Assessment of water yield and evapotranspiration over 1985 to 2010 in the Gomti River basin in India using the SWAT model

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Soil and Water Assessment Tool (SWAT) was used to assess the water yield and evapotranspiration for the Gomti River basin, India for over a period of 25 years (1985–2010). Streamflow calibration and validation of results showed satisfactory performance (NSE: 0.68–0.51; RSR: 0.56–0.68; |PBIAS|: 2.5–24.3) of the model. The water yield was higher in the midstream sub-basins compared to upstream and downstream sub-basins whereas evapotranspiration per unit area decreased from upstream to the downstream. Both evapotranspiration and water yield at upstream and midstream sub-basins increased from 1985 to 2010, whereas water yield at downstream decreased from 1985 to 2010. We found that the spatial and temporal patterns of evapotranspiration and water yield were closely linked to climatic conditions and irrigation in the basin. The long-term trends in water yield point to a drying tendency of downstream sub-basin covering the districts of Jaunpur and Varanasi.

Keywords: Irrigation, rainfall, modelling, streamflow, water use.

INCREASING water demands from different sectors of the society coupled with increasing population and socioeconomic development are causing extreme pressure on our water resources, especially in the river basins in the Gangetic Plains of India. Assessment of current water availability and its trend in a river basin are of paramount importance to allocate limited water supply for different sectors and to develop strategies for the sustainable use of water in the future. Further, estimation of water resources of a river basin/sub-river basin in a spatially and temporally explicitly way is the key to formulate appropriate policies for equitable and efficient use of limited water resources.

The Gomti River basin is predominantly agricultural and more than 80% of the crops in the basin are grown under full or supplementary irrigation. With the introduction of high-yielding varieties of crops, irrigation demand has significantly increased. Therefore, most irrigation systems have been under major rehabilitation in recent years to augment their discharge capacities[1]. Sustainability of agriculture in this basin is threatened by waterlogging and consequent soil salinity–sodicity in canal command areas whereas groundwater depletion is also occurring in some areas, resulting in reduced crop productivity. Dutta *et al.*[2] pointed out the need of a restoration plan for the Gomti River basin to improve poor water quality and poor water flow in the river. They discussed the water diversion plan from Shardha River to the drying Gomti River. However, this water diversion plan has not yet been implemented. It is therefore important to estimate the current water yield and evapotranspiration (ET) of the entire basin and its trends in the past, which may provide the basis for a sustainable water management plan in the basin.

Modelling spatially distributed hydrological processes over the entire basin helps in assessment of different water sources in a basin. Scientists use a wide range of models such as the Lund-Potsdam-Jena Dynamic Global Vegetation Mode-LPJmL[3], GIS based Environmental Policy Integrated Climate (GEPIC)[4], Global Crop Water Model (GCWM)[5], H08 (ref. 6), etc. in modelling water resources. However, the Soil and Water Assessment Tool (SWAT)[7] is a commonly used, semi-distributed hydrological model for different water resource applications and has been widely used in different parts of the world[8–12]. SWAT has also been successfully applied in the Indian context for simulation of different water resources to fulfill varied objectives[13–17].

Keeping the above background in view, the present study was undertaken to quantify the spatio-temporal patterns of water yield and ET in the Gomti River basin

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of India using observed data and SWAT model over the past 25 years (1985–2010).

Study area

The Gomti River basin lies mainly in Uttar Pradesh (UP), and its area is estimated to be 30,437 sq. km. The topography of the basin is undulating and the elevation ranges from 238 m amsl at origin to 58 m amsl downstream (Figure 1). The climate is semi-arid to sub-humid tropical with the average annual rainfall varying between 850 and 1100 mm. The river originates from a lake 'Fulhaar Jheel', about 3 km east of Pilibhit town and about 50 km south of the Himalayan foot-hills. This river is one of the important tributaries of the Ganga and it meets the main Ganga at Kaithi in Varanasi (UP) after flowing 960 km in south and south-east direction[2]. Singh *et al.*[18] reported that the Gomati River is characterized by sluggish flow throughout the year, except during the monsoon season, when heavy rainfall causes 20 to 50 times rise in its normal discharge. The basin is intensively cultivated with rice and wheat being the dominant cropping system. The two major cropping seasons are *kharif* (June–October) and *rabi* (November–April).

