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Impact assessment of land use/land cover changes on surface runoff characteristics in the Shetrunji River Basin using the SWAT model

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ABSTRACT

Land use/land cover (LU/LC) change has a considerable effect on the runoff characteristics of any watershed. LU/LC change studies are necessary for policymakers to identify the challenges and adopt the course of action such as soil and water conservation measures for improvement. The current research is undertaken for the upper Shetrunji River basin using a hydrological model linked with GIS. Input data like LU/LC, meteorological, and soil elements are necessary to execute watershed modeling. The model was calibrated and validated in SWAT-CUP using the SUFI-2 algorithm. The data from 2000 to 2010 were utilized for calibration, whereas the data from 2011 to 2020 were used for validation with a three-year warm-up period from 1997 to 1999. LU/LC change detection has been accomplished using ERDAS IMAGINE 2015 via a supervised classification approach. Close agreement was obtained between simulated and observed streamflow data during model calibration (NSE $=0.74$ and $R^2=0.78$) and validation (NSE $=0.70$ and $R^2=0.73$). LU/LC change detection shows that agricultural, urban, and water body areas increased between 2000–2010 and 2010–2020, and forest areas increased in 2010 and decreased in 2020. Thus, it is concluded that the change in LU/LC significantly influenced the runoff of the upper Shetrunji River basin.

Key words: GIS, Landsat image, LU–LC, remote sensing, Shetrunji River basin

HIGHLIGHTS

- The study has been made for a water-scarce area of India.
- Modern technique of data collection in fastest manner (remote sensing) is used for analysis to get quick and reliable results.
- The study relates to the problems of man-made changes to the Earth’s surface, thereby tilting the balance of water.

INTRODUCTION

Land use/land cover (LU/LC) change is one of the most important factors affecting the runoff characteristics of any catchment. For efficient water resource management and land use planning, knowledge of the relationship between runoff and LU/LC change is essential. LU/LC changes in the catchment, whether for short or long periods, are crucial, due to their impact on the hydrological and ecological characteristics of the area (Abbas *et al.* 2015).

For the improvement and growing needs of the Indian population, optimal management of water resources is a quintessential necessity. The National Water Policy of India (2002) recognizes the need for national viewpoints to control the improvement and management of water resources to develop and conserve finite water resources in a balanced and ecologically sound manner. One of the most important concerns in a watershed is the impact of LU/LC changes, watershed development on soil loss and population expansion, as well as water quantity and quality. Changes in land use can disrupt the hydrological cycle by affecting the basin’s baseflow and annual mean discharge (Wang *et al.* 2014). The demand for various land uses within the watershed has been increasing by the rapid expansion of the population and the need for economic development. As a result, efforts to carry out integrated optimum planning to achieve sustainable uses of these watershed resources have been critical in examining the spread of such problems, which have been encountered by various developing nations.

Prediction of surface runoff is one of the most efficient potentials of a GIS system. The prediction may be used to identify the characteristics of floods, utilized in the forecasting of the movement of water-borne contaminants, or help in reservoir management (Jain *et al.* 1996). Hydrological modeling is a robust way of hydrologic system

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study for both the practicing water resources engineers and the research hydrologists who are engaged in the planning and development of the integrated strategy for the management of water resources (Schultz 1993). Hydrologic models may be regarded as the mathematical or symbolic representation of acknowledged or presumed functions communicating the various aspects of a hydrologic cycle. The susceptibility to the resulting environmental stresses depends on two sets of factors: one, losses in these water systems (such as rainwater runoffs, floods, and groundwater contamination), which will eventually determine what fraction of resources are available for human use (where we focus mainly on irrigation and potable water), and two, existing use patterns.

