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Assessing Impacts of Landuse/Landcover Change on Surface Runoff for Panjshir Watershed: A Watershed Modelling Approach

Tooryalay Ayoubi, Dongshik Kang

Abstract— **Panjshir watershed plays an important role in surface runoff potential and ground water flow in the Kabul River Basin (KRB) in Afghanistan. Therefore, it is very necessary to know the impact of natural resources on water discharge and water balance in this important watershed. Also for sustainable water resource management, the evaluation of landuse and landcover (LULC) change on the hydrology of a watershed is essential. This will helps and easy to understand how each LULC class influences the hydrological components of the river basin. In this study the objective is first want to apply the GIS and SWAT (Soil and Water Assessment Tool) model to estimate daily water discharge and then assess the landuse change impacts on runoff generation in Shukhi station (Outlet 17) located within the watershed. The daily observed stream flow data was available from 2010-2013 in this station. Therefore, the daily simulation has carried out for the mentioned period. The daily model calibration and validation performed by SWAT-CUP software, which calibrated from 2010-2012 and validated in 2013 for discharge. Two scenarios were performed in this research. The scenario 1 (Landuse/cover 1993) performed first. Subsequently using SWAT-CUP software for calibration, NSI reached (0.76) and coefficient of determination R^2 achieved (0.81) from 2010 to 2012 in calibration and NSI gained good level at (0.74) and R^2 got (0.76) in validation step at Shukhi Station. Then land cover in 2010 processed same like the land cover in 1993 for the scenario 2 (Landuse/cover 2010), then set up SWAT model again. After that the second scenario also calibrated and validated. Both scenarios were compared to analyses the difference water flow. During landuse comparison the urban, garden, forest increased whereas snow & water, barren land and rainfed agriculture decreases but there is small changes in rangeland and irrigated agriculture which is not significant. Hence as result, 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 Scenario 2. The average annual total water yield decreased from 253.37mm to 227.76mm. In this study unfortunately because of lacking of time series observed sediment data, the calibration not performed for sediment yield estimation. But the effects of LULC change assessed between two scenarios (LULC 1993 and LULC 2010).**

Index Terms— **Panjshir Watershed, Landuse/Landcover Change, SWAT Model, Geographic information system.**

I. INTRODUCTION

Water is finite and vulnerable resource. Water is needed for different purposes, functions and services, therefore, water demand for and treat to this resource. Surface runoff is usually management should be integrated and take account of both affected by many natural factors, such as soil types and texture, geomorphologic condition, temperature, precipitation and also anthropogenic activities such as presence of reservoirs, dams and other irrigation canal, LULC change etc. The population growth increases demands for water in daily lives, decreases forests and change the agricultural fields to urbanization. Also due to development in a catchment, the impervious area and deforestation continuously increases which results in increasing velocity and quantity of runoff. The increasing 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 together with Remote Sensing (RS) data that can provide widely, regularly updated, and reliable data (Petchprayoon et al., 2010) [1]. Based on our previous research (Ayoubi[1] and Dongshik[2], 2016) [2] the monthly surface runoff investigated by SWAT model and GIS in three gage stations namely (Omerz, Pul-Ashawa and Shukhi) in Panjshir watershed which the model showed good performance. Hence, in this study the LULC change with respect to population growth is needed to sustainably manage the water scarcity and water resources at watershed level. Therefore, the objective of the study is to do daily runoff modelling and evaluate the landuse change effects on surface runoff in Panjshir watershed using Soil and Water Assessment Tool (SWAT) and GIS.

Tooryalay Ayoubi, Graduate School of Engineering and Science, University of the Ryukyus, Okinawa, Japan, 050-3550-0007.

Dongshik Kang, Information Engineering, University of the Ryukyus, Okinawa, Japan, 090-1949-9546.