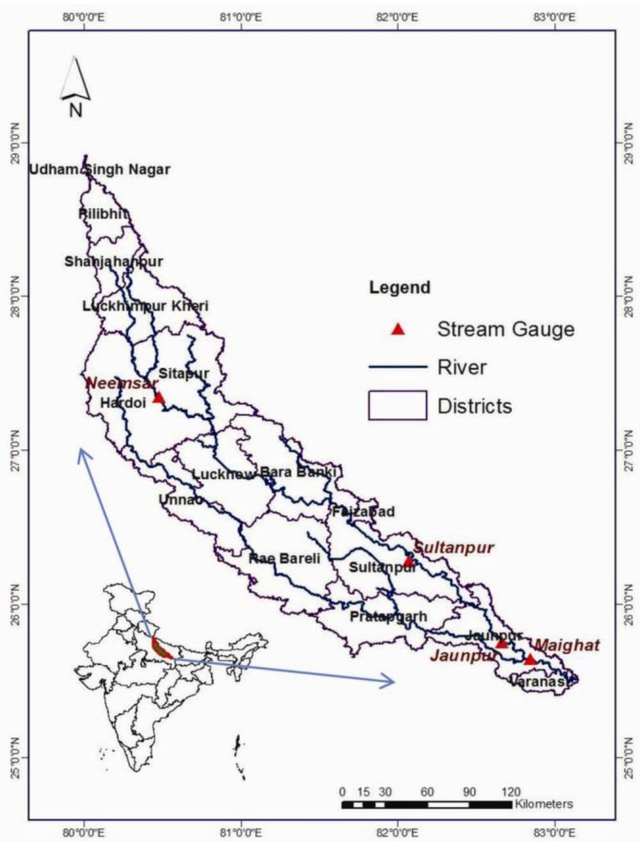

Figure 1. Geographical distribution of gauging stations, the major stream network and the districts of the Gomti River basin of India.

Material and methods

SWAT Modelling Tool

SWAT is a semi-distributed parameter model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in a large complex watershed with varying soils, land use and management conditions over long periods of time[19]. It also simulates agricultural management practices[20]. In SWAT, the watershed is divided into a large number of sub-watersheds that are further subdivided into unique soil, land-use and slope characteristics called hydrologic response units (HRUs), a spatial unit for model simulation.

This study implemented the latest version of SWAT (ver. 10.1.14) within ArcGIS (ver. 10.1). For SWAT simulations, the modules of SCS curve number procedure[21], the Penman–Monteith method[22] and variable storage coefficient method[23] were used for the estimation of runoff, ET and channel routing respectively. Actual ET in the SWAT model was simulated based on the methodology given by Ritchie[24].

SWAT model set-up and inputs

The Gomti River basin was delineated and subdivided into 21 sub-basins and 296 HRUs. The 90 m DEM (http://gisdata.usgs.gov/website/Hydro-SHEDS/) was used for slope and stream network characteristics estimation. The satellite remote sensing derived IWMI land-cover map of the study area at 56 × 56 m resolution was used for land cover inputs (Figure 2 *a*)[25]. The predominant land cover in this basin was cropland. 59% of the basin area was under irrigated conjunctive use double cropping (SWAT model class, R-08) class and 32% was under irrigated surface water double cropping (R-02) class. The soil map of entire Ganga river basin at a resolution of 78 × 78 m was downloaded from the website (http://gisserver.civil.iitd.ac.in/grbmp/iitd.htm) and subsetted for the Gomti basin. Its original data source are the soil maps prepared by the National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur. Soils of the area are predominantly alluvial and deep (Figure 2 *b*).

SWAT requires daily weather variables of rainfall, minimum and maximum temperatures, relative humidity, wind speed and solar radiation. The daily weather data for 12 district stations in the study basin for the 1982 to 2010 period were obtained from the NICRA web portal (http://www.nicra-icar.in/nicrarevised/).