It is well established that LU/LC change varies by geographic location, and the causes are frequently influenced by the ecological, socioeconomic, and historical–political environment (Lambin & Geist 2003; Das *et al.* 2018). Changes in land use in the watershed modify the hydrological response, which can have negative consequences such as increased runoff and erosion, as well as worsen drought and flood susceptibility. Hibbert (1967) saw a massive increase in water output when forest cover was reduced. Hollis (1975) determined that urbanization increases runoff after evaluating several studies. However, because experimental approaches for studying hydrological responses to land use change take time, hydrological models are increasingly being utilized to estimate the impact of land use changes. Through a model sensitivity analysis, Fohrer *et al.* (2001) employed a physically based model to estimate the impact of land use changes. Despite the availability of a variety of empirical and physically based watershed models (Arnold *et al.* 1998), the SWAT (Soil and Water Assessment Tool) 2012 model was employed in this research as it is a semi-distributed empirical model capable of giving good prediction after calibration. Das *et al.* (2018) assessed the impact of LU/LC change on the runoff, baseflow, and evapotranspiration dynamics in eastern Indian river basins during 1985–2005 using the variable infiltration capacity (VIC) approach. In this study, decadal LU/LC maps of 1985, 1995, 2005, and predicted-2025 of the Subarnarekha, Brahmani, Baitarani, Mahanadi, and Nagavali River basins of eastern India were analyzed in the framework of the VIC macroscale hydrologic model to estimate their relative consequences. LU/LC alterations via deforestation, urbanization, and cropland expansions led to reduced canopy cover for interception and transpiration that in turn contributed to the overall decrease in ET and the increase in runoff and baseflow. Munoth & Goyal (2020) applied the SWAT model to evaluate the LU/LC change impact on runoff and sediment yield of the Upper Tapi River Sub-basin, India. This study was conducted on four land use maps 1975, 1990, 2000, and 2016. Results of this study showed that LU/LC changes have resulted in a corresponding increase in surface runoff, water yield, and sediment yield. These studies indicate that the impact of land use changes on runoff characteristics varies from place to place. Therefore, it becomes imperative to assess the effect of LU–LC change on runoff characteristics in the area of interest, especially where unique features exist in such area. Chilagane *et al.* (2021) used the SWAT model to quantify the impact of land use and land cover dynamics on catchment water balance and sediment loads. There is a lot of evidence that SWAT can be used to model hydrological response under various LU/LC (Asres & Awulachew 2010; Bosch *et al.* 2011; Fiseha *et al.* 2012; Mengistu & Sorteberg 2012). SWAT simulates many hydrological processes, such as evapotranspiration, percolation, canopy storage, lateral and groundwater flow, surface runoff, and so forth. SWAT model use is very common in the discipline since it is open-source software with a predefined database that can be easily customized by the user (Gassman *et al.* 2014). SWAT is a daily time interval river basin size model. SWAT is an effective tool for hydrologic modeling because it can quantify long-term hydrological responses in a short amount of time. Weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, stream routing, and pond/reservoir routing are all included in the SWAT model for appropriate watershed modeling (Arnold & Fohrer 2005).

Human activities have mostly caused changes in the LU/LC class. To determine the future influence of LU/LC class changes on overall runoff, it is necessary to assess the long-term effects of LU/LC class changes on overall runoff characteristics (Wang *et al.* 2014). The present study evaluates the LU/LC class change and its impact on surface runoff (hydrological behavior) of the upper Shetrunji River basin in terms of water quantity and timing of hydrologic occurrence. The outcomes of this study could help watershed managers to develop sustainable LU/LC planning and water resource management.

STUDY AREA

The Shetrunji River is an important river in Saurashtra. Starting from Junagadh's Gir forest, it flows eastward, discharging in the Gulf of Khambhat. This east-flowing river is 277 km long. The basin is generally located between 70°50′ and 72°10′ East longitudes and 21°00′ and 21°47′ North latitudes. The Khodiyar and Shetrunji dams are located on the Shetrunji River, 55 and 160 km, respectively, from the river source. The entire basin is divided into two parts: upper and lower Shetrunji basins (Figure 1). This study is conducted in the upper Shetrunji River basin, which covers 3,573 square kilometers of area.