II. 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 km2. 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 snow caps and glaciers. The central region of the study area is relatively flat, and dissected by the Panjshir river, its tributaries, and irrigation canals (US Army Corps of Engineers, 2009) [3]. The main LULC classes includes irrigated and rainfed agriculture lands, fruit trees, vineyards, barren lands, sand cover, forest & shrubs, rangeland, snow & water and urbanization. For study of hydrological parameters, the watershed divided into 29 sub-basin and 492 Hydrological Response Units (HRUs) (Fig. 1).

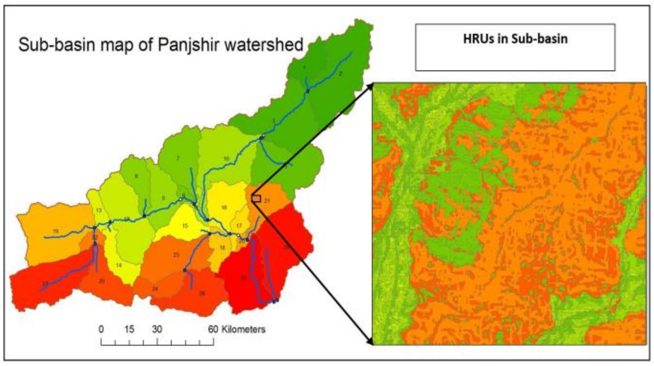


Fig. 1: Study Area, 29 Sub-basin and 492 HRUs.

III. Methodology

For this study firstly we arranged all required input data as topography (DEM), land use map, soil type map, climate condition and stations location with supporting ArcGIS 10.2.2 version. Afterward SWAT model version 2012 was applied to simulate daily water discharge. Subsequently the model calibrated and validated using SWAT-CUP software.

After achieving a satisfactory result land use 1993 was replaced by land use 2010 to evaluate and assess the impact of land use change on discharge hydrograph and total water flow. Also determine the SWAT model suitable to simulating water discharge in Shukhi station (Fig. 2).

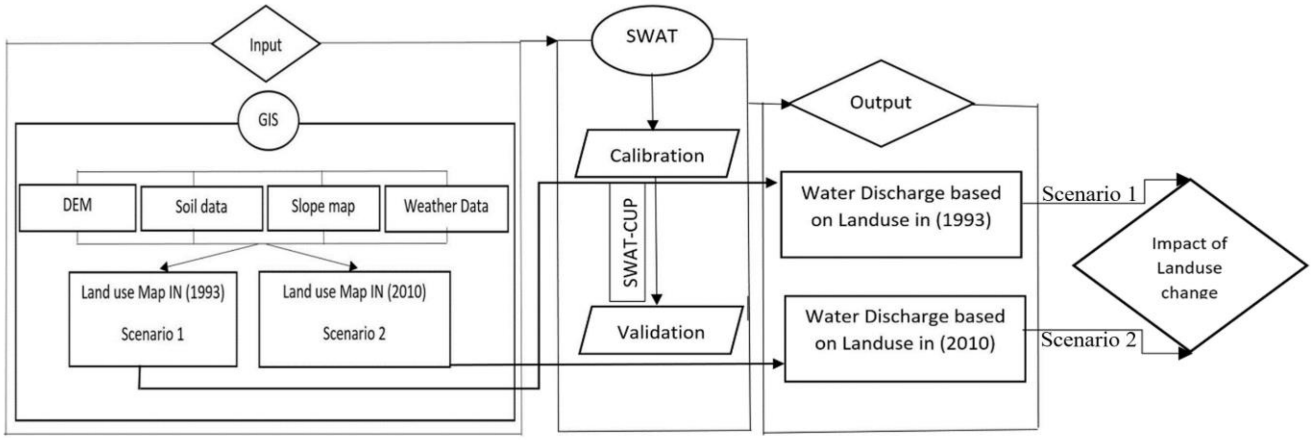


Fig. 2: Methodology of the research

A. *Brief Description of SWAT Model*

SWAT is 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) [4]. SWAT is a physically based model that requires a large number of input parameters, which complicates model parameterization and calibration (Arnold et al., 1998) [4]. The first version of SWAT was developed in 1990s and released as version 94.2. 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 addition the basin can be divided in to many sub-basins and each sub-basin separated into HRUs (Hydrologic Response Units) by using the soil types, landuse And slope classes that have homogeneous hydrologic response.The model needs calibration and validation for evaluation of its efficiency.