Crops have major influence on moisture and nutrient uptake and thus their removal can affect the hydrologic system[12,26]. There is a need to assign crop types to different land cover classes. The cropping pattern map of UP produced by Singh *et al.*[27] using IRS-P6 AWiFS satellite data, was used in this study for the purpose. It showed

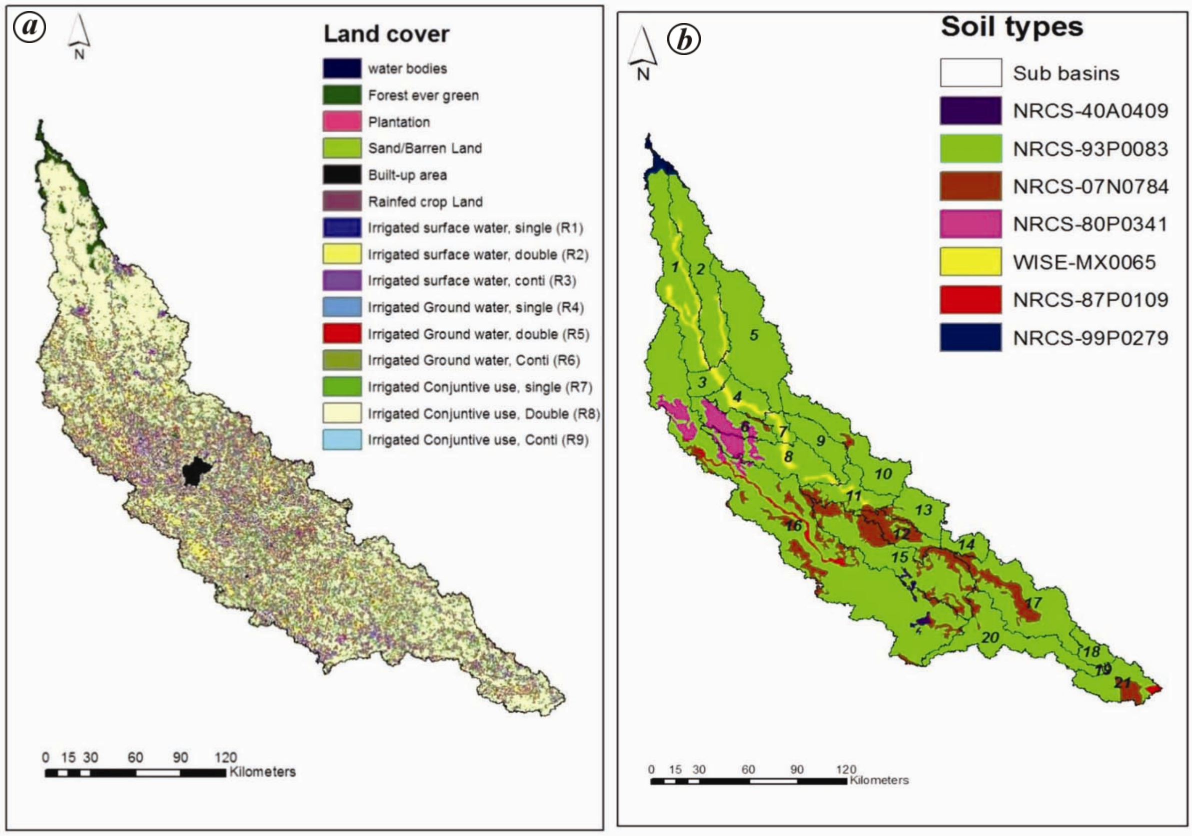

Figure 2. (***a***) Land cover and (***b***) soil type map of Gomti River basin (1–21 in soil map denotes the sub-basins).

that the order of the cropping pattern in terms of area was rice–wheat > sugarcane > rice–pulses > sugarcane–wheat. Therefore, the land cover category R-08 was assigned to irrigated rice (*kharif*) and wheat (*rabi*). The R-02 category was assigned to rice (*kharif*) and pulses (*rabi*) and R-03 category was assigned to sugarcane (annual) crop. The R-08, R-02 and R-03 categories occupy 59.58%, 32.45% and 1.38% of the basin area respectively. The management inputs on planting, harvesting and irrigation for these crops were obtained from the literature[28,29]. A considerable portion of the Gomti River basin is also supplied with canal water from Sharda Sahayak canal system (Figure S1, see Supplementary information online). Therefore, water source for the simulation of the rice, pulses and sugarcane was considered as canal water in HRUs wherever canal was located, and SWAT recognized it as an outside unlimited source. Based on the farmer's practice, 7 irrigation of 50–60 mm each were specified for rice growing HRUs besides rain water. For the other rice growing HRUs where canal is not located, source of irrigation was considered as shallow aquifer located in the same sub-basin. For the irrigation of wheat, auto irrigation option of SWAT was used in which source of irrigation water was considered as shallow aquifer located in the same sub-basin. For auto-irrigation, the plant water stress threshold that triggers irrigation was set to 0.9 initially[30]. The HRUs under sugarcane and pulse crops were irrigated similarly as that of wheat.