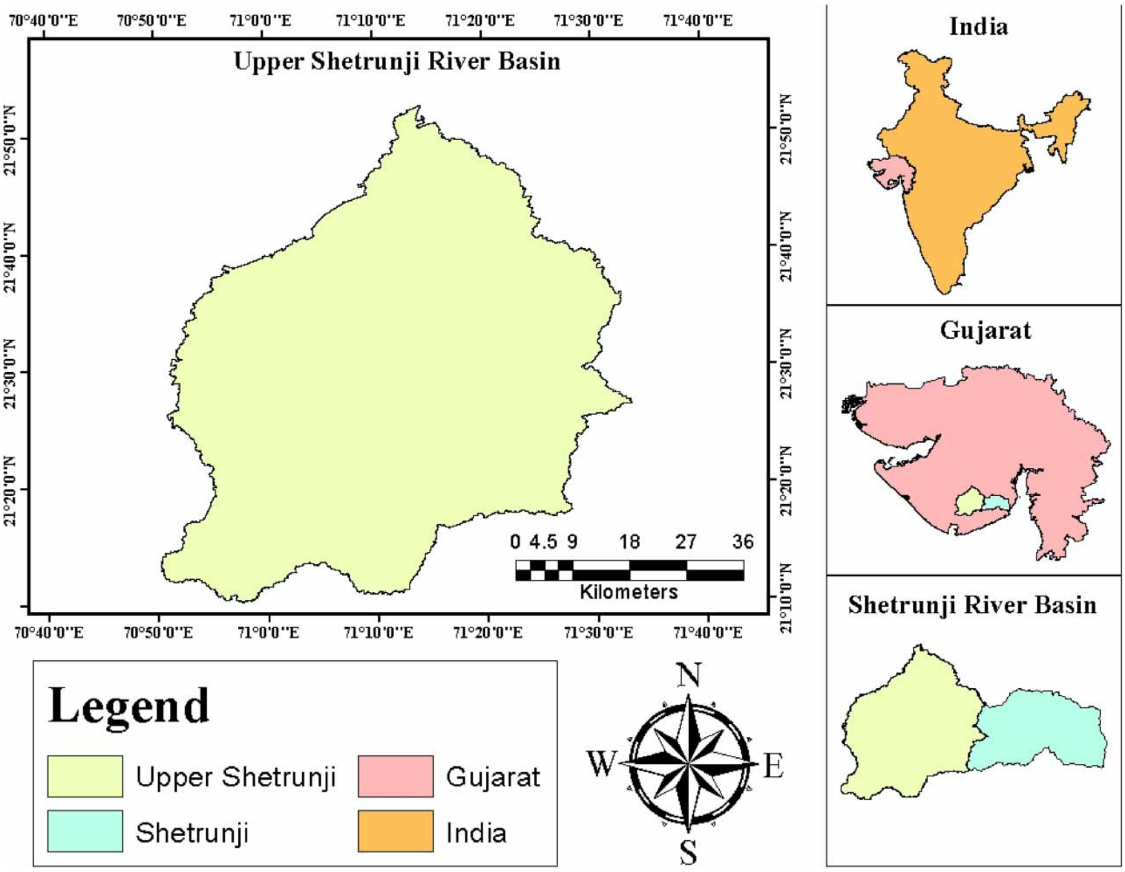

Figure 1 | Study area.

MATERIALS AND METHODOLOGY

The collected data of different parameters were used in analysis and the SWAT model was set up and evaluated.

SWAT model

SWAT is a physically based semi-distributed hydrologic model operating on a daily time step and uses a modified Soil Conservation Service-Curve Number (SCS CN) method to calculate runoff. It was developed by the USDA Agricultural Research Service (USDA ARS) and Texas A&M Agri-Life Research to predict the impact of various land uses and management practices on water, sediments, and agricultural chemical yields in large complex watersheds over long periods (Neitsch *et al.* 2011). The model allows the user to quantify the relative impact of management, soil, climate, and vegetation changes at the sub-watershed level (Hjelmfelt 1991; Arnold & Allen 1998). Because SWAT is also a deterministic model, each successive model run that uses the same inputs will produce the same outputs. This type of model is preferred for isolating hydrologic response from a single variable, such as land cover and land use change (e.g., management decisions), allowing the impact of any change to be isolated and analyzed for its effect on hydrologic response.

Digital elevation model (DEM)

ASTER DEM with 30 m resolution, downloaded from USGS, was used in the delineation and other topographic processing of the watershed. To minimize processing time, the study area was clipped and masked before processing.

Land use/land cover map preparation

In this study, LU/LC map was prepared by ERDAS IMAGINE 2015 by processing satellite images including image enhancement, preprocessing, and LU/LC classification. Landsat images for the years 2000, 2010, and 2020 were downloaded from the website of USGS (https://earthexplorer.usgs.go).

Remote sensing data acquisition

Landsat 5 TM (2000), Landsat 7 ETM + (2010), and Landsat 8 OLI/TIRS (2020) cloud-free images of the research area with the Path of 149 and row 045 were collected (downloaded) from the earth explorer. usgs.gov website (USGS). The data downloaded are in the world datum (WGS84) projection system. A detailed description of the satellite data used is shown in Table 1.

Table 1 | Description of satellite data used in the present study

Sr. No.	Image	Year	Resolution	Sensor	Path	Row	Multispectral band	Source
1.	Landsat 7	2000	30 × 30	ETM	149	45	1 to 5 and 7	USGS
2.	Landsat 5	2010	30 × 30	TM	149	45	1 to 5 and 7	
3.	Landsat 8	2020	30 × 30	OLI and TIRS	149	45	1 to 7 and 9	

Soil map

A digital soil map of the world in shapefile format was downloaded at 1:5.000.000 scale from the Food and Agriculture Organization of the United Nations (FAO) GeoNetwork (http://www.fao.org) website. Using ArcGIS spatial analysis tools, the essential soil data for the research region (upper Shetrunji River basin) was collected from the world soil map and projected using the WGS-1984/UTM zone 42 projected coordinate system.

Weather data

Daily rainfall data of the Shetrunji basin were downloaded from IMD Pune in gridded format. These data were converted into a SWAT format using ArcGIS. Temperature, relative humidity, solar radiation, and wind speed were obtained from NASA POWER.

Streamflow records

SWAT is designed to predict the impact of land use and management on water, sediment, and agricultural chemical yields in ungauged watersheds (Srinivasan *et al.* 2010). The model is run and applied even in the absence of data for calibration and validation. However, calibration and validation are still imperative in hydrologic modeling studies whenever feasible. Historical streamflow data from 1997 to 2020, collected by the Central water commission, Mahi division, through the establishment of a hydrograph and installation of staff gauge were used to calibrate and validate the model. Streamflow data were in the form of daily flow rate with a unit of l/s and were averaged to monthly discharge with a unit of m^3/s. The availability of observed streamflow data in the Shetrunji basin enabled the model calibration, validation, and uncertainty analysis before it was applied for LU/LC change evaluation. This is a much better approach than not performing any model calibration and validation, as in other studies, without observed streamflow data. Attempts have been made to utilize longer and recent flow data. Simulation using monthly time steps was done in this study for practical purposes as SWAT has been designed for continuous hydrologic modeling. Moreover, monthly streamflow simulation would suffice for water management strategies. The first 3 years of the streamflow data were used for model calibration while the remaining 4 years were used for validation.

