Understanding land use/land cover and climate change impacts on hydrological components of Usri watershed, India

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Abstract

Land use/cover (LULC) and climate are significant environmental factors that influence watershed hydrology across the globe. The present study attempts to understand the consequences of existing changing patterns of climate and LULC on the hydrology of the Usri watershed. Different water balance components were simulated using a semi-distributed Soil and Water Assessment Tool (SWAT) model. Sixteen scenarios were generated using combinations of four periods of climatic data (1974–84; 1985–1995; 1996–2006 and 2007–2016) and four sets of land use maps (1976; 1989; 2000 and 2014). The SWAT model performed well for monthly stream flows during calibration and validation. The study finds that the individual impact of LULC change contributes to increase in the streamflow and decrease in evapotranspiration (ET) primarily due to increase in urbanization and decrease in water bodies, forest cover and barren land of Usri watershed. The combined impact of climatic variations and land use change reveals complex interactions. The study provides insight into hydrological response to variations in climate and land use changes in Usri watershed in recent decades. The results of this study can be beneficial to the authorities, decision-makers, water resource engineers and planners for the best water resource management approaches in the perspective of climate change and LULC transformation of similar ecological regions as that of Usri.

Keywords SWAT model · Land use/cover · Climate · Streamflow

Introduction

Land use change and climate variability are important environmental components influencing water resource management and socioeconomic activities. They directly influence the policy framework along with planning activities required

for sustainable development (WMO 1966; Li et al. 2009; Wang et al. 2014a, b; Zhang et al. 2016; Yang et al. 2017; Sahoo et al. 2018). Changes in land use/land cover patterns and climate are dynamic. Prevalent process is mainly governed by natural phenomena and anthropogenic activities (Vitousek 1994; Southworth et al. 2004; Kamusoko and Aniya 2007; Xu et al. 2009; Günlü et al. 2009; Paul et al. 2017; Getachew et al. 2021). It has been observed that the changes in land use can significantly affect the streamflow, flood frequency, base flow, groundwater recharge and annual mean discharge of any watershed (Turner et al. 2001; Costa et al. 2003; Brath et al. 2006; Wang et al. 2006; Puno et al. 2019), whereas climate variability brings changes to hydrological regimes causes flow routing time, peak flows and volume (Prowse et al. 2006; Li et al. 2009; Mekonnen et al. 2018).

Quantifying the impact on the hydrologic responses of a watershed is a challenge due to its complex relationship with landscape, climate and hydrology. This makes it very important for the land use planner and water resource manager to understand and quantify these impact at a watershed scale. There are several studies that understand

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individual effect of either LULC or climate change on hydrological indicators (Ficklin et al. 2009; Wang et al. 2014a, b; Nirula et al. 2015). However, it is important to appreciate combined impact of these factors. There are few studies which understand combined impact of LULC and climate change (Mishra et al. 2009; Kim et al. 2013; Chawla and Mujumdar 2015; Yin et al. 2017).

The hydrological cycle is a system that is simple to understand, although it is difficult to quantify the processes within the system (Suryavanshi et al. 2017). Due to the complex nature of the hydrological processes, various models have been developed in the past to model the hydrological system (Arnold and Allen 1996). Models, such as the VIC model (Liang et al. 1994), Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS; Beasley et al. 1977), the Stanford Watershed Model or SWM/Hydrologic Simulation Package-Fortran IV (HSPF) (Crawford and Linsley 1966; Bicknell et al. 1997), Sacramento (Burnash et al. 1973), Agricultural Non-Point Source Pollution (AGNPS) (Young et al. 1995), Water Erosion Prediction Project (WEPP) (Lafren et al. 1991); Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998) have been extensively used for water resources management. There are several studies which use hydrological models to understand the impact of LULC and climate change on hydrological variables such as streamflow groundwater recharge etc. (Mishra et al. 2009; Nie et al. 2011; Dong et al. 2014; Nirula et al. 2015; Chawla and Mujumdar 2015; Yin et al. 2017; Zhang et al. 2018). Studies of change in land use and climate at regional and local scale are best suited and furnish insight to water resources planner. Numerous studies have been conducted in perspective of hydrological variables response to LULC and climate variability in a watershed using SWAT model (Mehdi et al. 2015; El-Khoury et al. 2015; Mishra et al. 2017; Yu et al. 2018; Bal et al. 2021; Bekele et al. 2021; Chiang et al. 2021; Lopes et al. 2021; Sinha et al. 2021; Teklay et al. 2021).