SWAT calibration and validation for streamflow

The SWAT model was parameterized for stream flow at four spatially distributed Central Water Commission (CWC) gauge stations (GS) at Neemsar, Sultanpur, Jaunpur and Maighat using their observed monthly average stream flow data (Figure 1). The SWAT simulations for the initial three years period (1982–1985) were used only to stabilize the initial conditions of the model. Depending on the observed data records, the model at Neemsar GS was calibrated using data of 1990–2000 and validated using data of 2001–2010. At Sultanpur and Jaunpur gauge stations, the model was calibrated using data from 1985 to 2000 periods. It was validated using the 2001–2010 data at Sultanpur and 2001–2008 at Jaunpur. At Maighat GS, the model was calibrated using 1985–1991 data and validated using the data from 1992 to 1998. Before undertaking calibration and validation, model sensitivity analysis was also performed. Most sensitive parameters were then calibrated manually considering their limits and using SWAT CHECK module. This study used statistical parameters such as Nash-Sutcliffe efficiency (NSE), RMSE-observations standard deviation ratio (RSR) and percentage

Table 1. Model performance rating based on RSR, NSE and PBIAS[31]

Performance rating	NSE	RSR	PBIAS %
Very good	$0.75 \leq NSE \leq 1.00$	$0.00 \leq RSR \leq 0.5$	$\lvert PBIAS \rvert < 10$
Good	$0.65 < NSE \leq 0.75$	$0.5 < RSR \leq 0.6$	$10 < \lvert PBIAS \rvert \leq 15$
Satisfactory	$0.5 < NSE \leq 0.65$	$0.6 < RSR \leq 0.7$	$15 < \lvert PBIAS \rvert \leq 25$
Unsatisfactory	$NSE < 0.5$	$RSR > 0.7$	$\lvert PBIAS \rvert > 25$

NSE, Nash-Sutcliffe efficiency; RSR, RMSE-observations standard derivation ratio; PBIAS, Percentage bias.

bias (PBIAS)[31] to compare the simulated and measured flow. For assessing the performance of the model, we used the model performance rating given by Moriasi *et al.*[31] (Table 1).

Wheat and rice yield simulation

In order to undertake improved simulation of water yield and ET, the rice and wheat crop yields were also simulated by EPIC model embedded in SWAT. Crop yield of both rice and wheat was calibrated by adjusting the parameters of harvest index (HVSTI), biomass energy ratio (BIO_E), Auto_NSTRS (nitrogen stress factor that triggers fertilization), Auto_WSTRS (water stress threshold that triggers irrigation) for both the crops. The planting and harvesting dates and heat unit to maturity for wheat and initial LAI, and biomass for rice were also fitted during calibrating. Adjustment of these parameters has been suggested to obtain comparable crop yields from SWAT[32–35]. The simulated yield values of rice and wheat were aggregated, first to sub-basin and then to district levels using area as weights. The district simulated yields were compared with the values reported by the state Department of Agriculture using |PBIAS| statistic and *t*-test[34–36], separately for rice calibration (1995–2002) and validation (2003–2008) phases, and also for wheat calibration (1996–2003) and validation (2004–2009).

Water yield and evapotranspiration

The water yield in the SWAT model is defined as follows

$$\text{Water yield} = SURQ + LATQ + GWQ - TLOSS - \text{Pond abstraction}, \quad (1)$$

where SURQ is the surface water flow, LATQ is the water that enters the stream from soil profile as lateral flow and GWQ is the water that returns to the stream from the shallow aquifer, i.e. shallow groundwater contribution. TLOSS is the total loss of water from the tributary channels via transmission through the bed[30]. So the water yield in this study represents mainly the surface water yield excluding the deep groundwater. ET was calculated using the SWAT parameter actual evapotranspiration (AET). We calculated water yield and ET for each of the sub-basin at monthly scale. However, results are presented only for annual, monsoonal (June–September) and non-monsoonal (October–May) periods. The results are spatially presented for upstream (u/s), midstream (m/s) and downstream (d/s) sub-basins. Upstream category refers to the sub-basins above 105 m amsl elevation, midstream to between 70 and 105 m amsl elevations and downstream to <70 m amsl elevation.