Setting up of the model

The watershed boundary was delineated from ASTER DEM 30 and was discretized into seven sub-watersheds using 1,000 ha as a minimum threshold for the upstream drainage area. The stream network was corrected based on 2014 Google Earth images and used as a burn-in to improve the accuracy and precision of watershed boundary delineation. An additional sub-basin outlet was manually added along the stream. Rasterized DSMW soil maps and land cover maps were reclassified and overlaid with slope maps creating 23 hydrologic response units (HRUs). HRUs are sub-watershed units treated as a homogeneous block of land use, management techniques, and soil properties (Hjelmfelt 1991; Arnold & Allen 1998). Since a significant portion of the catchment is mountainous, the orographic effect on precipitation was incorporated into the model through the setting up of elevation bands. Elevation bands were set with a specific interval from 200 to 700 m. The model uses Manning's equation to define the rate and velocity of flow and water is routed through the channel network using the variable storage routing method. To simulate plant development, SWAT utilized plant growth parameters summarized in the SWAT database. Leaf area index (LAI) and biomass were calculated based on these growth parameters. For this component, the model employs the heat unit theory in which plant growth and development are predicted based on the amount of heat absorbed. Finally, the model was run using the SCS CN method to calculate surface runoff and the Penman–Monteith equation to calculate evapotranspiration.

Model evaluation

RMSE (root mean square error) is also a commonly used statistic used to indicate the degree of closeness of predicted values to observed values. MAE (mean absolute error) and scatter index (SI) are other such indicators to describe model performance (Najafzadeh *et al.* 2022). To evaluate the simulating power of the model in the present study, the coefficient of determination, R^2, and Nash–Sutcliffe model efficiency (NSE) were used during model calibration and validation. A scatter plot of simulated and measured data together with their linear fit plotted against a 45° line was also used. The NSE (Nash & Sutcliffe 1976) was computed using Equation (1):

$$\mathrm{NSE} = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} (Q_o^t - \bar{Q}_m)^2} \tag{1}$$

where Q_o is the mean of observed discharges and Q_m is modeled discharge. Q_o^t is the observed discharge at time t. NSE can range from $-\infty$ to 1. An efficiency of 1 ($\mathrm{NSE} = 1$) corresponds to a perfect match of modeled discharge to the observed data. An efficiency of 0 ($\mathrm{NSE} = 0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($\mathrm{NSE} < 0$) indicates that the observed mean is a better predictor than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is.

The coefficient of determination (R^2) was computed using Equation (2):

$$R^2 = 1 - \frac{\mathrm{SS}_{\mathrm{rest}}}{\mathrm{SS}_{\mathrm{tot}}} \tag{2}$$

where $\mathrm{SS}_{\mathrm{tot}}$ is the total sum of squares and $\mathrm{SS}_{\mathrm{rest}}$ is the sum of squares of residuals. All calibration, validation, and uncertainty analyses were performed through SWAT Calibration and Uncertainty Program (CUP).

RESULTS AND DISCUSSION

LU and LC change detection analysis

The study area's LU/LC patterns have shown a considerable shift between 2000 and 2020. Agricultural land covered more than 82% of the area in all of the research years among the five main LU/LC groups. From 2000 to 2020, the urban area has grown. It went from 0.89% in 2000 to 1.49% in 2010 and 2.77% in 2020. From 2000 to 2010, the spread of forests increased. It went up from 2.41% in 2000 to 3.25% in 2010 and then fell to 2.6% in 2020. From 2000 to 2020, the water body fluctuated. The percentage of water bodies has also risen from 0.27% in 2000 to 0.71% in 2010 and subsequently to 1.46% by 2020. Agricultural land grew from 74.12% in 2000 to 76.23% in 2010, and then to 82.32% in 2020. From 2000 to 2020, there was a steady decline in pasture land. It was 22.32% in 2000, 18.33% in 2010, and 10.84% in 2020 (Table 2).

The research area's LU/LC change patterns revealed that pasture land has reduced by 407.18 km². Other classes exhibited rising and variable area coverage. The LU/LC fluctuations in the study region are shown in Figures 2 and 3.

As per Table 3, the major LU/LC groups in 2000 were agricultural and shrubland, according to the results of the LU/LC classification. These groups covered 96.62% surface area. Agricultural land accounted for 3,023.85 km² (85.58%) of the total area of 3,533.5 km², while shrubland accounted for 390.02 km² (11.04%).

Table 2 | LU/LC scenario and net changes between 2000 and 2020

		2000		2010		2020		
S. No.	**LU/LC classes**	**Area (km²)**	**Area (%)**	**Area (km²)**	**Area (%)**	**Area (km²)**	**Area (%)**	**Net change from 2000 to 2020**
1.	Water	9.5301	0.27	25.0488	0.71	51.8004	1.46	42.27
2.	Urban	31.5162	0.89	52.7076	1.49	98.3025	2.77	66.78
3.	Agricultural	2,629.675	74.12	2,704.667	76.23	2,921.012	82.32	291.34
4.	Forest	85.446	2.41	115.38	3.25	92.3076	2.60	6.85
5.	Pasture	791.926	22.32	650.3688	18.33	384.745	10.84	−407.18