In this study, a semi-distributed hydrological model, namely SWAT, has been used to monitor, model and understand the variations in LULC and climate on hydrology of the watershed. For this study, Usri, a vulnerable watershed in the India state of Jharkhand, has been selected. Owing to its vulnerability and as per Jharkhand Space Application Centre (JSAC) (2010), Usri requires urgent development and management. Hence, investigation of this watershed is very important (Kumar et al. 2018). The aim of this work is to understand the impact of changes in land use and climate on hydrological indicators such as streamflow and evapotranspiration (ET) for a period of 43 years (1974–2016). To achieve this, one factor was changed at a time, whereas other factors were kept constant. Calibrated and validated SWAT model was used to simulate combination of 4 periods of climate

data and 4 land use maps, thereby generating 16 scenarios (S1, S2... S16) of varying land use and climatic conditions.

Materials and methods

Study area

Usri watershed is situated between 24°35' and 24°35'N latitudes and 86°00' and 24°35' E longitudes, with elevation of 210–390 m from the mean sea level (Fig. 1). The watershed is located in southeast part of district Giridih, Jharkhand. Climate of this area varies in seasons. December is observed to be the coldest month (20 °C), whereas in May month temperature peaks up to 45 °C. The study area is dominated by loamy and silty loam soil and has a subtropical climate with rainy during monsoon. Often high temperature is accompanied by high humidity levels, especially during the month of June where pre-monsoon rain occurs. The monsoon season starts from the middle of June and continues till end of September or middle of October, and maximum rainfall occurs during the month of July and August. The study area receives about 1100 mm of annual rainfall.

Data collection and analysis

The datasets and their sources are given in Table 1. The historic daily data of 46 years (i.e., 1971–2016) for rainfall, minimum and maximum air temperature, solar radiation, relative humidity, and sunshine hour were obtained from Ganga River Basin Management plan website (<http://gisriver.civil.iitd.ac.in/grbmp/downloaddataset.aspx>).

Soil data for study area have been obtained from National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur. Soils of the study area are classified as loamy (48.55%), silty loam (49.88%), clayey (1.53%), silty clay loam (0.04%). For topographical analysis of the watershed, Advanced Space-borne Thermal Emission and Reflection (ASTER) digital elevation (DEM) data were used. The monthly streamflow data at the outlet of the Usri gauging site for the period of 1985–2006 were obtained from Damodar Valley Corporation (DVC), Hazaribagh. Orthorectified Landsat satellite images for four-time period, namely October 1976, October 1989, October 2000, and September 2014, were downloaded from USGS site (<http://www.usgs.gov/in>). Based upon training areas and maximum likelihood decision rule, a supervised classification of the water shed was conducted as also suggested elsewhere (Yuan et al. 2005; Paudel and Yuan 2012; Srivastava et al. 2014; Kumar et al. 2018).

