



# Assessing the Impact of Land-Use Dynamics to Predict the Changes in Hydrological Variables Using Effective Impervious Area (EIA)

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## Abstract

The present research examines the hydrological impacts of historical and future land use land cover (LULC) in a part of the Yamuna River basin. The GIS-Curve Number (CN) approach for calculating effective impervious area (EIA) for larger ungauged basins is evaluated and validated with the directly connected impervious area (DCIA) measured using spatial data. Soil and Water Assessment Tool (SWAT) has been used at daily intervals to simulate hydrological responses in different land-use scenarios (years 2005, 2010, 2016, and predicted 2031). The model sensitivity analysis yields SCS runoff curve number (CN2) and effective hydraulic conductivity in the main channel (CH\_K2) as the most sensitive parameter. The model reaffirmed that EIA is preferable to Total Impervious Area (TIA) in runoff calculation. The observed and simulated discharge matched with each other during calibration as well as validation ( $R^2 \geq 0.85$ ,  $NSE \geq 0.83$ , and  $PBIAS < 5$ ). It is observed that surface runoff is majorly affected by built-up, whereas evapotranspiration, percolation, and groundwater recharge are influenced by dense vegetation, sparse vegetation, and cropland. An increase in urbanization in all sub-basins is predicted to generate more runoff. The patterns reveal a decline in ET, percolation, and GWR in urban areas of the entire basin. During 2005–2031, an increase in surface runoff (49.2%) with a decline in percolation (-2.25%) is observed. The results indicate that groundwater resources in the basin are continuously declining, which will become more adverse with increasing urbanization. This work would be a benchmark in quantifying changes in hydrological components due to land-use alterations and evaluating runoff response concerning EIA compared to TIA. This study would provide important information to policymakers in planning and managing of land use and water resources.

**Keywords** Runoff · SWAT · Effective impervious area · Directly connected impervious area · Urbanizing sub-basin

## 1 Introduction

The changing land use land cover (LULC) impacts the hydrological processes and results in various environmental issues (Mittal et al. 2016; Moosavi et al. 2022). Understanding these variations in hydrological processes due to LULC changes is valuable for the sustainable management of land and water resources (Tekleab et al. 2014). Therefore, assessing the hydrological impacts of LULC changes has attracted much attention in hydrology (Li et al. 2019a, b; Aragaw et al. 2021). LULC changes affect evapotranspiration, canopy interception, and infiltration, resulting in altered peak flow, runoff volume, and flow route time (Bradshaw et al. 2007; Laurance 2007; Cai et al. 2009; Hurkmans et al. 2009).

Different hydrological models have been used to study impacts on the hydrological cycle due to changes in LULC. The hydrological models integrate the catchment's topography and climate to simulate hydrological processes, thus, understanding the region's hydrology (Abe et al. 2018; Li et al. 2019a, b). HEC-HMS (Hydrologic Engineering Center's Hydraulic Modeling System) has been used to predict streamflow in several regions (Ouédraogo et al. 2018; Huang et al. 2019). The hydrological and environmental impacts have been studied using MIKEFLOOD and CREST model (Li et al. 2018; Ma et al. 2018). The SWAT (Soil and Water Assessment Tool) hydrological model is the most reliable and efficient for resolving various hydrological problems at different scales in varying landscapes (Abe et al. 2018; Giri et al. 2018; Wang et al. 2018; Risal and Parajuli 2022). SWAT has been applied to simulate runoff and analyze hydrological processes in several river basins worldwide (Khatun et al. 2018; Li et al. 2019a, b).

Urbanization is a significant driver that impacts the hydrological response of the basin significantly, including its runoff, infiltration, evapotranspiration, and water yield (Zhou et al. 2013; Sinha and Eldho 2018). An increase in urbanization resulted in a rise in surface runoff and a decrease in percolation and baseflow in the Upper Bhima River basin (Shukla and Gedam 2019). An increase of 11.87% in runoff and 1.09% in water yield was observed, with an increase in urban areas from 5.6 to 17.05% in the Yangtze Delta region (Wang et al. 2018).

The Effective Impervious Area (EIA) has been identified as a better measure of assessing runoff and water quality in urban areas (Lee and Heaney 2003; Ravagnani et al. 2009). EIA is the portion of the Total Impervious Area (TIA) that is hydraulically connected to the storm drain. TIA represents the magnitude of the urbanization, but it does not count the relative proximity of impervious surfaces to the drainage system (Shuster et al. 2005). However, EIA considers the proximity of impervious areas to drainage systems and holds significance as most urban runoff originates on sidewalks, rooftops, and parking lots. The inappropriate use of TIA in urban hydrological modeling is observed to overestimate the rate and volume of runoff (Ravagnani et al. 2009; Ebrahimian 2016b). Directly Connected Impervious Area (DCIA), similar to EIA, is part of TIA that is directly connected to the stormwater drainage system (Ebrahimian et al. 2018). However, the fact that distinguishes EIA from DCIA is that an impervious road connected to the drainage system (i.e., DCIA) may not be ultimately EIA due to the presence of cracks/ surface depressions, vegetation interception, or clogged drains. EIA depends on rainfall–runoff response, whereas DCIA is described by map measurements or field surveys (Ebrahimian et al. 2016a, b).

