



Quantifying the impacts of land use/land cover change on the water balance in the afforested River Basin, Pakistan

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Abstract

Land use and land cover (LULC) change is one of the key driving elements responsible for altering the hydrology of a watershed. In this study, we investigated the spatio-temporal LULC changes between 2001 and 2018 and their impacts on the water balance of the Jhelum River Basin. The Soil and Water Assessment Tool (SWAT) was used to analyze the impacts on water yield (WY) and evapotranspiration (ET). The model was calibrated and validated with discharge data between 1995 and 2005 and then simulated with different land use. The increase was observed in forest, settlement and water areas during the study period. At the catchment scale, we found that afforestation has reduced the WY and surface runoff, while enhanced the ET. Moreover, this change was more pronounced at the sub-basin scale. Some sub-basins, especially in the northern part of the study area, exhibited an increase in WY due to an increase in the snow cover area. Similarly, extremes land use scenarios also showed significant impact on water balance components. The basin WY has decreased by 38 mm/year and ET has increased about 36 mm/year. The findings of this study could guide the watershed manager in the development of sustainable LULC planning and water resources management.

Keywords Hydrology · Water yield · Evapotranspiration · SWAT · Afforestation · LULC changes

Introduction

Land use and land cover (LULC) changes altering hydrological processes and have the potential to exert a large influence on earth water (Wagner et al. 2013; Kaushal et al. 2017). Rapid socio-economic development causes LULC changes that include changes of land cover classes, for example, conversion of agriculture or forest to industrialization and residential area due to population growth, in addition alteration within classes such as a change of crop rotations or crops (Wagner et al. 2013). Land use/cover change has been recognized as a key driver of hydrological processes such as surface runoff, ET and base flow (Zhao et al. 2013 and Garg et al. 2017). Juang et al. (2007) reported that the changes in

LULC have significant effects on atmospheric elements like precipitation and temperature, key driving elements of the hydrological cycle. Thus, it changes the water balance of a watershed that comprises stream flow, base flow and evapotranspiration (DeFries and Eshleman 2004; Shooshtari et al. 2017). Therefore, examining the practices and consequences of changing LULC are vital for the hydrologists, ecologists and land managers (Stonestorm et al. 2009; Mallinis et al. 2014).

To investigate the impact of land use and land cover changes on the hydrology of watershed, spatially dispersed hydrological models are employed including HEC-HMS (Younis and Ammar 2017; Koneti et al. 2018), InVEST (Geng et al. 2014; Li et al. 2018), VIC (Garg et al. 2017) and SWAT (Kumar et al. 2018; Li et al. 2019; Munoth and Goyal 2020). The SWAT has proven its suitability under conditions of limited data availability in hydrological studies (Stehr et al. 2008; Gassman et al. 2007). Therefore, it is an appropriate model to analyze the impact of LULC changes on the water resources in Indus Basin Pakistan.

The impact of LULC changes on water resources has been assessed in many studies at the regional level. For instance, Li et al. (2018) found that the expansion of built-up area

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and decline of vegetation area in Jing-Jin-Ji, China led to an increase of water yield (5%). Mango et al. (2011) conducted research over the Upper Mara river basin, Kenya and reported that if forest cover were converted to grass land then surface runoff increased by 20% but ET decreased by 2%. Furthermore, Zhu and Li (2014) quantified the impact of land use and land cover change on the hydrology of Little River basin, Tennessee. The results showed a small increase of 3% in streamflow but distinct spatial change across the basin. Ahiablame et al. (2017) investigated the impact of two future land use (LULC-2055 and LULC-2090) under three simulation scenarios (A1B, A2 and B1) on stream flow of James River watershed, United States and found that climate and land use changes would result in 12–18% and 17–41% increases in annual stream flow at the end of twenty-first century. In terms of temperature change, RCP8.5 is close to SRES A2, but below SRES A1FI. RCP4.5 follows SRES B2 up to 2060, but then drops to track SRES B1. RCP6.0 has lower temperature change to start, following SRES B1, but then increases toward SRES B2 by 2100 (Burkett et al. 2014). Wagner et al. (2013) reported an increase of WY and decrease of ET due to urbanization; whereas, increase of cropland led to rise in ET by up to 5.9% over Indian River basin. Additionally, Welde et al. (2017) assessed the impact of land use/land cover dynamics on the hydrology of Teke watershed, Ethiopia and found that increasing bare and agriculture area resulted in increase in stream flow.

Several studies on LULC changes have been conducted in northern Pakistan and Kashmir (part of the upper Jhelum River basin). Hassan et al. (2016) have reported deforestation and urbanization from 1992 to 2012 in the city of Islamabad and its surroundings. Similarly, a study on Simly watershed was conducted by Butt et al. (2015) and found an increase of settlement and a decrease of vegetation. Mannan et al. (2019) have found increase of agriculture and built-up area and decrease of forest area at the foothill of the Himalayas Mountains of Pakistan. Iqbal and Khan (2014) conducted their research at the sub-division of Azad Jammu and Kashmir to investigate the spatio-temporal land use/land cover change between 1998 and 2009 and found a decrease of forest and bare vegetation area and increase of settlement. Alam et al. (2014) have examined the LULC changes between 1992 and 2015 in Kashmir valley, India and observed an increase of plantation and built-up area while a decrease in agriculture. However, only one study has been carried out at the small area of Indus River to quantify the impact of LULC change on discharge using HEC-HMS hydrological model. Younis and Ammar (2017) concluded that overall change in discharge was negligible.