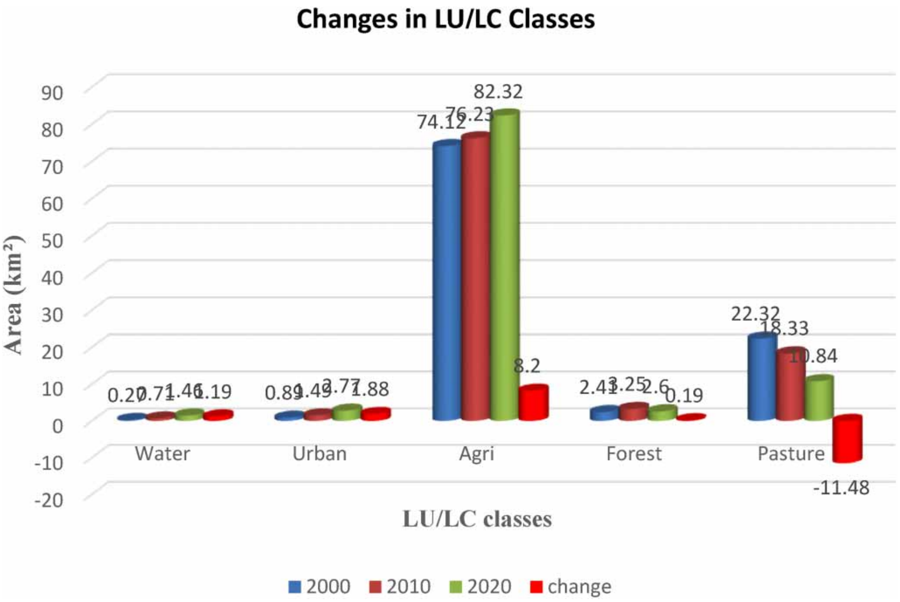

Figure 2 | LU/LC changes during 2000–2020.

The built area, plantation, and water body together accounted for 119.63 km² (3.38%) of the total area. Water bodies took up the least amount of space compared to the other groups. According to the 2010 image, agriculture accounts for the highest share of land in the study region, accounting for 2,983.66 km² (84.44%), followed by shrubland, accounting for 375.39 km² (10.62%). Other LU/LC types, such as built-area forests and water bodies, made up 4.94% of the total area. In 2010, water bodies took up the least amount of space compared to all other classifications. The findings from the LU/LC categorization of the 2020 image also indicated that the leading LU/LC categories were agricultural land and shrub land, which together accounted for 92.61% of the total area covered. Agricultural land covered 2,909.45 km² (82.34%) of the total area, while shrub covered 362.92 km² (10.27%). The built area, plantation, and water body were the other LU/LC groups, accounting for 5.39% of the total area.

Sensitivity analysis

The sensitivity analysis in the present study was carried out to specify the effect of a set of parameters on the flow simulated by the model. For the sensitivity analysis, the 'Latine Hypercube Sampling-One at a Time' method is used to determine the sensitivity of each parameter. Observed monthly discharge data from different stations were defined to be inputs for the sensitivity analysis process. The simulated monthly discharge data were obtained from the model for a period of 21 years (2000–2020), and the upper and lower limits of each sensitive parameter were set initially. In this study, 13 different sensitive parameters with the upper and lower bound for runoff were selected for sensitivity analysis. The selected most sensitive parameters are shown in Table 4.

