimated. Totally the hydrograph for both tow processing showed less deference in calibration period which is insignificant. Afterward validation performed by the criterion of coefficient of determination (R^2), using the equation:

$$R^2 = \frac{\sum_i \left[(Q_{m,i} - \overline{Q}_m)(Q_{s,i} - \overline{Q}_s) \right]^2}{\sum_i (Q_{m,i} - \overline{Q}_m)^2 \sum_i (Q_{s,i} - \overline{Q}_s)^2}$$

Where, R^2 is the coefficient of determination, Q is discharge, m and s stand for measured and simulated discharge respectively, and the bar stands for average, i is the i^{th} measured or simulated data. Figure 5 shows the Graphical and Figure 6 shows the statistical correlation results for validation periods.

5.2 Land use change Relationship

Overall the amounts of change detection and percentage growth at LULC is shown in Table 2. Based on percentage growth analysis, the percentage growth of Urbanization is higher 82.2% from all other LULC classes which increased due to population growth but in contrary the snow melting & water bodies and barren land decreased by 75.2% and 73.7% respectively. Although the hydrographs doesn't show the difference clear, so we also considered LULC change on the total -

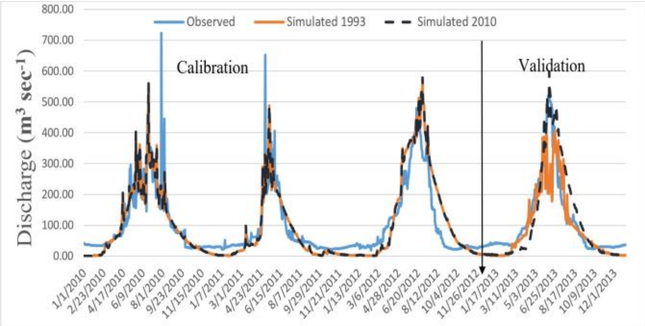

Figure 5. Diffidence of estimated discharges for both landuse.

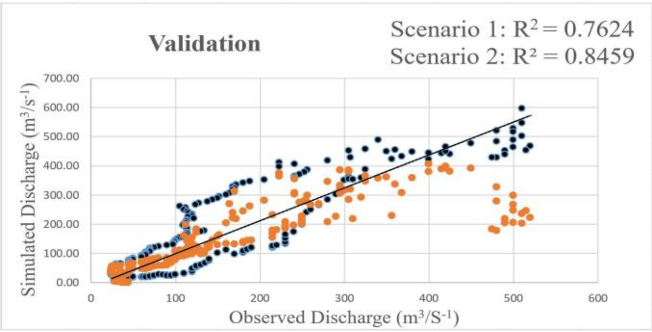

Figure 6. The degree correlation of simulated & observed values in verification period for two processing

Water yield to the outlet of Shukhi sub-basin Table 3. From Table 3 it can be seen that the average annual Total Water Flow of LULC 1993 is more than the LULC 2010. The amount of average annual Total Water Yield in 1993 is 253.37mm and in 2010 is 227.76mm, which shows 25.61mm decreasing of total water flow. Hence, the Surface Flow in 2010 have 3.04% decrease, which the Ground Water Flow have been increased by 3.41% However, the Lateral Flow didn't change so much.

Table 2. Overall amount of change (%) in LULC.

LULC type	*LU 1993 Area (Km2)*	*Percentage (%)*	*LU 2010 Area (Km2)*	*Percentage (%)*	*Amount of change (Km²)*	*Percentage growth compare to LU 1993*
Irrigated Agriculture	1088.93	8.54	1069.36	8.39	-19.57	-1.79
Rainfed Agriculture	186.67	1.46	152.42	1.2	-34.25	-21.67
Orchard/Garden	165.69	1.3	326.39	2.56	160.7	49.22
Barren/ sand cover	1331.64	10.44	766.2	6.01	-565.44	-73.71
Forest & shrubs	103.84	0.81	192.05	1.51	88.21	46.36
Rangeland	8998.72	70.56	9635.05	75.55	636.33	6.60
Water/Snow	855.48	6.71	489	3.83	-366.48	-75.20
Urban	21.98	0.17	122.48	0.96	100.5	82.29
Total	*12752.94*	*100*	*12752.94*	*100*	*0*	

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Table 3. Average annual water balance ratio of both processing.

	LULC 1993		*LULC 2010*		
	Value (mm)	*Percentage (%)*	*Value (mm)*	*Percentage (%)*	*Deference (mm)*
Surface flow	25.95	10.24	16.41	7.20	9.54
Lateral flow	49.88	19.69	43.99	19.31	5.89
Ground Water flow	177.54	70.07	167.36	73.48	10.18
Total Water Yield	253.37	100.00	227.76	100.00	25.61

6. Conclusion

This paper investigated the effects of Landuse change on water discharge in Shukhi outlet station, Panjshir watershed. The result showed that simulated average annual surface flow decreased by 10.24% to 7.2%, while the average annual ground water flow increased by 70.07% to 73.48% during the study period. It is also indicated that the average annual total water yield decreased from 253.37mm to 227.76mm in Panjshir watershed. Urbanization, increasing of barren lands, deforestation and snow melting is the strongest contributor for surface runoff which can be considered as a major environmental stress controlling the hydrological parameters such as runoff, water yield, Sediment yield, ET, PET for Panjshir watershed. To conclude the SWAT model can be used to calculate the impacts of landuse changes on runoff generation characteristics in Panjshir watershed with satisfactory accuracy.

Acknowledgement

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