Fig. 1 Location map of study area

Table 1 Acquired datasets and their sources

Sl. No.	Parameters	Duration	Procured from
1.	Metrological database	1976–2013	http://gissserver.civil.iitd.ac.in/grbmp/downloaddataset.aspx
2.	Soil data		National Bureau of Soil Survey and Land Use Planning, Nagpur, India
3.	Advanced Space-borne Thermal Emission and Reflection (Slope, Elevation)		http://www.gdem.aster.ersdac.or.jp/
4.	Land Use, Land cover Map/Satellite data	1976, 1989, 2000, 2014	www.usgs.gov
5.	Streamflow Data	1985–2006	Damodar Valley Corporation (DVC), Hazaribagh

SWAT model

SWAT is a semi-distributed hydrological model that can predict the impact of anthropogenic practices on hydrological processes at different scales. Application of SWAT in runoff and sediment yield modeling (Srinivasan et al. 1993, 1998, 2010; Chaplot 2005; Setegn et al. 2008; Betrie et al. 2011; Murty et al. 2014; Suryavanshi et al. 2017; Snija et al. 2018) and climate change impact study (Wu and Johnston 2007; Ficklin et al. 2009; Moradkhani et al. 2010; Sridhar and Nayak 2010; Bae et al. 2011) has drawn noteworthy recognition over the past two decades. SWAT has also been used to understand impact of LULC and climate change (Wang et al. 2013; Zhang et al. 2013; Kim et al. 2013; EL-Khoury et al. 2015; Nirula et al. 2015; Yan et al. 2018). Water balance acts as a drive for SWAT (Neitsch et al. 2005). Water balance equation used by the SWAT is given (Eq. 1):

$$SW_t = SW + \sum_{t=1}^t (R - Q - ET - P - QR) \quad (1)$$

where SW_t represents the final soil water content in the end of selected period (mm), SW is the initial soil water content (mm), t is the time (days), R is the amount of precipitation (mm), Q is the amount of surface runoff (mm), ET is the amount of evapotranspiration (mm), P is percolation (mm), and QR is the amount of return flow (mm).

For the present study, SCS curve number method has been selected for runoff estimation. A storage routing technique combined with a crack-flow model was used to compute percolation. For estimation of ET , Hargreaves method was selected. This method provides options that give realistic results in most cases (Arnold et al. 1998; Williams et al. 2008).

SWAT model setup for the Usri watershed

The SWAT model setup was performed with the interface of ArcSWAT 2009.93.7 within ArcGIS software. Stream networks, delineation of catchment boundary from the DEM and further subdivision of the catchment into sub basins

were done using this interface. Based on the unique combination of soil, land use and slope, the sub-basins are further subdivided into Hydrological Response Units (HRUs). Total of 5 sub-watersheds and 180 HRUs are generated in the process. The weather data are integrated into the model along with the flow data in order to run the simulations. Monthly calibrations were performed using manual adjustment of input parameters to achieve acceptable agreement between synthetic and observed streamflow. Simulation reliability was examined using a validation process. Finally, the calibrated model is utilized to describe conclusions about the spatial aspects of the hydrological processes of Usri watershed.

Criteria for model evaluation

Different types of statistics provide useful numerical measures of the degree of agreement between model simulated and recorded quantities (Chaube et al. 2011; Murty et al. 2014). In this study, statistical criteria such as coefficient of determination, R^2 (Willmott 1981; Leages and McCabe 1999) and the Nash–Sutcliffe efficiency coefficient, E_{NS} (Nash and Sutcliffe 1970) were used to evaluate model performance as given by Eqs. 2–3, respectively, where Y_i^{obs} is the i th observed data, Y_{mean}^{obs} is the mean of observed data, Y_i^{sim} is the i th simulated value, and Y_{mean}^{sim} is the mean model simulated value (Eqs. 2 and 3):

$$R^2 = \left(\frac{\sum_{i=0}^n (Y_i^{obs} - Y_{mean}^{obs})(Y_i^{sim} - Y_{mean}^{sim})}{\sqrt{\sum_{i=1}^n (Y_i^{obs} - Y_{mean}^{obs})^2} \sqrt{\sum_{i=1}^n (Y_i^{sim} - Y_{mean}^{sim})^2}} \right)^2 \quad (2)$$

$$E_{NS} = 1 - \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - Y_{mean}^{obs})^2} \right] \quad (3)$$

Evaluation of impact of LULC and climate change

To assess the outcome of change in LULC and climate upon the hydrological response of Usri watershed, one-factor-at-a-time approach as suggested by Li et al. (2009) was utilized. Climatic datasets for the period of 1974–2016 were broken into four periods, i.e., 1974–1984, 1985–1995, 1996–2006 and 2007–2016, and LULC maps for the year 1976, 1989, 2000 and 2014 were used in this study (Fig. 2). By using these datasets, sixteen scenarios were designed, which are shown in Table 2. These scenarios will provide deeper insight into the impacts of land cover and climate change within the Usri watershed.