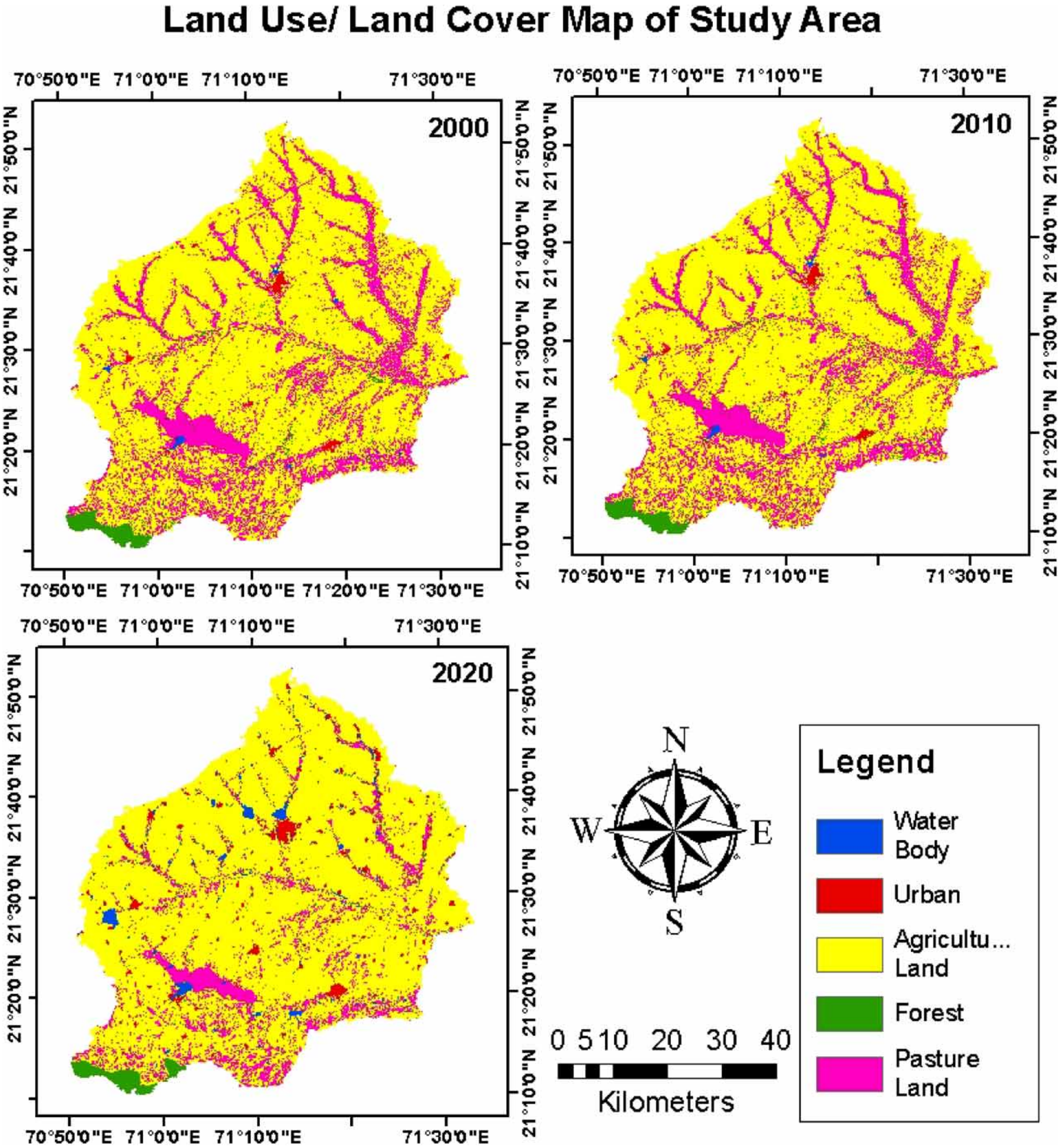

Figure 3 | LU/LC maps of the upper Shetrunji River basin for the years 2000, 2010, and 2020.

Table 3 | Summary of LU/LC classes from 2000 to 2020

	2000		**2010**		**2020**		**Change (2000–2020)**	
LU/LC classes	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Water body	14.88	0.42	39.33	1.11	62.95	1.78	48.07	1.36
Built area	54.27	1.53	75.87	2.15	124.1	3.51	69.83	1.98
Agricultural land	3,023.85	85.58	2,983.66	84.44	2,909.45	82.34	− 114.4	− 3.24
Plantation	50.48	1.43	59.25	1.68	74.08	2.1	23.6	0.67
Shrub land	390.02	11.04	375.39	10.62	362.92	10.27	− 27.1	− 0.77
Total	3,533.5	100	3,533.5	100	3,533.5	100	0	0

Table 4 | Selected seven most sensitive parameters for calibration

Rank	Parameter name	Physical descriptions	*P*-value	*T*-value
1	CN2.mgt	Initial curve number value (II)	0.0000000	−10.1605934
2	ALPHA_BNK.rte	Baseflow alpha factor for bank storage	0.0129345	−2.6155288
3	SOL_AWC.sol	Available water capacity of the soil layer	0.3051373	1.0402997
4	CH_N2.rte	Manning's '*n*' value for the main channel	0.3114451	1.0266266
5	GWQMN.gw	Threshold water depth in the shallow aquifer for flow	0.3612828	−0.9246945
6	SURLAG.bsn	Surface runoff lag time	0.3914988	0.8673435
7	GW_REVAP.gw	Groundwater 'revap' coefficient	0.5558205	−0.5946146

Calibration analysis

The calibration process was performed on the sensitive flow parameters found from the sensitivity analysis, and the values of these parameters were iteratively changed to the acceptable range. In this study, 11 years of the available runoff data (2000–2010) were used for calibration, with 3 years of the warm-up period for the Luwara gauging station, and the rest of the data were used for validation purposes. The coefficient of determination (R^2) and NSE for the Luwara gauging site were found to be 0.78 and 0.72. Furthermore, an NSE > 0.5 and R^2 values of over 0.5 were considered 'satisfactory and acceptable' based on the criteria reported by Santhi *et al.* (2001) and Van Liew *et al.* (2003). The model was run several times to get a better result, and the number of simulations was set to 500. The calibration ranges of the calibrated parameters with their fitted values are shown in Table 5. The scatter plots between observed and simulated discharge during the calibration period for monthly calibration are shown in Figure 4, which indicates a good correlation between the measured and simulated flow.