The most accurate calculation of EIA is achieved by analyzing rainfall–runoff data ((Boyd et al. 1993, 1994; Ebrahimian et al. 2016a, b). However, the method does not apply to ungauged basins. Ungauged basins lack hydrometric/discharge data partially or wholly (Grimaldi et al. 2021; Ebrahimian et al. 2018) devised GIS-CN

(Geographic Information System-Curve Number) method for estimating the EIA fraction for ungauged basins for a smaller area ( $\leq 20.38 \text{ km}^2$ ). The usefulness of the GIS-CN method in estimating EIA in ungauged basins has led us to employ this method in the present research. However, the applicability of the GIS-CN approach in estimating EIA in larger ungauged basins is evaluated in this research.

In India, the studies conducted to assess the hydrology of different river basins such as Ganga Basin (Anand et al. 2018), Kaveri Basin (Saini et al. 2018), Godavari Basin (Koneti et al. 2018) and eastern river basins (Das et al. 2018) have not used EIA for estimating the hydrological response. Few studies conducted in small urban agglomerations have considered EIA in runoff estimation (Sahoo and Sreeja 2014).

Delhi has been facing the problem of urban runoff in the form of water logging during heavy rainfall in monsoons. Hence, there is a need for an exhaustive study that can evaluate the response of runoff under different land-use scenarios. Previous studies have focused majorly on runoff characterization (Mittal et al. 2006; Jamwal et al. 2011) and possible runoff estimation (Mane et al. 2013). The current research examines the hydrological response to LULC changes and EIA in the Yamuna River basin.

With the above background, the current study demonstrates the estimation of EIA in a larger ungauged basin using the GIS-CN method (Ebrahimian et al. 2018), validating it with DCIA values and assessment of runoff response of Yamuna River basin using EIA and TIA under different LULC scenarios. The study incorporates EIA estimation to examine them as parameter of imperviousness in hydrological applications. This aspect has not been explored much in the field of urban hydrology.

## 2 Study Area

The study area is a part of the Yamuna River basin, which comprises four sub-basins i.e., Alipur-Khanjawala (hereafter referred to as Alipur), Najafgarh, Mehrauli and Trans-Yamuna (Fig. 1).

The river basin is situated between  $28.4084^\circ \text{ N}$  to  $28.8845^\circ \text{ N}$  and  $76.8328^\circ \text{ E}$  to  $77.3377^\circ \text{ E}$  and covers an area of  $1483 \text{ km}^2$ . The Alipur, Najafgarh, Mehrauli, and Trans-Yamuna sub-basin covers an area of  $519.11 \text{ km}^2$ ,  $482.69 \text{ km}^2$ ,  $373.12 \text{ km}^2$ , and  $127.39 \text{ km}^2$  respectively. The River Yamuna and Najafgarh drain flows through the basin. Urbanization is the predominant land-use phenomenon in the study area (Mallick et al. 2012). The region has recently faced severe urban floods in the years 1988, 1995, 1998, 2002, 2005, 2009, 2010, 2013, and 2016 (Irrigation and Flood Control 2019).

## 3 Data and Methodology

### 3.1 Preparation of Input Data

The LULC classification scheme and algorithm along with data required to estimate EIA and hydrological modelling are given in the supplementary file. The overall methodology adopted in this research work is presented in Fig. 2.