Based on the review literature and as far as the authors are aware, no previous study has been reported to date regarding LULC changes impact on the hydrology of the Jhelum River Basin (JRB). However, few studies (Mahmood and Jia

2016 and Saddique et al. 2019b) have assessed the impact of climate change on the stream flow of JRB forcing the Global Climate Models (GCMs) data. Therefore, this study filled this knowledge gap using different time periods land use data and employed SWAT hydrological model to simulate how these changes may affect the water resources of the basin. The main objectives of this study were to (1) assess the spatial–temporal LULC changes during the period of 2001–2018 and (2) analyze the impacts of land use/cover change on the water balance of Jhelum River Basin.

Study area and data

Description of the study area

The Jhelum River Basin (Mangla Dam Watershed) is located between 73–75.62°E and 33–35°N and has total drainage area about 33,397 km². Figure 1 shows the location of the study area and climate stations. The watershed topography characterized by mountainous with elevation varies from 232 m in the lowland area to 6285 m in the highland area. The catchment drains its whole flow into the Mangla reservoir that is the second-largest reservoir of Pakistan. The water of this reservoir is mainly used for two purposes: to irrigate 14.82 million acres of agriculture land and generate 1000 MW electricity which is 15% of the total electricity production through hydel power plants (Archer and Fowler 2008).

The whole basin has mean annual precipitation about 1196 mm and mean annual temperature by 13.2 °C. (Saddique et al. 2019a) The temperature of the basin decreases with increasing elevation (from south to north) but precipitation does not follow a specific trend in such a complex topography. More than 70% of rainfall occurs from March to August. The basin monthly average temperature ranges from 4.9 °C in January (coldest month) to 24.3 °C in July (hottest month). The JRB is characterized by highly heterogeneous soil and land cover; main types of soil include Gleyic Solonacks (49%), Calaric Phaeozems soil (23%), and Mollic Planosols soil (21%). The basin drainage area is covered by diverse land cover such as agriculture (31%), grass-sparse vegetation (37%), forest (28%), water (2%) and settlement (2%) (Saddique et al. 2019b).

Data description

The daily observed precipitation, maximum and minimum temperature data of fifteen stations were collected from the Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA) of Pakistan, and the India Meteorological Department (IMD). River discharge data of five stations were obtained from WAPDA for

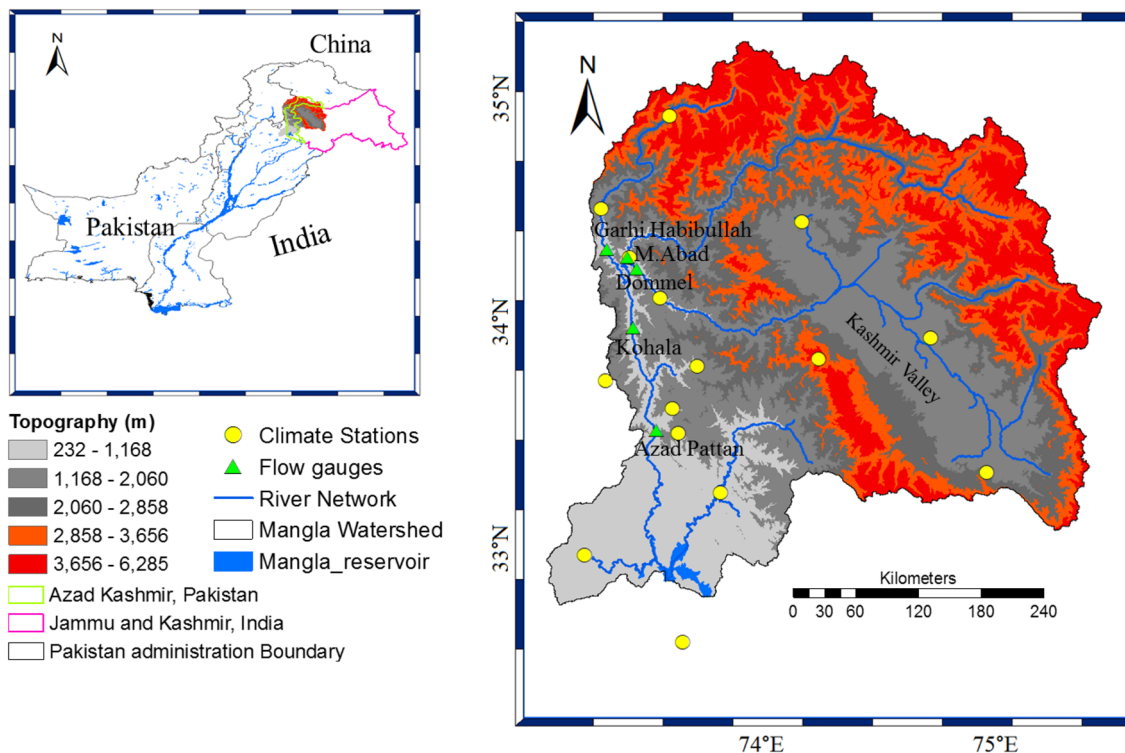


Fig. 1 Location of the Jhelum River Basin

calibration and validation of SWAT. Landsat imagery for the years of 2001, 2009 and 2018 freely obtained from the United States Geological Survey (USGS). Table 1 describes the Landsat images characteristics used in this study. Reference/ground truth data were collected from 3 September to 2 October 2018 using handheld GPS for image classification and accuracy assessment of LULC of the study area. Besides field visit and data obtained from the forest department of Azad Kashmir, high-resolution Google Earth imagery was also used to collect referenced points for classification (Mondal et al. 2015; Matlhodi et al. 2019).