If the LULC map and meteorological datasets were of almost same time period, then it is termed as a real or baseline scenario and if the LULC and meteorological datasets are of different time periods, then it is termed as a hypothetical scenario. The difference between hydrological variables (streamflow and ET) for real and hypothetical scenarios will give the isolated and combined impact of climate and LULC change. For example, in scenario S1, the LULC of 1976 and climate data of 1974–84 period was used and therefore it is termed as a real or baseline scenario. In scenario S2, the LULC of 1989 and climate data of 1974–84 was used and therefore it is termed as a hypothetical scenario. The difference between streamflow obtained from scenario S2 and S1 would give the isolated impact of LULC during 1976–89 period. In scenario S5, LULC of 1976 and climate of 1985–95 was used and difference between streamflow

Table 2 Different scenario for assessing hydrological impacts of land use and climatic variability during 1974–2016

Scenarios considered	Land use	Timeline of considered climatic conditions (Temp., Rainfall.)
S1	1976	1974–1984
S2	1989	1974–1984
S3	2000	1974–1984
S4	2014	1974–1984
S5	1976	1985–1995
S6	1989	1985–1995
S7	2000	1985–1995
S8	2014	1985–1995
S9	1976	1996–2006
S10	1989	1996–2006
S11	2000	1996–2006
S12	2014	1996–2006
S13	1976	2007–2016
S14	1989	2007–2016
S15	2000	2007–2016
S16	2014	2007–2016

obtained by S5 and S1 would give the effect of climate change during 1974–95.

In scenario S6, LULC of 1989 and climate data of 1985–95 was used. The difference between streamflow obtained from S6 and S1 will give the combined effect of LULC and climate change during 1974–95 period. The percentage change in

Fig. 2 Land use/land cover maps of study area: **a** 1976; **b** 1989; **c** 2000; **d** 2014 (Modified after Kumar et al. 2018)

streamflow is due to individual LULC, climate and combined LULC and climate given by Eqs. 4a–c, respectively.

$$\Delta SR_{LULC}^{1985-95} = \left(\frac{S2 - S1}{S1} \right) \times 100 \quad (4a)$$

$$\Delta SR_{climate}^{1985-95} = \left(\frac{S5 - S1}{S1} \right) \times 100 \quad (4b)$$

$$\Delta SR_{combined}^{1985-95} = \left(\frac{S6 - S1}{S1} \right) \times 100 \quad (4c)$$

Similar analogy is adopted for studying the individual and combined impact of LULC and climate parameters on streamflow and ET for other time periods (i.e., 1996–2006 and 2007–2016).

Results and discussion

Evolution of the SWAT model for Usri Watershed

This procedure includes calibration and validation of SWAT model. Manual calibration has been adopted for this study. Before starting to calibrate, few important observations of the model developer and users of the model were studied; this helped in deciding the parameters to be adjusted. The parameters such as threshold depth of water in the shallow

aquifer for percolation to occur (REVAPMN), Manning coefficient for main channel (CH_N₂), SCS runoff Curve Number for moisture condition II (CN₂), plant evaporation compensation factor (EPCO) and available water capacity of the soil layer (Soil_Awc) were used for model calibration. Value between lower and upper limits has been taken to perform the model. The default model value and calibrated values used in the SWAT model are presented in Table 3.