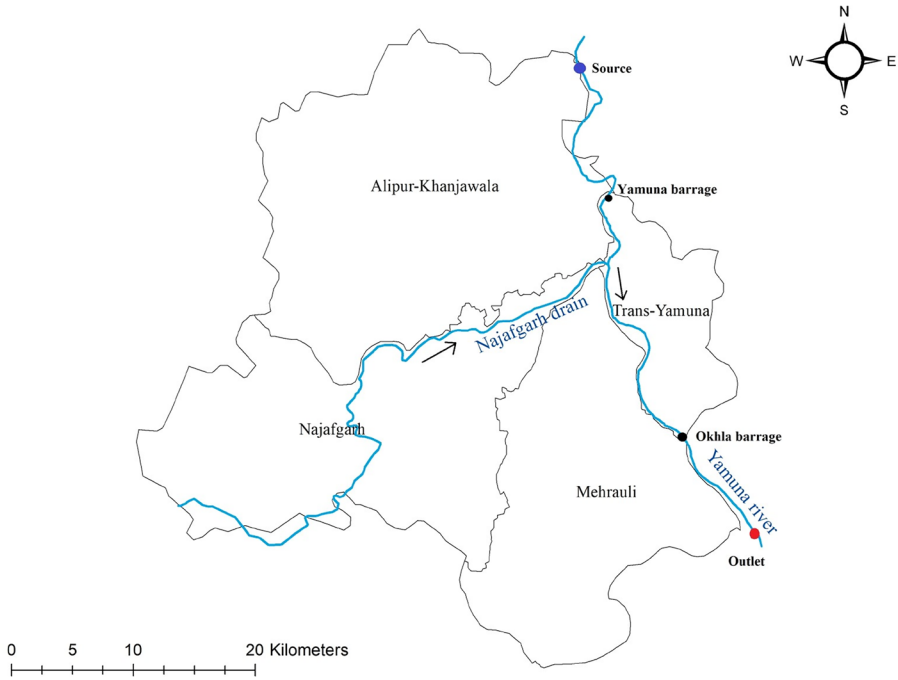


Fig. 1 Study area

### 3.2 Estimation of EIA Using the GIS-CN Method

The GIS-CN method uses a simple hydrologic framework that estimates EIA based on watershed characteristics, i.e., land use and soil (Ebrahimian et al. 2018). The method uses an asymptotic Curve Number ( $CN_{\infty}$ ) for ungauged basins. The GIS-CN method involved certain steps to estimate EIA (Fig. S1), which is detailed in the supplementary file.

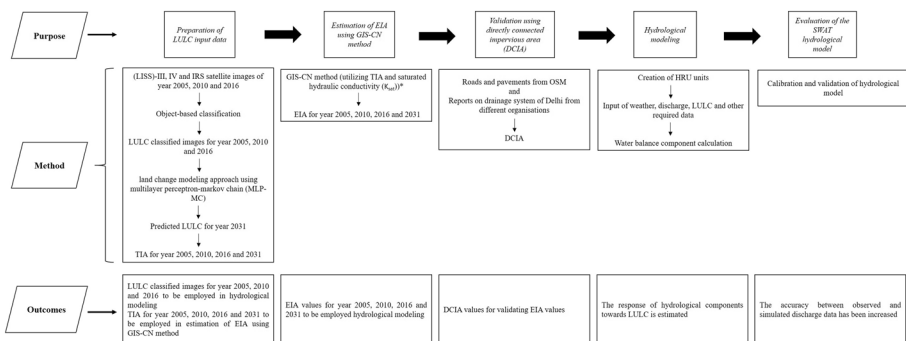


Fig. 2 Overall methodology used in the study

### 3.3 Validation Using Directly Connected Impervious Area (DCIA)

The GIS-CN method used to estimate EIA (Ebrahimian et al. 2018) was validated by the calculation of DCIA. The approach of estimation of DCIA is mentioned in Supplementary file.

### 3.4 Hydrological Modeling

Soil and Water Assessment Tool (SWAT), a physical semi-distributed continuous model developed by the United States Department of Agriculture, Agricultural Research Service (Arnold et al. 1998), is used to calculate runoff in the current study. SWAT model is chosen due to its wide applicability in small and large basins of different dominant LULCs (Harik et al. 2023; Wang et al. 2023; Xu et al. 2023). The hydrological modeling was carried out using QSWAT (Dile et al. 2016) of open source QGIS platform. The model used SRTM 30 m DEM (digital elevation model) and a pre-defined stream network. The basin derived from the drainage map was used as input to delineate the watershed into multiple sub-watersheds. Further, using classified LULC map, soil map, and slope, sub-watersheds were divided into hydrologic response units (HRUs) (Neitsch et al. 2011). The daily climate data (rainfall, temperature, relative humidity, solar radiation, and wind speed) and daily observed discharge were incorporated into SWAT. SWAT calculates water balance components in each HRU, sub-basin, and outlet. The equations involved in SWAT simulation are mentioned in supplementary file.

The model was simulated at daily intervals from 1997 to 2013. The time period of 8 years, i.e., 1997–2004, was considered a warm-up period for the model and therefore was not included in the analysis.

### 3.5 Evaluation of the SWAT Hydrological Model

SWAT calibration and uncertainty program (SWAT-CUP) (Abbaspour 2015) helps in the calibration, validation, and sensitivity analysis of the SWAT model (Abbaspour 2014). The present study used the Sequential Uncertainty Fitting (SUFI-2) algorithm (Abbaspour et al. 2007) for model calibration in SWAT-CUP. The algorithm calculates all kinds of uncertainties (inputs, model, parameters etc.) and attempts to cover most of the measured data within 95% prediction uncertainty (95PPU) with iterations. 95PPU is measured at 2.5% and 97.5% levels of the cumulative distribution of an output variable derived through latin hypercube sampling. Two bands, i.e., 95PPU band representing model simulation and another band representing measured data and its error, are compared, and goodness of fit is determined by “p-factor” and “r-factor”.