Table 5 | Calibrated range and fitted values of parameters

Parameter name	Physical descriptions	Fitted value	Min value	Max value	Method
CN2.mgt	Initial curve number value (II)	−0.156	−0.337275	0.025275	Relative
ALPHA_BNK.rte	Baseflow alpha factor for bank storage	0.03	−0.458492	0.518492	Replace
SOL_AWC.sol	Available water capacity of the soil layer	−0.05	−0.277097	0.177097	Relative
CH_N2.rte	Manning's '*n*' value for the main channel	0.171	0.08448	0.25752	Replace
GWQMN.gw	Threshold water depth in the shallow aquifer for flow	0.62	−0.076355	1.316355	Replace
SURLAG.bsn	Surface runoff lag time	22.8025	11.344101	34.260899	Replace
GW_REVAP.gw	Groundwater 'revap' coefficient	0.062	−0.007639	0.131639	Replace
GW_DELAY.gw	Groundwater delay	235.799988	127.2926	344.30737	Replace
SOL_K.sol	Saturated hydraulic conductivity	−0.016	127.2926	344.30737	Relative
CH_K2.rte	Effective hydraulic conductivity in main channel alluvium	11.25	−48.52468	71.024673	Replace
SOL_BD.sol	Moist bulk density	−0.137	−0.508848	0.234848	Relative
ESCO.hru	Soil evaporation compensation factor	0.962	0.880356	1.043644	Replace
ALPHA_BF.gw	Bases flow Alfa factor	0.99	0.491732	1.488268	Replace

Validation

The rest of the data from the same observation site was utilized in the validation process (2011–2020). The range of parameters was similar to the calibration, and discharge data for the validation period were input to SWAT-CUP. SWAT-CUP is conducted on a monthly time frame after setting up the input discharge data and parameters, with the same number of simulations (500) used for calibration. The actual and predicted discharge levels match quite well, as can be seen in the scatter plots shown in Figures 5 and 6. The comparison between observed and validated results gives the NSE and R^2 values to be 0.70 and 0.73, respectively, for the monthly time step. This shows that there is a good correlation between the measured and simulated flows. Based on

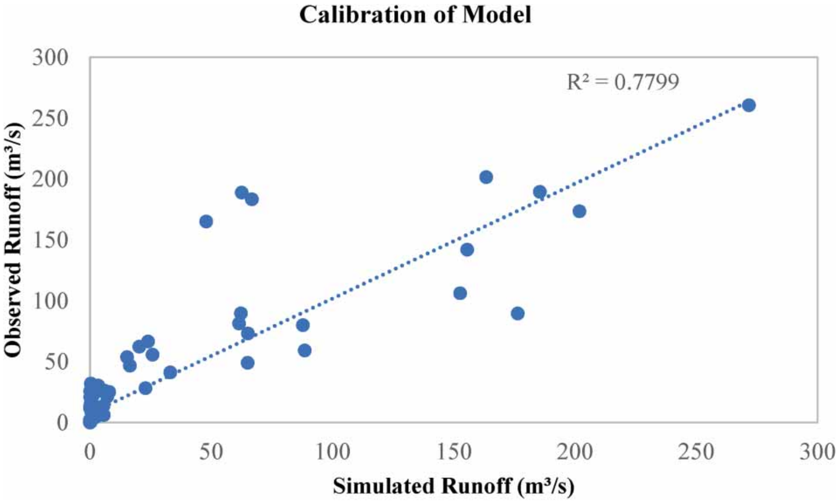

Figure 4 | Plot between model-simulated and observed monthly runoff.

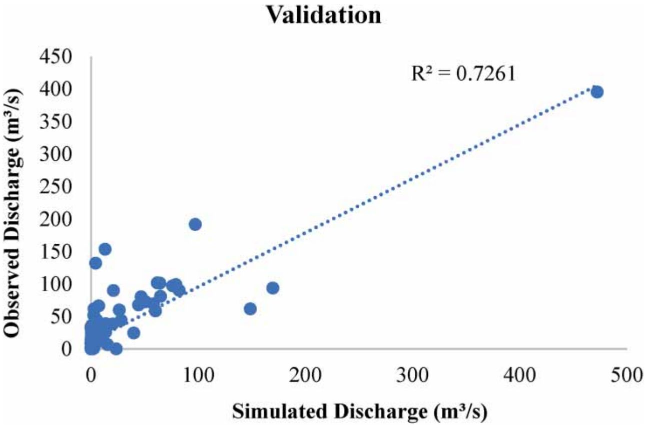

Figure 5 | Plot of simulated model output and observed monthly discharge for validation.

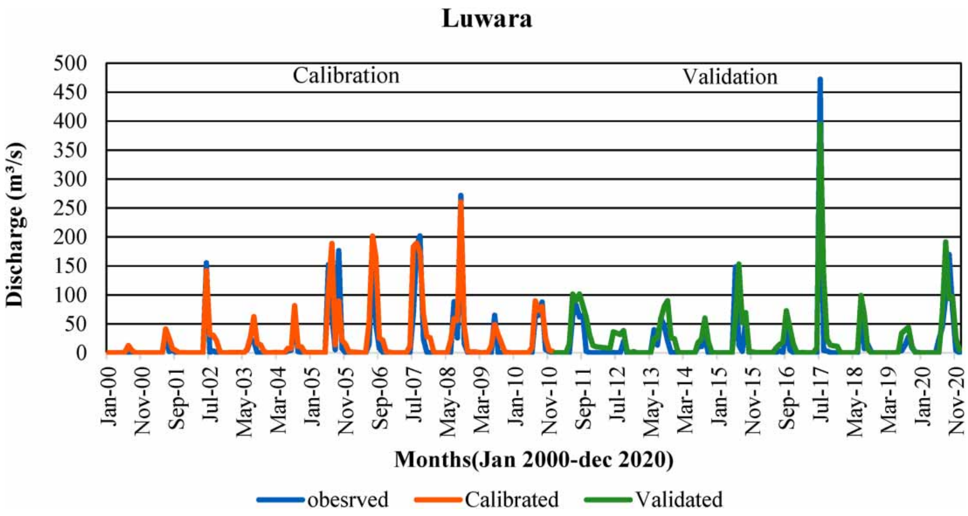

Figure 6 | Observed and simulated daily discharge during calibration (2000–2010) and validation (2011–2020).

two different statistics values, the model provides better results for monthly calibration and validation compared to daily calibration and validation.