A. *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 the data collected from national and global sources which includes Digital Elevation Model (DEM), Soil map, landuse, Meteoroidal and Hydrological 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. Slope map divided into five classes as (0-10%, 10-20%, 20-30%, 30-50% and more than 50 %), that most parts of the watershed has more than 50 percent slope. 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 Table 1. Land use map data for the Panjshir watershed in 1993 and 2010 were collected from MAIL/AFG (Ministry of Agriculture and Life Stock in Afghanistan). Same to the soil classes the land use also reclassified into eight classes (Fig. 3). 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. Table 2 shows the data details and sources. Hydrological data for Shukhi station was available from 2010- 2013 and used to calibrate and validate the model. The period of the calibration was 3 years (2010 to 2012) and validation was for one year (2013).

Table 1: Soil Classes in Study Watershed

Soil NAME	*Area (%)*	*Texture*	*Clay*	*Silt*	*Sand*	*Soil Hydrologic group (SHD)*
LITHOSOLS(1)	*36.32*	*Loam*	*26*	*30*	*44*	*C*
LITHOSOLS(2)	*47.477*	*Loam*	*22*	*33*	*45*	*D*
CALCARIC FLURISOLS	*14.03*	*Loam*	*18*	*35*	*47*	*D*
GLEYSOLS	*2.173*	*UDW*	*5*	*25*	*70*	*D*

IV. RESULTS AND DISCUSSION

A. Model Calibration in Shukhi Station

First the discharge estimated by SWAT model with Land use 1993 (scenario 1). The model was setup for 29 sub-basin and the measured discharge was available from 2010-2013 for Shukhi station in study area to calculate and calibrate the runoff of the model. 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 software. Based on sensitivity analysis which has done on 27 parameters that affects the discharge hydrographs and total amount of runoff, we found 11 parameters was more effective fitting the hydrograph and estimation of water quantity in Shukhi station. SWAT-CUP was set up to calibrate the model with four iterations. Each iteration was 500 simulation that totally 2000 simulation done to calibrate the model. For each parameter the fixed values obtained during calibration. Table 3 shows the calibrated parameters value. Then the land use in 1993 was replaced by land use 2010 without farther changes of other inputs for scenario 2. SWAT ran performed again for Panjshir watershed with 29 sub-basin to estimate discharge quantity and discharge hydrograph.