The evaluation of the calibrated SWAT model in predicting runoff was done by Nash-Sutcliffe efficiency (NSE), coefficient of determination ( $R^2$ ), and percent bias (PBIAS) (Das et al. 2019). Sensitivity analysis was examined using the t-statistic and the p-value.

## 4 Results and Discussion

### 4.1 LULC Change Analysis

The LULC maps have obtained an overall accuracy of >85% and a kappa statistic of >0.80. The LULC results indicate that urban area increased by 36.49% during

2005–2016 and is predicted to increase by 14.05% during 2016–2031. Agricultural land (including cropland and fallow land) declined by 26.57% during 2005–2016 and is anticipated to decline further by 6.37% during 2016–2031. Similarly, open land and scrubland/forest decreased by 82.21% and 42.26%, respectively, during 2005–2016 and is predicted to continue to decline by 50.36% and 23.13%, respectively, during 2016–2031. Dense and sparse vegetation increased during 2005–2016 (5.05% and 36.13%, respectively), whereas they are predicted to decline during 2016–2031 (0.64% and 18.47%, respectively). An increase in vegetation could be attributed to the government policies aiming to cover at least 33% of the total area under forest/tree cover as a target of National Forest Policy, 1988. The LULC maps of all sub-basins are shown in Fig. S2. It can be observed that all the sub-basins have witnessed urbanization during 2005–2031. An increase in urbanization over time is found to occur at the loss of agricultural land, open land, scrubland/forest, and sparse vegetation. The negatively correlated values between different LULC classes in Table S2 show the conversion of one LULC class to another.

## 4.2 EIA Estimation

The values of EIA calculated using the GIS-CN method are mentioned in Table 1. All the sub-basins have observed an increase in TIA and EIA in the given time period. The maximum values of EIA were observed in the Alipur sub-basin, followed by Najafgarh, Mehrauli, and Trans-Yamuna sub-basins.

Table S3 consists of EIA values calculated using the GIS-CN approach and DCIA range values measured using GIS data. The road network data used in DCIA measurement belongs to the year 2014. Therefore, EIA values calculated for the year 2016 are considered for comparison. The results show that the calculated EIA value, i.e., 263.30 km<sup>2</sup>, agrees with the measured DCIA values range, i.e., 270.46 km<sup>2</sup> – 377.62 km<sup>2</sup> (Table S3). The DCIA value range is specified due to uncertainty in the precise estimation of rooftop connectivity. However, the value range indicates that DCIA (including roads and pavements) equals 270.46 km<sup>2</sup>, whereas including rooftops leads to the DCIA value  $\leq 377.62$  km<sup>2</sup>. This provides the best possible approximate estimation of rooftop DCIA connectivity without an existing DCIA database. Hence, with a close approximation of values between EIA and DCIA, it can be inferred that the GIS-CN approach is suitable for estimating EIA in large basins with an area greater than 20.38 km<sup>2</sup> (Ebrahimian et al. 2018).

**Table 1** Calculated EIA values for different sub-basins during 2005–2031

Year	Alipur		Najafgarh		Mehrauli		Trans-Yamuna		Entire basin	
	TIA	EIA	TIA	EIA	TIA	EIA	TIA	EIA	TIA	EIA
Area (km <sup>2</sup> )	510.00		480.00		370.00		123.00		1483.00	
2005	123.10	84.88	155.22	80.64	155.67	64.25	69.05	23.1	503.04	252.87
2010	161.91	86.64	189.18	82.63	170.62	65.34	75.14	23.69	596.85	258.3
2016	209.31	88.99	213.71	83.89	182.76	66.09	80.81	24.34	686.59	263.31
2031	274.04	93.53	242.03	85.9	185.1	66.26	81.9	24.48	783.07	270.17

### 4.3 Hydrological Modeling

#### 4.3.1 Model Calibration

Model calibration requires fitting the values of parameters by comparing the simulated output data and measured data till a satisfactory value for the chosen objective function(s) is attained (Sao et al. 2020). The SWAT model was calibrated with daily discharge data for 2005–2010 and validated for 2011–2013. The calibration and validation were done using two-gauge stations for the time period 2005–2010 and 2011–2013, respectively i.e. the Yamuna barrage and the Okhla barrage (Fig. 3). Table S4 shows the key sensitive parameters identified in the sensitivity analysis and employed in the calibration of the model. The maximum and minimum parameters were observed within the recommended ranges of SWAT and other studies conducted in north India (Mishra et al. 2017; Shivhare et al. 2018; Das et al. 2019). The value of t-stat indicates parameter sensitivity. The higher the t-stat, the more sensitive the parameter. The p-value depicts the significance of the t-value, i.e., the lower the p-value, the lesser chances of a parameter being randomly allocated as sensitive (Abbaspour 2015).