For calibration, observed monthly streamflow at Usri gauging site was equated with the model simulated streamflow as shown in Figs. 4 and 5. For calibration purpose, model run was performed between years 1985–1995 (11 years) with land use of year 1989. It is evident from Fig. 3 that the peak values of the simulated monthly streamflow closely match with observed one but at different magnitude. It is noticed from Fig. 4 that the simulated streamflow values are dispersed uniformly about the 1:1 line for lower values of observed streamflow; however, the model slightly under-predicts the high values of discharge. A satisfactory value of R^2 , i.e., 0.87, and E_{NS} model efficiency, i.e., 0.76, indicate a familiarity between the observed and simulated streamflow as shown in Table 4. The result obtained from SWAT model gives the satisfactory result of monthly discharge of the watershed which allows for the further investigation.

For further utilization of the model, the calibrated model evaluated against a different set of measured streamflow during 1996–2006 (11 years) with land use of year 2000 at Usri site. The observed monthly streamflow and simulated monthly streamflow of Usri site for the validation period were compared as shown in Figs. 5 and 6. Simulated monthly streamflow and observed monthly streamflow show a good consensus of Usri watershed site which is shown in Fig. 4. The simulated peaks are, however, marginally under-predicted from the measured spikes for the months of Aug–Sept 1996, Aug 1998, Sept 2000, Sept 2001, Sept 2002, July 2004 and Sept 2006. It is evident (Fig. 6) that most of the compared points are uniformly distributed for

Table 3 Initial and calibrated parameter values

Sl. No.	Parameter	Default value	Values after calibration
1	Revapmn	10.0	11.5
2	CH_N ₂	0.014	0.10
3	Cn2	Varies	5% increase
4	EPCO	1	0.01
5	Soil_Awc	0–1	0.5

Fig. 3 Observed and simulated streamflow (calibrated) for June 1985–1995

Fig. 4 Comparison between the observed and simulated streamflow for the years 1985–1995 for model calibration

Table 4 Statistical analysis of observed and simulated monthly streamflows during calibration (1985–1995) and validation (1996–2006) process

Statistical parameters	Streamflow (m ³ /sec) during calibration (1985–1995)		Streamflow (m ³ /sec) during validation (1996–2006)	
	Observed	Simulated	Observed	Simulated
Mean	53.88	45.07	48.15	45.57
Maximum	122.2	114.5	96.15	89.57
Count	44	44	44	44
Coefficient of determination	0.87		0.83	
Nash–Sutcliffe efficiency	0.76		0.82	

lower discharge, but for the higher values of discharge, the simulated values are slightly below 1:1 line.

Table 4 shows the statistics for all the year of streamflow. It has been observed that coefficient of determination and Nash–Sutcliffe model efficiency was found to be close (0.83 and 0.82) for the year 1996–2006. For the model validation, the coefficient of determination (R^2) and Nash–Sutcliffe model efficiency (E_{NS}) were found to be 0.83 and 0.82, respectively, which reflect a close agreement between the simulated monthly streamflow and observed monthly streamflow for the years 1996–2006. The calibration and validation results indicate good streamflow simulations as per the model evaluation guidelines given by Moriasi et al. (2007). Hence, results indicate overall prediction of monthly

Fig. 5 Observed and simulated streamflow for 1996–2006 for model validation

Fig. 6 Comparison between the observed streamflow and simulated streamflow of 1996–2006 for model validation at Usri

Table 5 Average annual hydrological components in different land use classes with climatic condition (C1)

Scenarios	Land use	Climate (C1)	Precipitation (mm/year)	Stream-flow (mm/year)	Groundwater contribution to streamflow (mm/year)	ET (mm/year)
S1	1976	1974–1984	975.8	500.63	106.38	375.4
S2	1989	1974–1984	975.8	519.68	99.65	358.8
S3	2000	1974–1984	975.8	662.53	12.55	311.2
S4	2014	1974–1984	975.8	668.78	10.52	307.2

Table 6 Average annual hydrological components in different land use classes with climatic condition (C2)