Methodology

LULC classification

Satellite images are known to have distortion; hence, pre-processing prior to the detection of change is required to build a more direct linkage between the acquired data and biophysical phenomena (Coppin et al. 2004). Environment for Visualization Images (ENVI) was used for radiometric, atmospheric and geometry correction of images. In addition, images mosaicking and sub-setting were done in R. Supervised classification was applied for the image classification using Random Forest (RF) machine learning algorithm in R for the Jhelum River Basin land use categories (Mango et al. 2011). LULC was classified into five classes including Agriculture, Forest, Grass, Settlement and Water. Table 2 provides a detail description of different LULC classes. The

Table 1 Landsat images characteristics for the Jhelum River Basin

Year	Satellite	Sensor	Path/Row	Resolution	Acquisition date (day/month)	Cloud cover
2001	7	ETM+	148/37,149/36–37,150/36–37	30 m	2,4,11/09	< 10
2009	5	TM	148/37,149/36–37,150/36–37	30 m	5,10,12,19/09	< 10
2018	8	OLI	148/37,149/36–37,150/36–37	30 m	12,21/09	< 10

Table 2 Description of different LULC classes

Class code	LULC class	Description
1	Agriculture	Wheat, rice, fodder crops and vegetables
2	Forest	Evergreen and deciduous forests and orchards like apple, pear, walnut, almond etc.
3	Grass	This class includes mountainous rangelands, state owned grass lands and sparsely vegetated area
4	Settlement	Residential areas, roads, industrial zones, barren land and dry stream channels
5	Water	Rivers, lakes, ponds and snow cover

accuracy of LULC maps was assessed by calculating three different accuracies and kappa coefficient from the confusion matrix (or error matrix).

SWAT hydrological model

The SWAT model was used to simulate the discharge of JRB. It is a semi-distributed physical-based hydrological model that has been commonly used for investigating the impacts of LULC change on water resources around the world (Githui et al. 2010; Wagner et al. 2013 and Garg et al. 2017). SWAT operates at a daily time step with complex terrain conditions including different land use, soils and management practices. Two phases (land and routing) are involved for simulating the hydrological process in SWAT. The land phase controls the amount of water and other elements delivered to the main channel from each sub-basin and routing phase is the movement of water, sediment and nutrients loadings through channel network and finally reach the outlet of watershed (Neitsch et al. 2005). A watershed is divided into multiple sub-basins during the delineation process in SWAT and after that, these sub-basins are further divided into Hydrological Response Units (HRUs). HRUs are composed of similar land cover, soil type and slope classification. The hydrological cycle in SWAT model is simulated by Eq. 1 of water balance (Neitsch et al. 2005).

$$SW_t = SW_o + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}), \quad (1)$$

where SW_t is the final soil water contents (mm); SW_o is the initial soil water content (mm); t is the time in days; R_{day} is the precipitation amount on day i (mm); Q_{surf} is the measure of surface runoff on day i (mm); E_a is the amount of ET (mm); W_{seep} is the amount of water that enters the vadose zone from soil profile (mm); Q_{gw} is the amount of base flow on day i (mm).

Water yield is one of the vital parameters calculated for sustainable water resources management of the watershed. Water yield in a catchment is calculated by the Eq. 2 (Arnold et al. 2011).

$$Q_{yld} = Q_{srf} + Q_{lat} + Q_{gw} - T_{loss}, \quad (2)$$

where Q_{yld} is the amount of water yield (mm); Q_{srf} is the surface runoff (mm); Q_{lat} is the amount of water contributed by lateral flow (mm); Q_{gw} is the ground water flow contribution (mm); T_{loss} is the loss of water through transmission process (mm).

In this study, a threshold of 5% was used for soil and slope in each sub-basin during HRUs definition in SWAT. The JRB was divided into 27 sub-basins (Fig. 2) and 627 HRUs. The soil conservation service (SCS) curve number and the Manning equation were used for the estimation of runoff, flow rate and velocity. The ET was calculated with the Hargreaves method as the data of wind speed, solar radiation and relative humidity were not available for the simulation time period (Neitsch et al. 2005). In SWAT model, two different processes were taken into account such as snowmelt

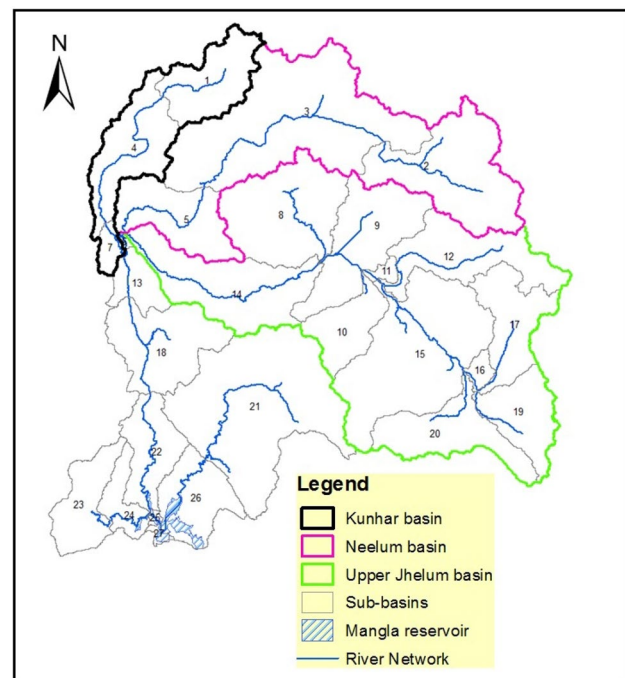


Fig. 2 Three major river basins in study area and sub-basins generated during delineation

and orographic effect on precipitation and temperature; for this elevation bands were generated at the sub-basins scale. The SWAT model was run for 14 years, which included 1992–1994 warm-up period, 1995–2000 calibration period and 2001–2005 validation period. Sensitivity analysis, calibration and validation were conducted using the SUFI-2 algorithm in SWAT-CUP. Global Sensitivity Analysis (GSA) technique was used to identify the sensitive parameters for discharge over JRB. Among the 30 parameters (Table 3) selected on the basis of the literature review, 18 parameters were found sensitive for this study.