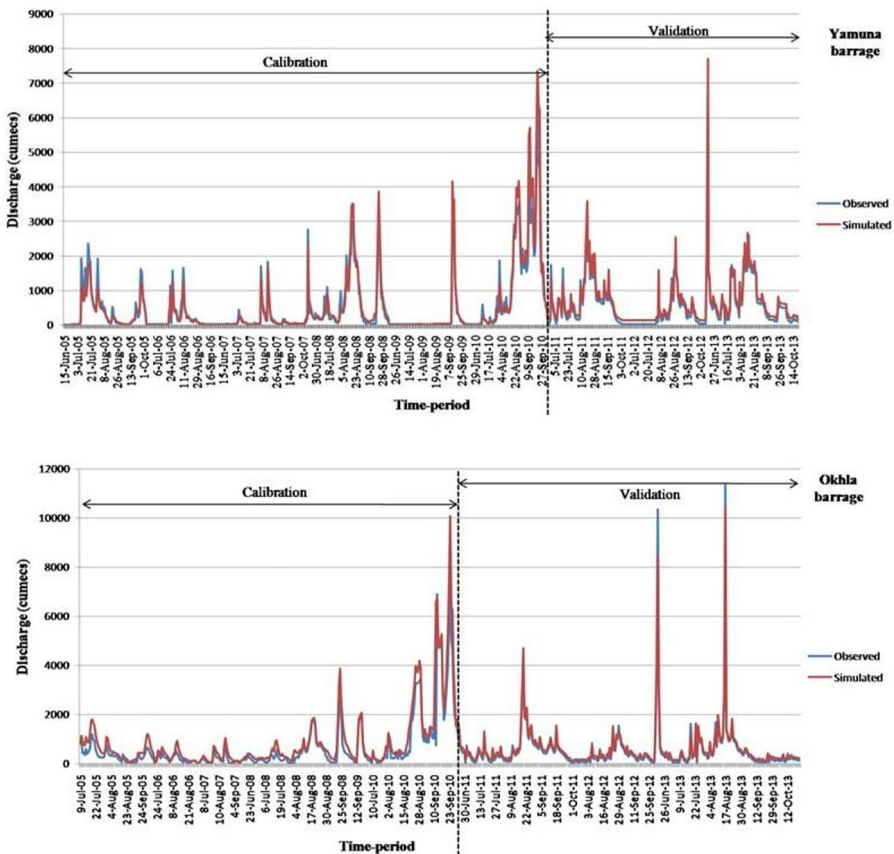


Fig. 3 Plot of observed discharge and simulated discharge at a Yamuna and b Okhla barrages

Out of the 15 parameters, CN2 (t-stat=3.8, p-value=0.00) and CH\_K2 (t-stat=2.7, p-value=0.00) were found as the most sensitive parameters (Table S4), which are in agreement with other similar studies conducted in Ganga basin, Gomti basin and Semra basin, Allahabad in north India, which also found CN2 (Mishra et al. 2017; Das et al. 2019) and CH\_K2 (Mishra et al. 2017; Shivhare et al. 2018) as the most sensitive parameters.

The observed and simulated discharge of both gauge stations are observed to match each other during calibration as well as validation ( $R^2 \geq 0.85$ ,  $NSE \geq 0.83$ , and  $PBIAS < 5$ ). Though the validation period comprises fewer years in comparison to the calibration time-period, it shows equally good simulation results as calibration. According to the SWAT model evaluation criteria, the model's performance (Table 2) is excellent (Moriasi et al. 2007). Hence, the SWAT model can simulate hydrological processes in the river basin. The observed and simulated annual average discharge at Yamuna Barrage during the entire time period was 560.15 mm and 548.89 mm, respectively, and at Okhla Barrage was 590.03 mm and 581.5 mm, respectively.

#### 4.4 Runoff Response to TIA and EIA

The calibrated model is simulated twice, with and without EIA. The deviation of monthly discharge generated using EIA and TIA parameters for monthly observed discharge is shown in Fig. 4. It can be observed that during the entire time period for observed discharge, the deviation of discharge generated using TIA is higher than that generated using EIA. This indicates that the discharge value generated using TIA was higher than that generated using EIA. This affirms that using TIA in the hydrological model has overestimated discharge values. Hence, EIA is a more preferred parameter than TIA for runoff estimation (Lee and Heaney 2003). Therefore, the hydrological model used in this research has incorporated EIA for simulation and further analysis.