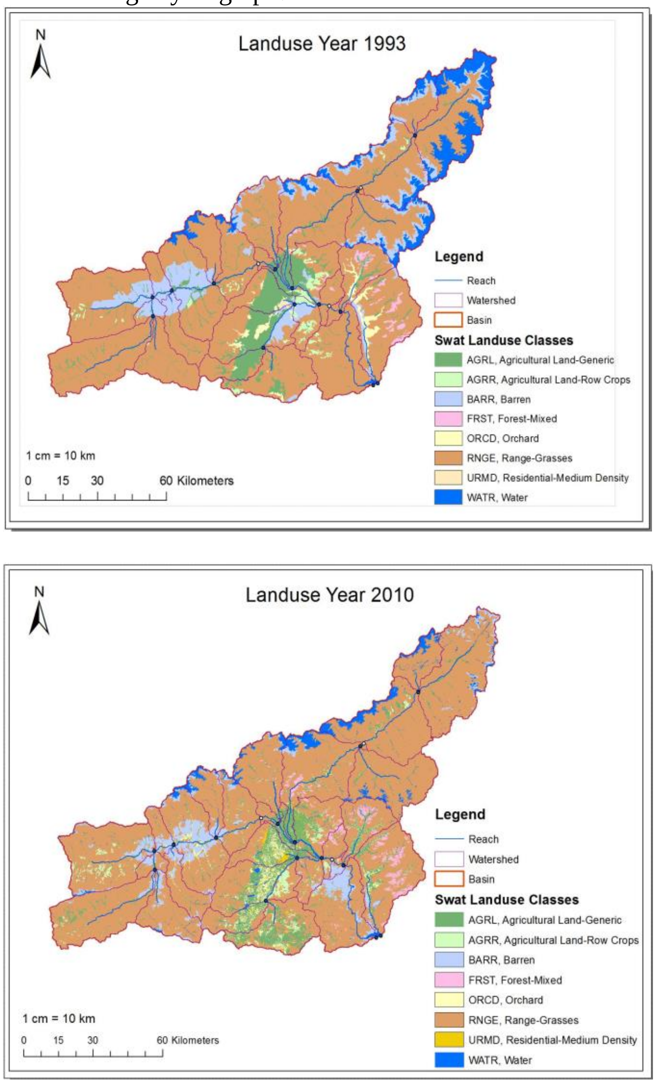


Fig. 3: Land use map of study area for two Scenarios.

Table 2: Descriptions and sources of Data

Sort	Format	Description	Sources
DEM	Raster	ASTER 30 m Resolution	US Geological Survey
Land use	Raster	30m Resolution	MAIL/AF
Precipitation &Temperature (9 stations)	DBF	Rainfall mm Temperature (min^{0}C and max^{0}C),	MEW/AF
Precipitation, temperature, wind, solar and relative humidity (13 stations)	DBF	Relative Humidity, Solar radiation and wind in 0.25^0 Resolution	Climate Forecast System Reanalysis (CFSR)
Soil	Raster	Soil FAO 1:50000 scale	FAO

Table 3: 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

By this method, we could assess the suitability of fixed parameters for both two scenarios. The statistics results of coefficient of determination R^2 for daily discharge estimation reached at 0.815 for scenario 1 and 0.817 for scenario 2 respectively, which showed very good correlation between observed and estimated discharge. Fig. 4 represents the daily surface runoff hydrograph in Shukhi station for scenario 1 and scenario 2 respectively. Whereas Fig.5 represents the correlation plots for both scenarios respectively. As a result in calibration we could find from both scenarios that the model under estimated the peak discharges in Sep 2010 and May 2011. The base flow for all years during dry periods under estimated. Totally the hydrograph for both two scenarios showed less deference in calibration period that is insignificant.

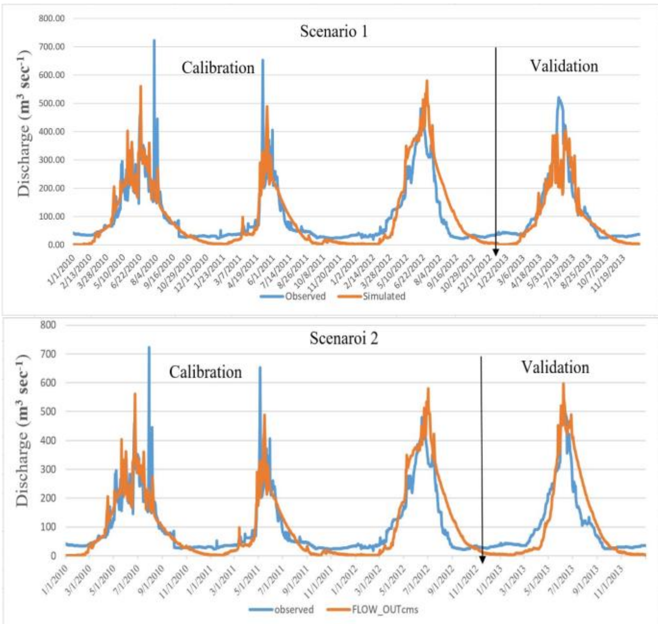


Fig. 4: Observed and simulated daily water discharge for two scenarios in Shukhi station.