Results and discussion

Land use and land cover classification

Results of accuracy assessment of five different classes are given in Table 4 in terms of user's accuracy (UA), producer's accuracy (PU), overall accuracy (OA) and kappa coefficient (KC).

The spatial distribution of land use and land cover of the study area for the year of 2001, 2009 and 2018 is shown in Fig. 3.

Table 5 presents the LULC change matrix for the period of 2001–2018 and Table 6 provides the quantitative changes in LULC within last 18 years. Major changes can be observed in agriculture (decrease) and forest (increase) class. These outcomes are comparable with previous studies (Kuchay

Table 3 List of parameters selected for sensitivity analysis

	Parameters	Description	Unit
1	GW_DELAY	Groundwater delays	Days
2	GW_REVAP	Groundwater revap coefficient	–
3	GWQMN	Threshold depth of water in shallow aquifer required for return flow to occur	mm
4	REVAPMN	Threshold depth of water in shallow aquifer required for “revap” to occur	mm
5	RCHRG_DP	Deep aquifer percolation fraction	–
6	ALPHA_BF	Base flow alpha factor	Days
7	CN2	Initial SCS runoff curve number for moisture condition II	–
8	CH_K2	Effective hydraulic conductivity in the main channel alluvium	mmh ⁻¹
9	CH_N2	Manning's “n” value for the main channel	–
10	EPCO	Plant uptake compensation factor	–
11	ESCO	Soil evaporation compensation factor	–
12	SOL_AWC	Available water capacity of the soil	mmmm ⁻¹
13	SOL_K	Saturated hydraulic conductivity	mmh ⁻¹
14	SUB_SFTMP	Snowfall temperature	°C
15	SUB_SMTMP	Snow melt base temperature	°C
16	SUB_SMFMX	Maximum melt rate for snow on June 21	mm°C ⁻¹ day ⁻¹
17	SUB_SMFMN	Minimum melt rate for snow on December 21	mm°C ⁻¹ day ⁻¹
18	SUB_TIMP	Snow pack temperature lag factor	–
19	SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover	mm
20	SNO50COV	Snow water equivalent that corresponds to 50% snow cover	mm
21	SOL_D	Soil bulk density	gcm ⁻³
22	SOL_Z	Depth from soil surface to bottom of layer	mm
23	ALPHA_BNK	Base flow alpha factor for bank storage	Days
24	CH_D	Average depth of main channel	m
25	CH_L	Length of main channel	m
26	CANMX	Maximum Canopy storage	mm
27	SURLAG	Surface runoff lag coefficient	–
28	PLAPS	Precipitation lapse rate	mmKm ⁻¹
29	TLAPS	Temperature lapse rate	°CKm ⁻¹
30	SHALLST	Initial depth of water in the shallow aquifer	mm

Bold text parameters were selected for calibration

Table 4 Summary of LULC maps accuracies for 2001, 2009 and 2018

LULC class	2001				2009				2018			
	UA %	PA %	OA %	KC %	UA %	PA %	OA %	KC %	UA %	PA %	OA %	KC %
Agriculture	93	91	90	89	93	92	92	90	95	94	95	94
Forest	94	93			92	94			96	97		
Grass	83	90			82	88			95	94		
Settlement	83	83			92	93			94	93		
Water	91	93			93	94			100	100		

UA user's accuracy, PA producer's accuracy, OA overall accuracy, KC kappa coefficient

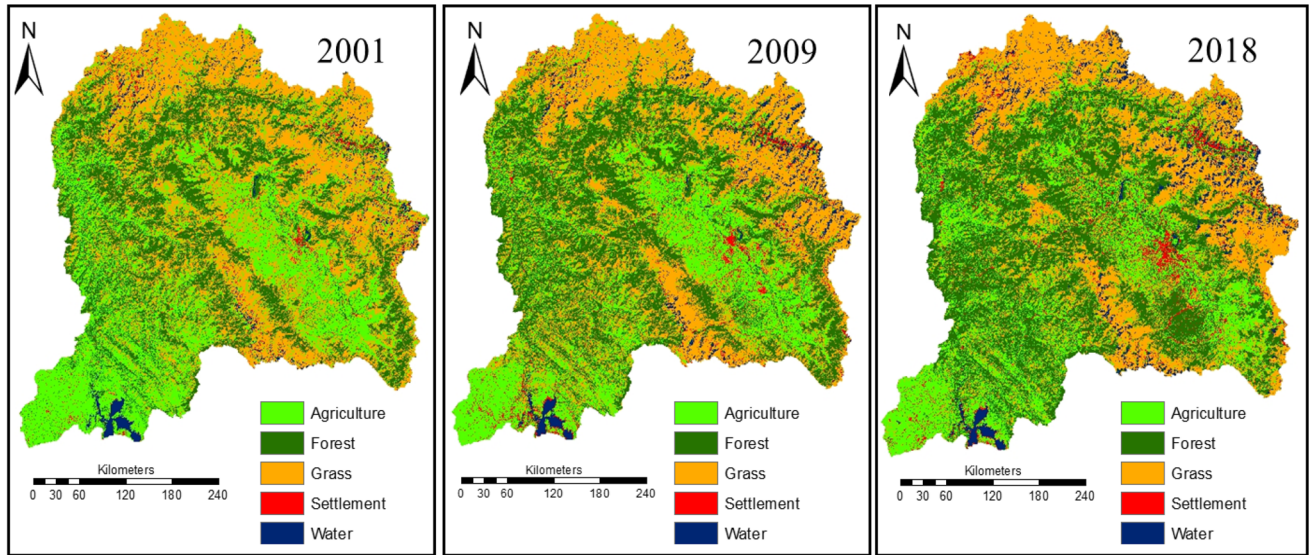


Fig. 3 Land use/land cover of the Jhelum River basin for the period of 2001, 2009 and 2018