#### 4.5 Impact of LULC on Hydrological Components

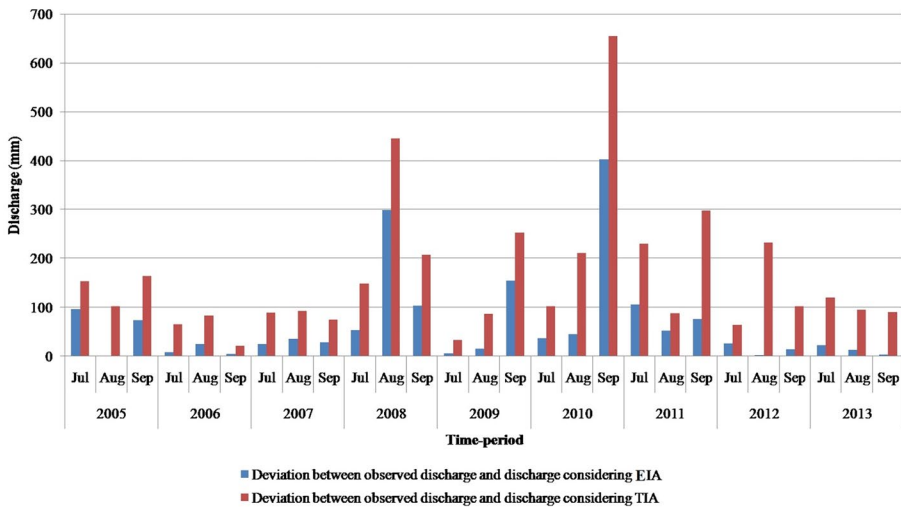
The calibrated model was used to simulate the hydrological processes for different land-use scenarios, i.e., 2005, 2010, 2016, and 2031. The spatial distribution of different hydrological components is examined to understand the changes in their patterns during 2005–2031 (Fig. 5i). The spatial pattern maps indicate an increase in ET, percolation, and groundwater recharge (GWR) during 2005–2016 in the center and peripheral region of the basin, which is majorly covered with dense vegetation, scrubland/ forest, sparse vegetation, and cropland. During 2005–2016, an increase in ET is observed in Alipur (7.89%), Najafgarh (15.44%), and Mehrauli (4.60%) sub-basin (Fig. 5iii).

Similarly, a slight increase is observed in percolation in Alipur (1.38%), Najafgarh (2.67%), and Mehrauli (0.43%). An increase in GWR is observed in Alipur (22.86%) and Najafgarh (2.04%) during 2005–2016. These could be attributed to Alipur and Najafgarh witnessing 49.52% and 65.94% increases in cropland, respectively, Mehrauli witnessing an increase of 24.87% in sparse vegetation, 23.29% in dense vegetation and 0.42% in cropland during 2005–2016 (Table S5). During 2016–2031, an increase in ET is observed in Alipur (3.48%) and Mehrauli (1.17%). An increase in percolation (1.36%) and GWR (2.91%) is observed in Alipur. These could be attributed to an increase of 89.83% in cropland in Alipur and 5.08% in sparse vegetation in Mehrauli during 2016–2031. On this basis, variation in ET appears to be mostly attributed to changes in cropland, sparse vegetation, and dense vegetation. These findings strongly



**Table 2** Model performance at gauge stations

Gauge station name	p-factor		r-factor		R <sup>2</sup>		NSE		PBIAS	
	Yamuna barrage	Okhla barrage	Yamuna barrage	Okhla barrage	Yamuna barrage	Okhla barrage	Yamuna barrage	Okhla barrage	Yamuna barrage	Okhla barrage
Calibration (2005–2010)	0.90	0.93	0.86	0.87	0.89	0.90	0.85	0.85	3.50	2.25
Validation (2011–2013)	0.89	0.91	0.84	0.86	0.85	0.88	0.83	0.84	4.01	3.62