Scenarios	Land use	Climate (C2)	Precipitation (mm/year)	Stream-flow (mm/year)	Groundwater contribution to streamflow (mm/year)	ET (mm/year)
S5	1976	1985–1995	1083.4	574.43	117.58	391.8
S6	1989	1985–1995	1083.4	595.3	110.12	376.3
S7	2000	1985–1995	1083.4	746.93	12.34	331.8
S8	2014	1985–1995	1083.4	753.00	11.01	328.2

Table 7 Average annual hydrological components in different land use classes with climatic condition (C3)

Scenarios	Land use	Climate (C3)	Precipitation (mm/year)	Streamflow (mm/year)	Groundwater contribution to streamflow (mm/year)	ET (mm/year)
S9	1976	1996–2006	944.9	490.89	103.67	357.9
S10	1989	1996–2006	944.9	508.18	96.09	344
S11	2000	1996–2006	944.9	637.54	11.01	308.6
S12	2014	1996–2006	944.9	642.25	8.97	306.1

streamflow by the SWAT during the calibration and validation period was satisfactory and therefore accepted for further analysis.

Impact of LULC and climatic variability on hydrology under a hypothetical scenario

In order to assess the impact on hydrology due to land use and climatic factors, different land uses are compared with

Table 8 Average annual hydrological components in different land use classes with climatic condition (C4)

Scenarios	Land use	Climate (C4)	Precipitation (mm/year)	Streamflow (mm/year)	Groundwater contribution to streamflow (mm/year)	ET (mm/year)
S13	1976	2007–2016	1109	643.17	111.27	355.6
S14	1989	2007–2016	1109	665	105.25	337
S15	2000	2007–2016	1109	808.27	13	294.7
S16	2014	2007–2016	1109	814	10.87	291.3

the different climatic conditions. Rainfall with hydrological components such as streamflow, groundwater contribution to streamflow (GwQ) and evapotranspiration (ET) simulated by SWAT with different land use patterns and climatic conditions is presented in Tables 5, 6, 7 and 8. Table 5 shows the different hypothetical scenarios S1, S2, S3, and S4 implying the sole effects of land use change with climatic condition of 1974–1984. Similarly, Tables 6, 7 and 8 exhibit the hypothetical scenarios S5, S6, S7 and S8 with climatic condition of 1985–1995; hypothetical scenarios S9, S10, S11 and S12 with climatic condition of 1996–2006 and hypothetical scenarios S13, S14, S15 and S16 with climatic condition of 2007–2016.

By comparing the baseline scenario (Table 5) S1 (land use, 1976; climatic condition 1974–1984) with S2, S3 and S4, it was found that there is an increase of streamflow (19.05 mm, 161.90 mm and 168.15 mm in 1989, 2000 and 2014, respectively) in S2, S3 and S4 scenarios. However, a decline in GwQ (−6.73 mm, −93.83 mm and −95.86 mm) and ET (−16.60 mm, −64.20 mm and −68.20 mm) was found. Similar results (increase in streamflow and decrease in GwQ and ET) can be observed in different hypothetical scenarios of S5–S16 although with different magnitudes (Tables 6, 7, 8).

Kumar et al. (2018) conducted a study on land use change in Usri watershed for years 1976, 1989, 2000 and 2014. The results obtained from the study concluded that there was an increase of settlement (3% in 1976 to 17% in 2014) and agriculture (25% in 1976 to 41% in 2014). That study also reveals that a decline in total forest cover (dense and open forest) (28.75% in 1976 to 14.89% in 2014) and barren land (36% in 1976 to 24% in 2014). The changes in land use pattern (as suggested by Kumar et. al. 2018) may be a reason for increasing streamflow and decreasing GwQ and ET. The results infer the sole effect of land use change between the given hypothetical scenarios in Usri watershed.