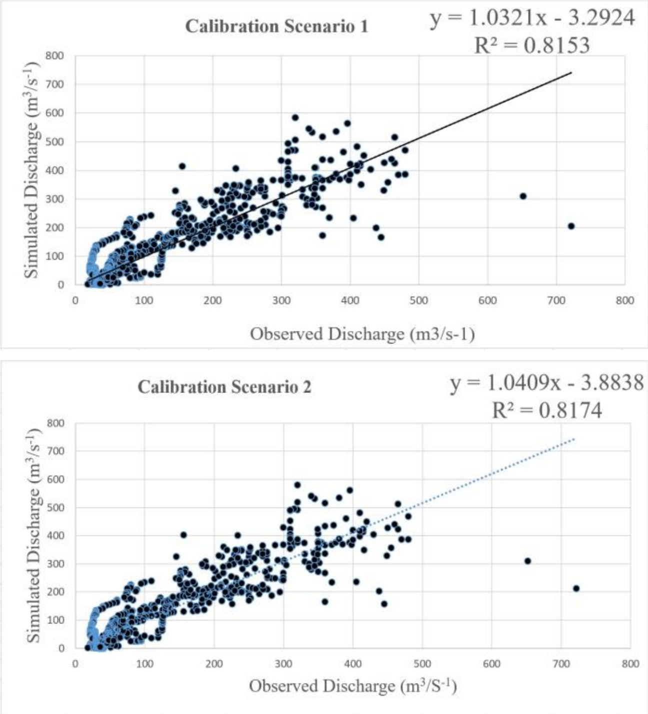


Fig. 5: Correlation of simulated & observed discharge values in calibration period for both scenarios.

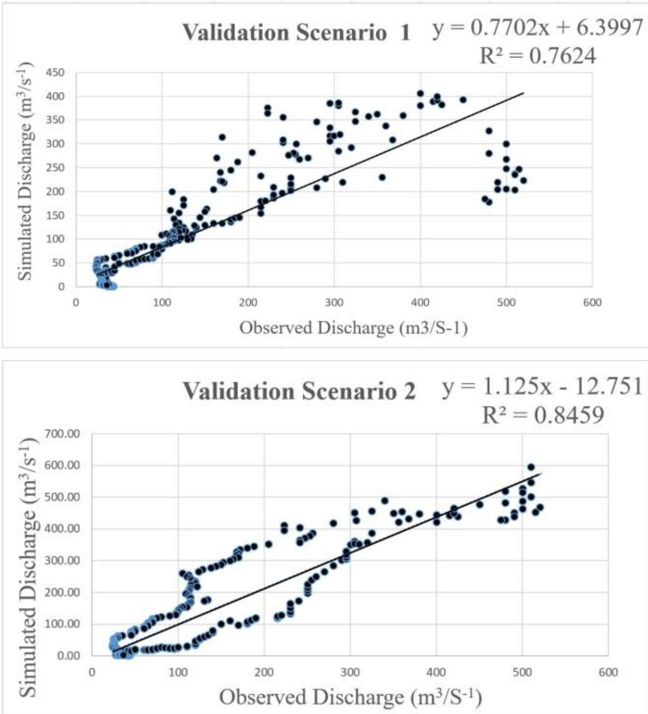


Fig. 6: The degree correlation of simulated & observed values in verification period for two scenarios.

A. *Model's Performance Evaluation*

Validation is the final step for the component of interest (streamflow, sediment yields, etc.) Model validation is the Process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although "sufficiently accurate" can vary based on project goals (Refsgaard, 1997; Arnold et al., 2012) [5]. Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration. Generally, graphical and statistical methods with some form of objective statistical criteria are used to determine when the model has been calibrated and validated (Arnold et al., 2012) [5]. The adequacy of the curves of the observed discharges and simulated discharges was assessed by the criterion of coefficient of determination. The calculation applied to this R^2 method is based on the following formula (1).

$$R^2 = \frac{\sum_i \left[(Q_{m,i} - \overline{Q}_m)(Q_{s,i} - \overline{Q}_s) \right]^2}{\sum_i (Q_{m,i} - \overline{Q}_m)^2 \sum_i (Q_{s,i} - \overline{Q}_s)^2} \qquad (1)$$

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. After the validation performance discharge estimation hydrograph has been shown in Fig. 4 for both scenarios and the statistical correlation results were shown in Fig.6. The fit result evaluation between observed and estimated water discharge showed good correlation in both calibration and validation of the model. The R^2 result for the scenario 1 was 0.76 whereas for the scenario 2 it was 0.84 respectively.