Table 5 LULC change (Km²) matrix for the period of 2001–2018

		LULC 2018					Total
		Agriculture	Forest	Grass	Settlement	Water	
LULC 2001	Agriculture	6998	2130	716	346	102	10,292
	Forest	323	8455	328	32	173	9311
	Grass	507	1533	9594	198	455	12,287
	Settlement	0	0	22	656	14	692
	Water	0	0	16	28	771	815
	Total	7828	12,118	10,676	1260	1515	33,397

Table 6 Area statistics and changes in LULC in 2001–2018

LULC class	2001		2009		2018		Change 2001–2018	
	Area (Km ²)	Area (%)	Area (Km ²)	Area (%)	Area (Km ²)	Area (%)	Area (Km ²)	Area (%)
Agriculture	10,292	30.82	8455	25.31	7828	23.43	- 2463.88	- 6.39
Forest	9311	27.88	10,745	32.17	12,118	36.28	2806.87	8.4
Grass	12,287	36.79	11,989	35.90	10,676	31.97	- 1611.24	- 4.82
Settlement	692	2.07	1031	3.08	1260	3.77	567.84	1.7
Water	815	2.44	1177	3.52	1515	4.53	700.42	2.09
Total	33,397		33,397		33,397			

et al. 2016 and Alam et al. 2019) conducted in Kashmir Valley (Upper Jhelum). They found that horticulture practices (apple trees) have replaced the agriculture area. Pakistan forest conservation policy is also playing key role to increase the forest. Figure 4 shows the changes occurred within each class during different periods (2001–2009, 2009–2018 and 2001–2018) across the JRB. It can be seen that high change occurred during 2001–2009 as compared to 2009–2018 in all classes except grass.

Sensitivity analysis

The results obtained from sensitivity analysis in SWAT-CUP using GSA revealed that the maximum melt rate of snow during year (SMFMX), minimum melt rate of

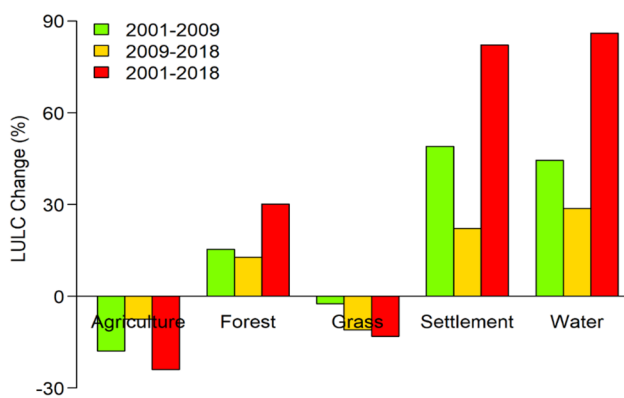


Fig. 4 Percentage changes in land use/land cover within each class (2001–2009, 2009–2018 and 2001–2018)

snow during the year (SMFMN), snowfall temperature (SFTMP), snow melt base temperature (SMTMP), snow pack temperature lag factor (TIMP) were the most sensitive parameters for the Neelum and Kunhar basins, and ground water control parameters were sensitive at the lower elevation basins. Table 7 gives the parameters initial ranges and their calibrated values at different basins of the watershed.

SWAT calibration and validation

Figure 5 exhibits the comparison of daily simulated and observed flow for the calibration period (Jan-1995 to Dec-2000) and validation period (Jan-2001 to Dec-2005). Table 8 provides the model evaluation indicators such as NSE, R² and Pbias. The simulated flow data closely matched the observed flow over the entire period. However, there are small over-estimations or under-estimations in flow. It can be seen that at all the gauging stations NSE and R² values were above 0.5 and Pbias values were in the range of ± 15. The SWAT model simulation results fall under a good category according to the performance criterion of Moriasi et al. (2007). However, the performance indices for the validation period are poor than the calibration period as seen at the Garhi Habibullah station (Due et al. 2009; Pinto et al. 2013; Fukunaga et al. 2015) because the parameter values are specifically optimized for the calibration period. Additionally, DEM, land use and soil were not changed during the entire simulation period, which have a substantial effect on the hydrological process (Jing et al. 2015).

Table 7 Parameters initial ranges and fitted values at different basins

Sr. no.	Parameter	Category	Initial range	Neelum basin	Kunhar basin	Upper Jhelum basin
1	GW_DELAY	Groundwater	0–500	417.03		207.77
2	GW_REVAP	Groundwater	0.02–0.2			0.05
3	GWQMN	Groundwater	0–5000	3308.45		2959.75
4	REVAPMN	Groundwater	0–500			
5	RCHRG_DP	Groundwater	0–1			0.48
6	ALPHA_BF	Groundwater	0–1	0.45	0.31	0.05
7	CN2	Runoff	± 0.25	– 0.23	– 0.03	0.16
8	CH_K2	Channel	0.001–200	107.98		158.87
9	CH_N2	Channel	– 0.01–0.3	0.03		0.19
10	EPCO	Evaporation	0–1			
11	ESCO	Evaporation	0–1	0.10		
12	SOL_AWC	Soil	± 0.20			
13	SOL_K	Soil	± 0.20	– 0.04		
14	SUB_SFTMP	Snow	– 5–5	– 2.19	– 2.77	0.96
15	SUB_SMTMP	Snow	– 5–5	1.24	4.32	– 2.11
16	SUB_SMFMX	Snow	0–10	3.99	2.62	8.15
17	SUB_SMFMN	Snow	0–10	5.06	3.08	4.39
18	SUB_TIMP	Snow	0–1	0.61	0.50	0.73

Impacts of LULC change on the hydrology of JRB

Historical land use change impacts

To investigate the impact of LULC changes on the water balance components in the JRB, land use of three different periods (2001, 2009 and 2018) was used in SWAT model independently, while during simulation all other inputs were kept similar. The assessment included surface runoff, base flow, WY and ET under each LULC change scenario (2001/2009/2018).