In this study, the influence of climatic variability upon the hydrology of Usri watershed has been assessed. In order to do so, comparisons were made using the hypothetical scenarios (S1, S5, S9 and S13), where similar land use (1976) was compared with different climatic conditions (1974–84, 1985–95, 1996–2006, 2007–16) (Tables 5, 6, 7, 8). Result exhibits that increase in precipitation by 107.6 mm (with

scenario S1 and S5) causes increase in streamflow by 73.80 mm, whereas decrease in precipitation by 138.5 mm (with scenario S5 and S9) causes decrease in streamflow by 83.54 mm. Similarly, increase in precipitation by 164.1 mm causes increase in streamflow by 152.28 mm (scenario S9 and S13). The obvious distinctions between S1, S5, S9, and S13 indicate the effects solely originate by climate variability. Repeated trial (scenarios S2, S6, S10 and S14; S3, S7, S11 and S15; S4, S8, S12, S16) (Tables 5, 6, 7, 8) also shows that increase in rainfall causes increase in streamflow and decrease in rainfall causes decrease in streamflow. The findings of hypothetical scenarios explain that both LULC and climatic variability have a noteworthy and intermingled effect on the hydrology of Usri watershed.

Impact of LULC and climatic variability on hydrology under real scenario

In order to understand the hydrology of Usri watershed, the real scenario is presented where land use and climatic variability changes simultaneously. The climatic conditions of 1974–1984 were chosen with land use of 1976 (S1); climatic conditions of 1985–1995 were chosen with land use of 1989 (S6); climatic conditions of 1996–2006 were chosen with land use of 2000 (S11) and climatic conditions of 2007–2016 were chosen with land use of 2014 (S16) (Tables 5, 6, 7, 8). The result exhibits that increase in precipitation (S1 with S6) and change in land use causes increase in streamflow by 94.67 mm, increase in GwQ by 3.74 mm and ET by 3.74 mm. However, change in land use and decrease in precipitation (S6, S11) also tend to increase in streamflow by 42.24 mm, decrease in GwQ by 99.11 mm and decrease in ET by 67.7 mm indicate that combined effect of land use and precipitation play an important role. Again increase in precipitation with different land use (S11, S16) causes increase in streamflow by 176.46, decrease in GwQ by 0.14 and decrease in ET by 17.3 mm.

Discussions

Isolated impact of LULC on streamflow and ET

LULC contributes to increase in the streamflow during all the three periods analyzed. During 1985–1995, 1996–2006 and 2006–16, the streamflow increased by 3.8%, 25.4% and 0.7%, respectively (Fig. 7a, b). The increase in streamflow is primarily due to urbanization, which results in reducing infiltration, thus increasing the surface runoff. During 1974–2014, the settlement area increased by 398% resulting in greater streamflow. The maximum increase in streamflow was observed during 1996–2006 period. During that period, the percentage area under settlement increased from 8% in 1989 to 13.5% in 2000. During 2006–2016 period, the percentage area under settlement further increased to 16.8% resulting in an increase in streamflow. Urbanization leads to increase in impervious areas, resulting in a decreased soil infiltration. With the reduction in base flow contribution to stream flow, the surface runoff increases, which proceeds in more recurrent and severe flooding (Rose and Peters 2001; Kim et al. 2002; Huang et al. 2008; Wang et al. 2014a, b). The increase in streamflow is also attributed to decrease in water bodies and forest cover.

Fig. 7 **a** Individual and combined impact of LULC and climate on surface runoff; **b** individual and combined Impact of LULC and climate on ET

LULC results in decrease in ET during all the three periods analyzed. During 1985–1995, 1996–2006 and 2006–16, the ET decreased by 4.4%, 11.8% and 0.8%, respectively. Decrease in ET is primarily due to decrease in forest cover, water bodies and barren land. The forest cover, water bodies and barren land during 1974–2014 period were reduced by 92%, 54% and 30%, respectively. During 1976, the percentage area under forest cover was 28% which reduced to 23.7% in 1989 and further reduced to 19.4% and 2% during 2000 and 2014, respectively. The percentage area under water bodies also reduced from 6% in 1976 to 5.1% in 1989 and further reduced to 3.5 and 2.7% during 2000 and 2014, respectively. Similarly, the percentage area under barren land was 36% in 1976, which reduced to 34% in 1989 and further reduced to 30% and 24% during 2000 and 2014, respectively. The percentage area under agriculture increased from 25% in 1976 to 28.5% in 1989 and further increased to 33% and 40% during 2000 and 2014, respectively. Liu et al. (2003) reported that the forest area contributes to the largest fraction of the total ET. During 1974–2014 period, agriculture area also increased by 22%, but its contribution to total ET was less as compared to that of forest land (Liu et al. 2003).