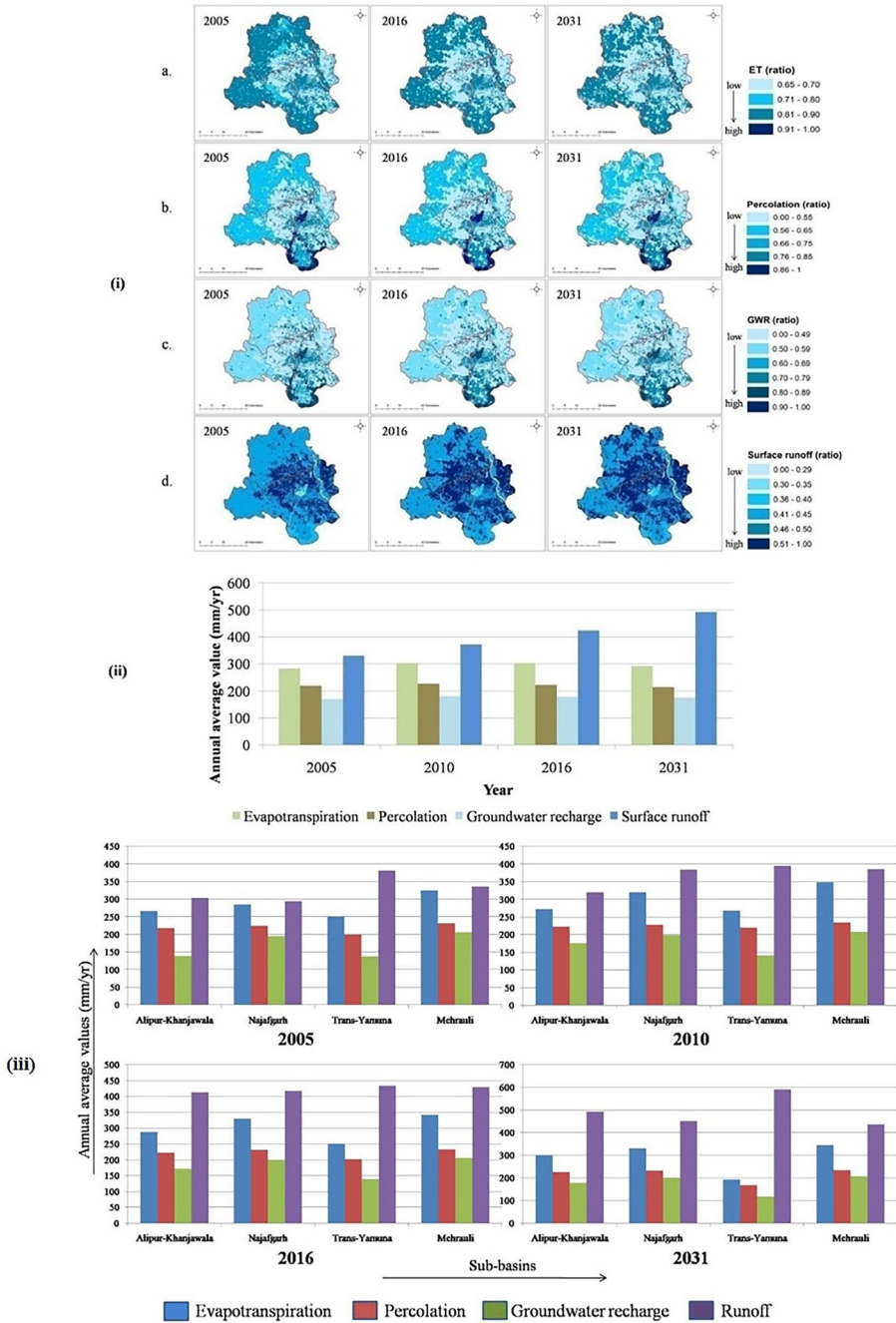


**Fig. 4** Error bar diagram of discharge generated using EIA and TIA for observed discharge

agree with the SWAT model, which calculates ET based on plant transpiration rate, canopy water evapotranspiration interception, and maximum soil evaporation rate (Neitsch et al. 2011). A direct relationship between ET and vegetation is also found in the Ganga basin (Anand et al. 2018) and other tropical regions (Ngondo et al. 2022).

The spatial patterns found in the present research also reveal a decline in ET, percolation, and GWR in urban areas of the entire basin. The trans-Yamuna sub-basin, which is found to be the most urbanized, experienced a negligible increase (0.4%) in ET during 2005–2016. With more urbanization predicted during 2016–2031, Trans-Yamuna witnessed a decline of 23.90% in ET, 16.5% in percolation, and 15.22% in GWR. This indicates that urban expansion leading to loss of vegetation, causes a decline in ET and alters surface and subsurface flows, thereby reducing infiltration ((Balha et al. 2020b). Similar findings are found for the Ganga basin (Anand et al. 2018), where imperviousness affected water balance adversely.

The statistical results obtained (Table S2) also support that variation in evapotranspiration, percolation, and GWR is by modifications in vegetation, and changes in runoff is in agreement with that of urban areas. In the entire basin, GWR has slightly increased (3.06%) with a decrease in percolation (-2.25%) during 2005–2031 (Fig. 5ii). The findings indicate that although GWR has increased during the entire time period, its rate of increase is not significant. Thus, the state of groundwater resources appears to be critical ((Balha et al. 2020b). This also suggests that despite declining or lesser percolation, the increase in GWR in the basin could be due to artificial sources of GWR ((Balha et al. 2020b). Central Ground Water Board (CGWB) augments groundwater in the basin through artificial recharge sources such as recharge from canal irrigation, seepage from canals, irrigation, tanks, water conservation structures, and return flow from groundwater irrigation (CGWB 2016). By the findings of this research, LULC of the entire basin for 2031 is expected to witness more urbanization and a decline in green cover, which would continue to lower the processes of evapotranspiration and percolation thereby, impact groundwater resources adversely.