The results of average annual surface runoff, base flow, water yield and ET are given in Table 9. It can be seen that surface runoff and WY decrease during 18 years' period. On the other hand, ET and base flow increased. This increase can be partly attributed to the increase of the area of forest and water. The increase in forest land leads to an increase

in the rate of infiltration and transpiration, hence increase in base flow and ET. These results are similar to the previous studies (Bi et al. 2009) which suggested that the increase in forest caused the increase in ET and decrease in WY.

Extreme LULC scenarios impacts

Although obvious changes in water balance components have been observed with historical LULC in SWAT model, the impacts of some assumed scenarios need to be further determined. As the forest is the highest increasing class in the basin as compared to other classes. Alam et al. (2019) reported that people shift in land use practice from paddy (agriculture) to apple (forest) cultivation as high economic return. Plantation especially in the form of horticulture (e.g., apple orchards) and social forestry (poplar and willow trees) is a LULC that has grown fast and extensively across the

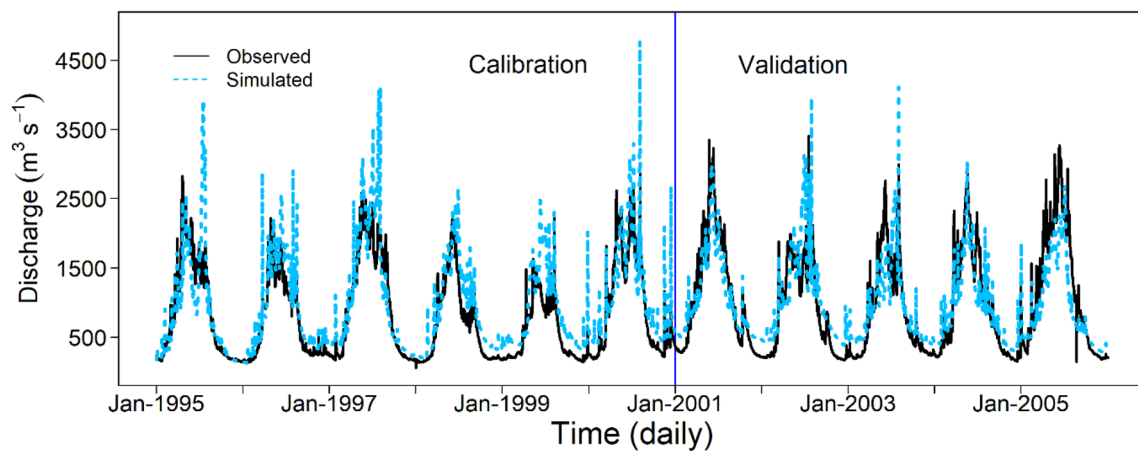


Fig. 5 Daily simulated and observed discharge at Azad Pattan (station) for the calibration and validation

Table 8 SWAT model calibration and validation performance statistics

Stations (Rivers)	Calibration			Validation		
	NSE	R ²	Pbias	NSE	R ²	Pbias
Azad Pattan (Jhelum)	0.71	0.74	- 13.6	0.71	0.73	1.1
Kohala (Jhelum)	0.71	0.77	- 14.2	0.70	0.74	- 2.2
Domel (Jhelum)	0.75	0.80	- 12.3	0.77	0.81	5.6
Muzaffarabad (Neelum)	0.56	0.71	- 14.4	0.52	0.59	- 12.9
Garhi Habibullah (Kunhar)	0.72	0.72	- 4.6	0.57	0.61	13.1

Table 9 Comparison of mean annual hydrological components using the three historical LULC in SWAT model over JRB

Historical LULC	Surface runoff (mm)	Base flow (mm)	Water yield (mm)	Evapotranspiration (mm)
LULC 2001	539.03	222.56	927.67	462.22
LULC 2009	527.21	225.3	920.58	469.41
LULC 2018	508.15	232.88	910.87	479.60
Changes 2001–2018	- 30.88 (- 5.7%)	+10.32 (4.6%)	- 16.80 (- 1.8%)	+17.38 (3.7%)

Kashmir Valley. Horticulture contributing 7–8% to Gross State Domestic Product (GSDP) has been the primary economic activity of about 60% of people of valley. Additionally, with serious efforts of different sections of society and law forcing agencies, the timber smuggling was curbed to a large level (Alam et al. 2019). Also, forest growth and forest conservation policies of Pakistan are playing a key role to increase the forest area in the northern part of Pakistan (Shahbaz et al. 2011). The area under horticulture changed from 14.37% to 27.02% during 1992 and 2015. Therefore, three extremes forest dominant land use scenarios (all agriculture converted to forest, all grass converted to forest and all agriculture and grass converted to forest) were applied in this section to explore the impacts on water resources of JRB. We consider the soil information during scenarios generation. As more than 90% basin area is covered by three kinds of soils (mentioned in study area), we have observed that forest grow in all kinds of soils in historical periods. Therefore, we implemented the LULC scenarios at all area agriculture. All these scenarios are applied on the 2018 LULC classification.