V. Land Use Change Relationship

The Panjshir watershed mostly occupied by Irrigated agriculture, Rainfed agriculture, Orchard & Garden, Rangeland, Forest & shrubs, Barren land, Snow &water and Urban throughout the study Period. The LULC changes for the study area from 1993 – 2010 were shown in Fig. 3 and overall the amounts of change detection and percentage growth at LULC is shown in Table 4. Based on amount of change detection and percentage growth the LULC map throughout the study area indicates the most significant changes occurred in urban, snow & water, bare lands, orchard & garden, forest & shrubs, and rainfed agriculture from all classes. Urban, orchard & garden, forest and shrubs increased whereas snow & water, barren lands and rainfed agriculture decreases whereas there is small changes in rangeland and irrigated agriculture which is not significant. In Panjshir watershed land use and land cover change from 1993 – 2010, proportional extent of urban area increased by 0.7% to 0.96 %, rangelands by 70.56% to 75.55%, forests by 0.81% to 1.51%, orchard by 1.3% to 2.56% whereas remain classes decreased which are snow &Water by 6.71% to 3.83%, barren by 10.44% to 6.01%, rainfed agriculture by 1.46% to 1.2%, irrigated agriculture by 8.54% to 8.39%. 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. After the calibration and validation of both scenarios we compared both discharge hydrographs which doesn't show significant deference during calibration but during the validation the peak of discharge was very good fit in scenario 2, refer to (Fig.4). There is a good correlation between observed and simulated values in validation. R^2 for validation and observed values are 0.76 for scenario 1 whereas 8.4 for scenario 2 (Fig.6).

Table 4: Area (Km^2) and overall amount of change (%) in LULC 1993 - 2010.

LULC type	LU 1993 Area (Km2)	Percentage (%)	LU 2010 Area (Km2)	Percentage (%)	Amount of change (Km^2)	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*	

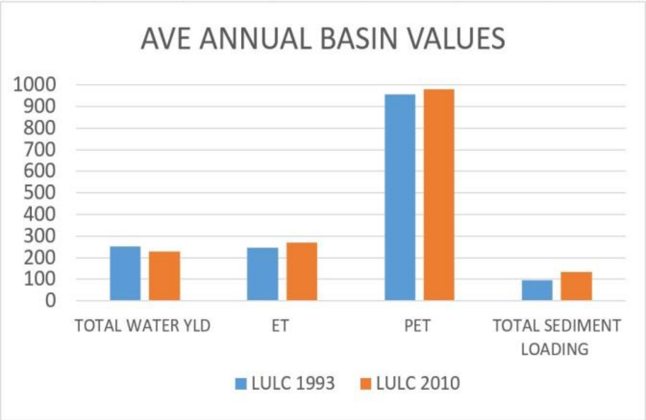
As result, simulation result of both scenarios for surface runoff were not significant different. Because the main reason is that this watershed located in a rural and mountainous area and more than 70% is rangeland which doesn't change much during this period. Although the hydrographs doesn't show the difference clear, so we also considered LULC change on the total water yield to the outlet of Shukhi sub-basin (Table 5).

From Table 5 we can see that the average annual Total Water Flow of LULC 1993 is more than the LULC 2010. Beside this 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 in both LCLU.

Table 5: Average annual water balance ratio for both scenarios in Shukhi station.

	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

In this study for sediment yield estimation analyses, unfortunately the observed time series data in the study period wasn't available for Shukhi station. Hence, the calibration and validation did not performed for sediment yield. But just we compared the both scenarios (landuse 1993, landuse 2010) change effects on sediment transportation, Evaporation (ET), Potential Evapotranspiration (PET) and Total water yield in Panjshir watershed outlet point. Fig.7 shows the all mentioned hydrological and sediment yield changes in Panjshir watershed. From the Fig.7 it is indicated that the total water flow is decreased in year 2010 compared to 1993. But in contrary Evaporation, Potential Evapotranspiration and Sediment loadings increased. The increasing of sediment yield is the result of population growth in recent years, changing the agricultural Lands to urbanization and the Erosion from Rangelands and other farm lands.