Isolated impact of climate variability on streamflow and ET

Climate variability contributes to the increase in the streamflow during 1985–1995 and 2007–16 period, whereas streamflow decrease during 1996–2006 (Fig. 7a). During 1985–1995 and 2006–16, the streamflow increased by 14.7%, and 26.7%, respectively, and during 1996–2006, it decreases by 14.6%. The average precipitation increased from 975.8 mm during 1974–84 period to 1083.4 mm in 1985–1995 period, which resulted in an increase in streamflow. During 1996–2006, the average precipitation reduced to 945 mm which results in a decrease in streamflow. During 2007–16 period, average precipitation increased from 945 to 1109 mm; this also resulted in increase of streamflow.

Climate variability results in increase in ET during 1985–1995 period, and it decreases in 1996–2006 and 2007–16 period (Fig. 7b). During 1985–1995, ET increased by 4.3% and during 1996–2006 and 2007–16 period it decreased by 8.5% and 4.5%, respectively.

Combined impacts of LULC and climate changes on streamflow and ET

Combined effect of LULC and climate change showed an increase in the streamflow during all the three period analyzed (Fig. 7a, b). During 1985–1995, 1996–2006 and 2006–16, the streamflow increased by 18.9%, 7% and 27.6%, respectively. The percentage area under settlement increased during all the three periods considered. During

Fig. 8 Runoff-to-rainfall ratio (RR) and dryness index (ET/P) during 1974–2016

1985–1995 and 2006–16 periods, there was a greater percentage increase in streamflow as compared to 1996–2006. This is primarily due to combined effect of increase in precipitation and urbanization. In spite of reduced precipitation during the period from 1996–2006, the increase in streamflow was observed, primarily due to LULC change. Combined effect of LULC and climate change results in a marginal increase in ET during 1985–1995 periods, and then, it decreases during 1996–2006 and 2007–16 period. During 1985–1995, there was an increase of 0.24% and during 1996–2006 and 2007–16 ET decreased by 18% and 5.6%, respectively.

Runoff-to-rainfall ratio (RR) and dryness index (ET/P) were also computed for the four baseline scenarios (S1, S6, S11 and S16), and it was found that LULC and climate variability contribute to an increase in runoff-to-rainfall ratio and decrease in dryness index (Fig. 8).

Compared to 1974–84 period, the RR increased by 43% during 2007–16 period and dryness index reduced by 31.7%. There was an increase in precipitation and runoff by 13% and 62.6%, respectively, and decrease in ET by 22.4% during 1974–84 to 2007–16 period.

Common to many Indian watersheds, Usri is exposed to the pressure of developing urban and rural population and climate-related hazards. Consequently, appropriate management decisions and actions by the government unit focusing on the restoration of natural resources have to be given into consideration.

Conclusions

This research investigates the individual and combined impact of land use change and climatic variations in Usri watershed implying a semi-distributed SWAT model. The results affirm that:

- SWAT is an accurate model for diagnosis of the Usri watershed and can be further utilized for analysis.
- Isolated impact of LULC on streamflow and ET reveals that due to increase in urbanization and decrease in water bodies, forest cover and barren land (LULC change), there are an increase in streamflow and decrease in ET in Usri watershed.
- The isolated impact of climate variability also reveals the same trend of streamflow and ET, although with different magnitudes.
- The combined impacts of LULC and climate variability on streamflow and ET reveal an intricate relation between land use change and climate variability in the Usri watershed.

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Declarations

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