Table 10 provides the impacts of extremes land use scenarios on the surface flow, base flow, WY and ET. When all the agriculture converted to forest land, it resulted in decrease (25 mm/years) in water yield. However, this decrease in WY was less as compared to the second scenario because area under grass (10,676 km²) was greater than agriculture (7828 km²). Highest increase (in ET and base flow) and decrease (in surface runoff and WY) were occurred in the basin (Zhang et al. 2001; Xiao et al. 2019) when all agriculture and grass converted to forest, as in this condition more than 90% area of the basin is cultivated under forest. This suggested that forests could not only absorb water through leaves and roots but also promote the infiltration of rainwater into the underground aquifer (shallow or deep).

Implementation of extremes LULC scenarios suggests that JRB basin would face a decrease in WY in future. Furthermore, through these scenarios, the basin would be more exposed to water stress because of high ET from expanded forest. The watershed managers should pay attention to sustainable LULC for proper water resources management.

These findings showed agreement with other studies (Suarez et al. 2014; Mwangi et al. 2016 and Guzha et al. 2018) that have reported an increase in ET and decrease

in WY. The decline in surface runoff can be attributed to increase infiltration (Benegas et al. 2014). Anderson et al. (2009) conducted an experimental study and found agroforestry buffer treatments increase infiltration and water storage compared to row crop treatment areas. Moreover, change in base flow (increase or decrease) is fundamentally dependent on the aquifer water budget (Bruijnzeel 2004). If the incoming water through infiltration exceeds the water abstraction through tree roots, then the additional available water may lead to increase in base flow. Consequently, WY which is aggregate sum of surface runoff, lateral flow and base flow also reduced with an increase in the area under forest.

Impact of LULC changes on ET and WY at the sub-basin scale

Figures 6, 7 show the percentage changes in ET and WY at the sub-basin scale. Furthermore, Table 11 showed the interaction between LULC changes and hydrological responses in sub-basins 2, 3, 15, 16 and 17. On the large scale, positive and negative effects cancel each other and resulted in small change in ET and WY during the 18-year period. The mean annual ET changes range from a decrease of – 2.15% in sub-basin 12 to increase of 7.79% in sub-basin 16 in 2001–2009. The effect of land use change is more pronounced in 2001–2018, where ET has increased by 11.61% in sub-basin 16 and decreased – 1.11% in sub-basin 3. A major increase in ET can be observed in the eastern part (Kashmir valley) of the basin in 2001–2018. Main decrease in ET is obvious in the upper North and southern parts of catchment. This change in ET can be attributed to change in LULC in each sub-basin. The sub-basin 2 water cover area increases from 6 to 17% and grass area decreases from 62 to 52% during the analysis of land use change at the sub-basin scale in 18 years. While, the basins 15 and 16 showed increase in forest and subsequent decrease in agriculture and grass. Larger increase in forest area increases ET which attributing a decrease in WY.

Figure 7 illustrates the change in WY at sub-basin scale in three periods. The changes in mean annual WY range from a decrease of – 13.91% (– 48.32 mm/years) in sub-basin 17 to increase 12.29% (76 mm/years) in sub-basin 2.

This might have attributed due to the increase of leaf area index (LAI) and increased transpiration from more

Table 10 Comparison of mean annual hydrological components under extreme LULC scenarios

Scenarios	Surface runoff (mm)	Base flow (mm)	Water yield (mm)	Evapotranspiration (mm)
All agriculture converted to forest	465.63	247.98	885.84	504.0
All grass converted to forest	439.95	264.38	883.23	506.9
All grass + agriculture converted to forest	421.09	271.25	873.01	515.7

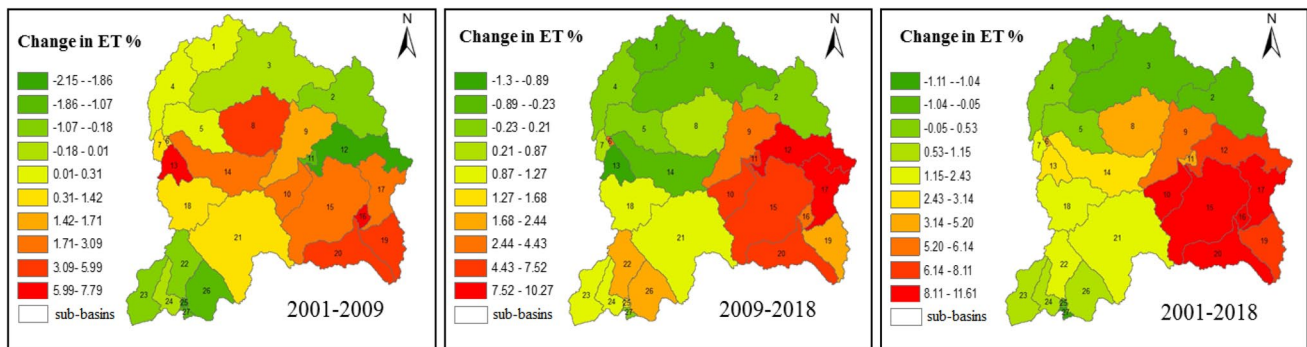


Fig. 6 Percentage changes in ET in each sub-basin over the Jhelum River basin between 2001 and 2009, 2009 and 2018, and 2001 and 2018