**Fig. 5** i Spatial patterns of (a) evapotranspiration (ET) (b) percolation (c) groundwater recharge (GWR) (d) surface runoff at HRU level in different land-use scenarios 2005, 2016 and predicted future time-period 2031, ii Annual average values of hydrological components in the basin during different land-use scenarios, iii Annual average values of hydrological components in different sub-basins during different land-use scenarios

The spatial patterns indicate that increased surface runoff agrees with urban expansion. In 2016, maximum runoff was observed in Trans-Yamuna (433 mm/yr), followed by Mehrauli (429 mm/yr). This is in accordance with the urban area percentage (65.69%, and 49.39%, respectively) in the respective sub-basins. In 2005, the least runoff was observed to be generated from Alipur (266 mm/yr), preceded by Najafgarh (285 mm/yr). However, in 2016, Najafgarh produced more runoff than Alipur due to the vast urban expansion in Najafgarh during that period—the increased urban expansion results from various factors, such as accommodating the housing requirements of an ever-accelerating population. The surge in urbanization in Trans-Yamuna is due to the lower price valuation of land ((Balha et al. 2020a). The vast availability of agricultural land in Alipur, Najafgarh, and Mehrauli sub-basins led to the expansion of either sub-cities as government initiatives to provide urban housing or form urban clusters by lower-wage income people at the outskirts due to lower land valuation ((Balha et al. 2020a).

During 2005–2016, a substantial increase in surface runoff is observed in all the sub-basins (Alipur (35.52%), Najafgarh (41.01%), Mehrauli (27.67%), Trans-Yamuna (13.35%)) which could be attributed to increase in urbanization by 70.03%, 37.68%, 17.40% and 17.03%, respectively in the sub-basins during the given time period. It indicates that Trans-Yamuna, already the highly urbanized sub-basin (56.13% in 2005), has become more densely urbanized (65.69% in 2016). Other sub-basins witnessed accelerated urban expansion because of the demographic reasons discussed above. During 2016–2031, the maximum increase in runoff is predicted in Trans-Yamuna (36.25%) followed by Alipur (19.41%), Najafgarh (7.93%), and Mehrauli (1.39%), which could be attributed to urban expansion anticipated in the sub-basins during the time period. Given the landscape setting, an increase of 1 km<sup>2</sup> of the urban area is observed to result in a runoff increase of 0.45 mm in 2005–10, 0.57 mm in 2010–16, and 0.71 mm in 2016–31.

The findings indicate that significant urban expansion with the loss of green cover impacts surface runoff, ET, percolation, and GWR. Similar findings are observed for the Ganga basin (Anand et al. 2018) and other tropical basins (Wagner et al. 2013; Gumindoga et al. 2014; Remondi et al. 2016). The LULC types considered in this study impact hydrological parameters significantly. As discussed, the decrease in ET, percolation, and GWR and the increase in runoff signify the hydrological instability of the basin. Based on this, the changes identified in urban areas, dense vegetation, sparse vegetation, cropland, and open land should be administered to reduce their associated impacts on hydrological parameters and achieve hydrological stability in the basin.

## 5 Conclusion

The present research has employed and demonstrated the usefulness of the GIS-CN approach in estimating EIA for larger ungauged basins. This holds significance as the majority of the basins in the world are ungauged. The values of EIA and DCIA are found to be in good agreement. The SWAT findings indicate that the discharge generated using TIA was higher than that generated using EIA, confirming that TIA overestimates the discharge value in hydrological modeling. Hence, the study infers that EIA is a more preferred parameter than TIA for runoff estimation. The findings indicate that increasing imperviousness due to urbanization has led to a decline in percolation. Hence, the increase in GWR might be attributed majorly to artificial recharge sources, including seepage from canals, irrigation, tanks, and water conservation structures. The study's findings suggest

that land-use planning and development efforts are required to reduce runoff and increase percolation/GWR in the study area. It includes incorporation of best management practices (BMPs), i.e., rain barrels, bioretention areas, vegetated swales, green roofs, permeable pavements, etc., in the basin's drainage and land-use plan. The study reaffirms EIA as a preferable parameter in runoff calculation, to achieve more effective solutions for planning and managing water resources. This would be beneficial in establishing more effective sustainable drainage systems (SuDS) of suitable capacity in the basin to prevent and deal with waterlogging or flood events. The findings of this research would help planners and hydrologists set up and implement adequate measures for land-use planning and water resource management in the basin in the future.

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**Author Contributions** **AB**: Conceptualization; Data curation; Formal analysis; Investigation; Methodology, Validation; Visualization; Roles/Writing - original draft **AS**: Validation; review; editing **SP**: Supervision; Data curation; **CKS**: Conceptualization; Formal analysis; Investigation; Methodology; Resources; Software; Supervision; Writing - review & editing.

**Data Availability** The data will be made available on request.

## Declarations

**Competing Interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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