Spatial and temporal impacts of LU–LC change

Since LU/LC changes in the upper Shetrunji River basin occurred at various locations and intensities, their hydrologic effects also varied spatially and temporally. SWAT was able to determine the hydrologic response to changes in LU/LC. In calculating the proportion of precipitation converted to surface runoff, the curve number (CN2) was discovered to be the most sensitive parameter. The variation in average CN2 is proportional to the variation in the basin's total annual water yield. This indicates that an increase in average CN2 will lead to an increase in annual water yield, while a reduction in average CN2 will lead to a decrease in annual water yield for a certain sub-basin. Six sub-basins show an increase in water output when the average CN2 rises. Between 2000 and 2010, the average CN2 and water yield in sub-basin no. 4 decreased by 1.67 and 62 mm, respectively. A move to more vegetative LU–LC would reduce CN2, but a decline in vegetation would result in a considerable rise in CN2. LU/LC change in the upper Shetrunji River basin drove the increase in average CN2 from 72.82 to 72.89 in 2010 and 73.21 in 2020 for the entire catchment driving the slight increase in the surface runoff but the decrease in baseflow and groundwater recharge as shown in Table 6. Surface runoff roughly increased from 31.55 to 31.62% in 2010 and 31.93% in 2020 while baseflow and groundwater recharge decreased. Baseflow decreased from 24.82 to 24.80% in 2010 and 24.77% in 2020 while there was a slight decrease in groundwater change of 0.01% in 2020 only.

Table 6 | Water budget for 2000, 2010, and 2020 LULCs

	2000		2010		2020	
Hydrological variables	**mm**	**%**	**mm**	**%**	**mm**	**%**
Precipitation	804.6	100	804.6	100	804.6	100
Evapotranspiration	337.2	42.40	336.8	42.35	334.6	42.07
Surface runoff	250.93	31.55	251.5	31.62	254.01	31.93
Baseflow	197.41	24.82	197.2	24.80	197.05	24.77
Deep aquifer recharge	9.59	1.21	9.6	1.21	9.58	1.20
Revap from shallow aquifer	0.18	0.02	0.18	0.02	0.18	0.02

As forest cover reduces, evapotranspiration and surface roughness decrease, resulting in less accessible water for infiltration and percolation. Several studies have shown that the construction of agricultural and forest plantations resulted in lower baseflow or dry season flow as a result of higher transpiration rates and subsequent reduction in groundwater recharge (Locatelli & Vignola 2009). According to Brüijnzeel (2004), removing vegetation can boost baseflow if soil infiltration capacity is maintained. This study, on the other hand, substantiates the assumption that if vegetation removal is followed by land use practices that compact soils and expose them to degradation, the groundwater recharge would be reduced due to decreased infiltration and percolation (Chandler 2006; Zimmermann *et al.* 2006; Bonnell *et al.* 2010).

CONCLUSION

The present study was carried out on the upper Shetrunji River basin to evaluate the impacts of LU/LC changes on the hydrology of the basin. The SWAT tool which runs under the ArcGIS interface has been chosen to model the runoff discharge for the basin. The LU/LC change detection was performed on ERDAS IMAGINE 2015 and ArcGIS. LU/LC maps were prepared using Landsat images of 2000, 2010, and 2020 by the supervised classification method. The model gives satisfactory results for calibration and validation. The comparison between the observed and calibrated data shows the NSE and R^2 values to be 0.74 and 0.78, respectively. The comparison between observed and validated results gives the NSE and R^2 values to be 0.70 and 0.73, respectively, for the monthly time step. The following key outcomes of the study were observed:

(1) This modeling study showed that LU/LC change influences the hydrologic behavior of the upper Shetrunji River basin in terms of water quantity and timing of hydrologic occurrence.

(2) Based on model simulations, the annual surface runoff and water yield increased while the baseflow and groundwater recharge decreased when there is a loss in forest cover, reduction in rangeland, and increased cultivated land and urban area.
(3) The impacts of LU/LC change on the hydrologic response are non-uniform over space and time.
(4) Sub-basins with a decrease in forest cover or shift to lesser vegetated land cover tend to increase in streamflow during the rainy season and decrease flow during the dry season. On the other hand, sub-basins with an increase in forest cover or a shift to more vegetated land cover would result in an opposite flow regime.

The runoff behavior in any area changes with LU/LC pattern and necessitates frequent studies to manage available water in the catchment.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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