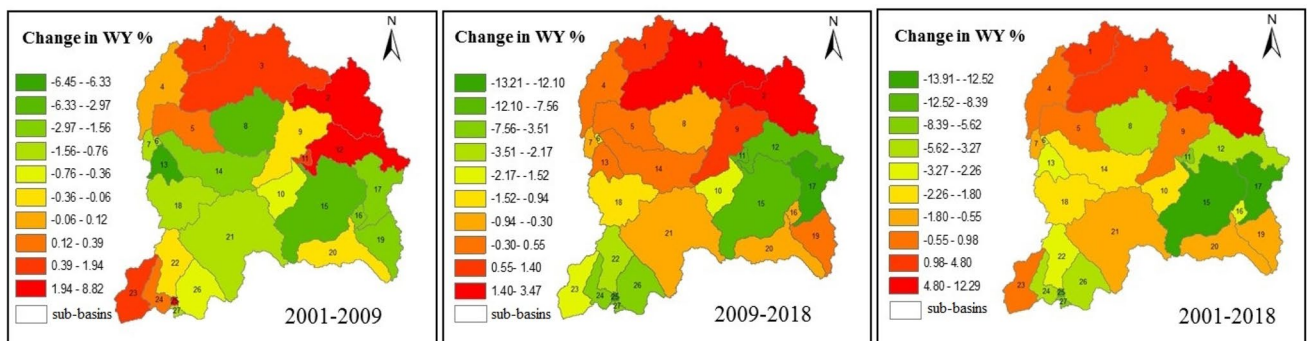


Fig. 7 Percentage changes in WY in each sub-basin over the Jhelum River Basin between 2001 and 2009, 2009 and 2018, and 2001 and 2018

vegetated surface (forest cover increase from 19 to 29%) in sub-basin 17. On the other hand, in basin 2 water cover area increased (from 6 to 17%) and vegetated surface decreased. The decrease in WY is more pronounced in eastern part of the basin (in basins 15 and 17) in 2001–2018. On the other, increase in WY is significant in the northern part (basin 2 and basin 3) of the catchment. The key factor involved in decreasing the WY is the forest cover gain. Ashagrie et al. (2006) were conducted research at a large catchment and found that the overall impact of land use changes in the Meuse basin is too small to be detected. In this study, impact of land use changes on WY and ET was more pronounced at the sub-basins scale as compared to the catchment scale.

Conclusion

This study analyzed the LULC changes and their impacts on hydrological components. The results showed that the Jhelum River Basin had experienced significant changes in LULC during the 18 years' interval. Five major LULC classes were identified which included agriculture, forest, grass, water and settlement. Among these land use, forest class showed significant increase in the 2001–2018 change period; this was at the expense of agriculture and grass.

However, a significant gain and lost was observed within each class like agriculture converted to forest and forest converted to agriculture. The main cause of significant increase in forest land was due to the increase of horticulture (cultivation of apple) practices in catchment.

The SWAT model simulated discharge was compared with observed discharge at the five different hydrological stations that lie at various geographical locations, for both calibration and validation during the period of 1995–2005. The NSE and R^2 values greater than 0.5 at daily time scale showed that the SWAT hydrological model could effectively reproduce discharge. The calibrated model was used to analyze the impacts of land use changes on the hydrological components.

Our analysis indicates that increase in forest (afforestation) would decline the surface runoff and WY while accelerate the ET over the JRB. This decrease in surface runoff was largely attributed to improve water infiltration and retention. The relative change in the hydrological components was proportional to the magnitude of forest change. Generally, decline in WY was attributed to greater water absorb by trees from the shallow or deep aquifer due to their deep roots and increase transpiration because of larger aerodynamic conductance. The spatial distribution of ET showed increase in most sub-basins. However, this increase was more pronounced in the

Table 11 LULC change and corresponding hydrological responses

Basin no.	Fraction LULC class area			ET (mm)			WY (mm)		
	2001	2009	2018	2001–2009	2009–2018	2001–2018	2001–2009	2009–2018	2001–2018
2 (Kunhar Basin)	AGRL:0.14	AGRL:0.09	AGRL:0.11	– 2.16	– 3.05	– 5.21	54.54	21.02	76.32
	FRST:0.14	FRST:0.13	FRST:0.12						
	RNGE:0.62	RNGE:0.60	RNGE:0.52						
	URMD:0.04	URMD:0.05	URMD:0.08						
	WATR:0.06	WATR:0.13	WATR:0.17						
3 (Neelum Basin)	AGRL:0.11	AGRL:0.09	AGRL:0.10	– 0.50	– 2.51	– 3.00	24.02	55.15	59.04
	FRST:0.29	FRST:0.29	FRST:0.29						
	RNGE:0.56	RNGE:0.55	RNGE:0.48						
	URMD:0.02	URMD:0.02	URMD:0.02						
	WATR:0.02	WATR:0.05	WATR:0.11						
15 (Upper Jhelum Basin)	AGRL:0.37	AGRL:0.37	AGRL:0.22	13.21	31.93	45.14	– 11.23	– 34.56	– 45.01
	FRST:0.20	FRST:0.25	FRST:0.38						
	RNGE:0.38	RNGE:0.29	RNGE:0.28						
	URMD:0.04	URMD:0.07	URMD:0.10						
	WATR:0.01	WATR:0.02	WATR:0.02						
16 (Upper Jhelum Basin)	AGRL:0.53	AGRL:0.59	AGRL:0.66	39.44	19.94	59.38	– 11.99	– 23.23	– 35.22
	FRST:0.12	FRST:0.17	FRST:0.21						
	RNGE:0.34	RNGE:0.22	RNGE:0.11						
	URMD:0.01	URMD:0.02	URMD:0.02						
	WATR:0.00	WATR:0.00	WATR:0.00						
17 (Upper Jhelum Basin)	AGRL:0.19	AGRL:0.15	AGRL:0.13	11.96	39.97	51.93	– 6.30	– 42.02	– 48.32
	FRST:0.19	FRST:0.25	FRST:0.29						
	RNGE:0.54	RNGE:0.51	RNGE:0.49						
	URMD:0.04	URMD:0.04	URMD:0.05						
	WATR:0.04	WATR:0.05	WATR:0.04						

AGRL agriculture, FRST forest, RNGE grass, URMD urban, WATR water

eastern part of the basin. On the other hand, WY was more pronounced in the northern part of the basin due to increase of snow cover. Our research findings would be helpful to water resources managers to consider the impact of land use changes in the Jhelum River Basin.

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