Note: The value for the total water flow, ET and PET is in mm whereas total sediment loading is in Tons/ha.

Fig. 7: Average annual sediment and other hydrological values

VI. Conclusion

This paper investigated the landuse change effects on surface runoff in Panjshir watershed. The LULC changes for the study area from 1993 – 2010 were shown in Fig.3 which the proportional extent of urban area increased by 0.7% to 0.96 %, rangelands by 70.56% to 75.55%, forests by 0.81% to 1.51%, orchard by 1.3% to 2.56% whereas remain classes decreased which are snow &Water by 6.71% to 3.83%, barren by 10.44% to 6.01%, rainfed agriculture by 1.46% to 1.2%, irrigated agriculture by 8.54% to 8.39%. The model simulated average annual surface flow decreased by 10.24% to 7.2%, whereas the average annual ground water flow increased by 70.07 percent to 73.48 percent 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.

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References

[1] Petchprayoon Pakorn, Peter D. Blanken, Chaiwat Ekkawatpanit, and Khalid Hussein. (2010). "Hydrological impacts of land use/land cover change in a large river basin in central– northern Thailand". [INTERNATIONAL JOURNAL OF CLIMATOLOGY].Vol.30, Issue.13, PP 1917–1930. Available: DOI: 10.1002/joc.2131 and http://onlinelibrary.wiley.com/doi/10.1002/joc.2131/abstract.

[2] Ayoubi[1] Tooryalay and Dongshik[2] Kang. 2016. "PANJSHIR WATERSHED HYDROLOGIC MODEL USING INTEGRATED GIS AND ARCSWAT INTERFAC". [International Journal of Geology, Earth & Environmental Sciences]. Vol. 6 No. 1, pp 145-161. Available:

http://www.cibtech.org/J-GEOLOGY-EARTH-ENVIRONMENT/PUBLICATIONS/2016/VOL_6_NO_1/JGEE-06-01-Contents.htm.

[3] US Army Corps of Engineers. “Provincial water resource data summery of Parwan/Afghanistan, UNCLASSIFIED//FOUO 1-7”, (2009).

[4] J.G. Arnold, R. Srinivasan, R.S. Muttiah, and J.R. Williams[2]. (1998). “Large area hydrologic modeling and assessment, part I: Model development”. [Journal of the American Water Resources Association] Vol. 34, No.1, pp 73-89. Available: DOI: 10.1111/j.1752-1688.1998.tb05961.x and http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.1998.tb05961.x/abstract.

[5] J.G. Arnold, D.N. Moriasi, P.W. Gassman, K.C. Abbaspour, M.J. White, R. Srinivasan, C. Santhi, R.D. Van Harmel, A. Van Griensven, M.W. Van Liew, N. Kannan, M.K. Jha. (2012). “SWAT: Model use, Calibration, and Validation”. Transactions of the ASABE. [2012 American Society of Agricultural and Biological Engineers ISSN 2151-0032] Vol. 55(4): 1491-1508. Available: http://swat.tamu.edu/publications/calibrationvalidation-publications/.

Tooryalay Ayoubi, Tooryalay Ayoubi is a graduate of Geo-Science faculty from Kabul University, Afghanistan. Currently, he is pursuing his master degree at the university of the Ryukyus, department of information engineering, Okinawa, japan. His area of interest include Geography, Water resource management, Geographic Information System, Remote sensing and SWAT model applications.

Dongshig Kang, Dongshik Kang is an Associate Professor at the Faculty of Information Engineering, University of the Ryukyus. His previous position was as an Assistant Professor at University of the Ryukyus (1999-2004). He received a Ph.D. in Engineering from Osaka University, Osaka Prefecture. He is a member of the IEEJ, IEICE and GISA. His current research interests are neural networks, geographic information system, and intelligent systems