Results and discussion

Model calibration and validation

In order to identify the sensitive model parameters and to reduce the number of parameters in calibration, sensitivity analysis was performed for the four gauging stations. Based on the literature review[37–39], 17 hydrological parameters were identified for sensitivity analysis of the streamflow simulation. Of these 17 parameters, 14 were identified as sensitive for all the 4 gauging stations (Table 2). The fitted calibration value obtained for these 14 parameters for the 4 gauging stations are also given in Table 2.

The comparison of observed and simulated mean monthly stream flows during calibration and validation for the four gauging stations is shown in Figure 3. The hydrographs showed a reasonable agreement between simulated and observed discharge values. The model performance statistics of NSE, RSR and |PBIAS| during calibration and validation are given in Table 3. Model calibration statistics NSE varied from 0.51 to 0.66 and RSR from 0.58 to 0.68, and |PBIAS| from 8.2 to 24.3. The performance of the model during calibration was found to be good to satisfactory (Table 2)[31]. Validation results also indicated the model's good to satisfactory performance as NSE values ranged from 0.56 to 0.68, RSR from 0.56 to 0.66 and |PBIAS| from 2.5 to 9.5. Overall for the basin, the NSE and RSR were 0.62 and 0.61 during calibration but their values during validation declined to 5.9 and 0.62 respectively, while |PBIAS| value improved from 16.7 to 5.0.

Wheat and rice yield simulation

Table 4 shows the comparison of simulated rice yield and wheat yield with reported yield for the four districts.

Table 2. Calibrated values of sensitive hydrologic parameters of the SWAT model at four gauging stations in the Gomti River basin

Sensitivity Rank	Parameter	Parameter description	Neemsar	Sultanpur	Jaunpur	Maighat	SWAT range
1	RCHRG_Dp	Aquifer percolation coefficient	0.58–0.6	0.25–0.5	0.5	0.45–0.5	0–1
2	SOL_AWC	Available water capacity (mm/mm)	0.1–0.25	0.18–0.37	0.20–0.24	0.20–0.24	0–1
3	SOL_K	Saturated hydraulic conductivity (mm/h)	3.9–8	3.9–24.14	3.9–24	3.9–24	0–2000
4	GW_DELAY	Delay of time for aquifer recharge (days)	80	60–70	40	40–60	0–500
5	EPCO	Plant uptake compensation factor	0.95–0.98	0.6–0.8	0.9	0.9	0–1
6	OV_N	Manning's 'n' value for overland flow	0.6	0.1–0.14	0.1–0.15	0.14	0.01–30
7	ESCO	Soil evaporation compensation factor	0.05–0.1	0.2–0.4	0.4–0.6	0.35–0.5	0–1
8	CN2	Curve number	FRSE: 77, R02: 62, R08: 61	FRSE: 77, R02: 65, R08: 67, URBN-85	R02: 68 R08: 68	R02: 70, R08: 69	35–98
9	GW_REVAP	Groundwater 'revap' coefficient	0.02	0.02	0.02	0.02	0.02–0.2
10	ALPHA_BF	Base flow alpha factor (days)	0.15	0.15–0.19	0.25–0.27	0.29–0.7	0–1
11	GWQMIN (mm)	Threshold water depth in the shallow aquifer for flow	0	0	0	0	0–5000
12	REVAPMIN (mm)	Threshold water level in shallow aquifer for revap	420	300–325	200–400	100–420	0–500
13	CANMAX (mm)	Maximum canopy storage	R-08 and R02: 0.5, FRSE: 1.5	R-08, R02:0.5, FRSE: 1.5, R03: 1.1	R-08, R02:0.5,	R-08, R02:0.5,	0–100
14	CH_K2 (mm/hr)	Channel effective hydraulic conductivity	5.5	6.3	5.5–0.6	5.5–0.6	–0.01–500

R-08: Irrigated conjunctive use double cropping areas; R-02: Irrigated surface water double cropping areas; R-03: Irrigated surface water continuous cropping areas, FRSE: Forested area, URBN: Built up areas.

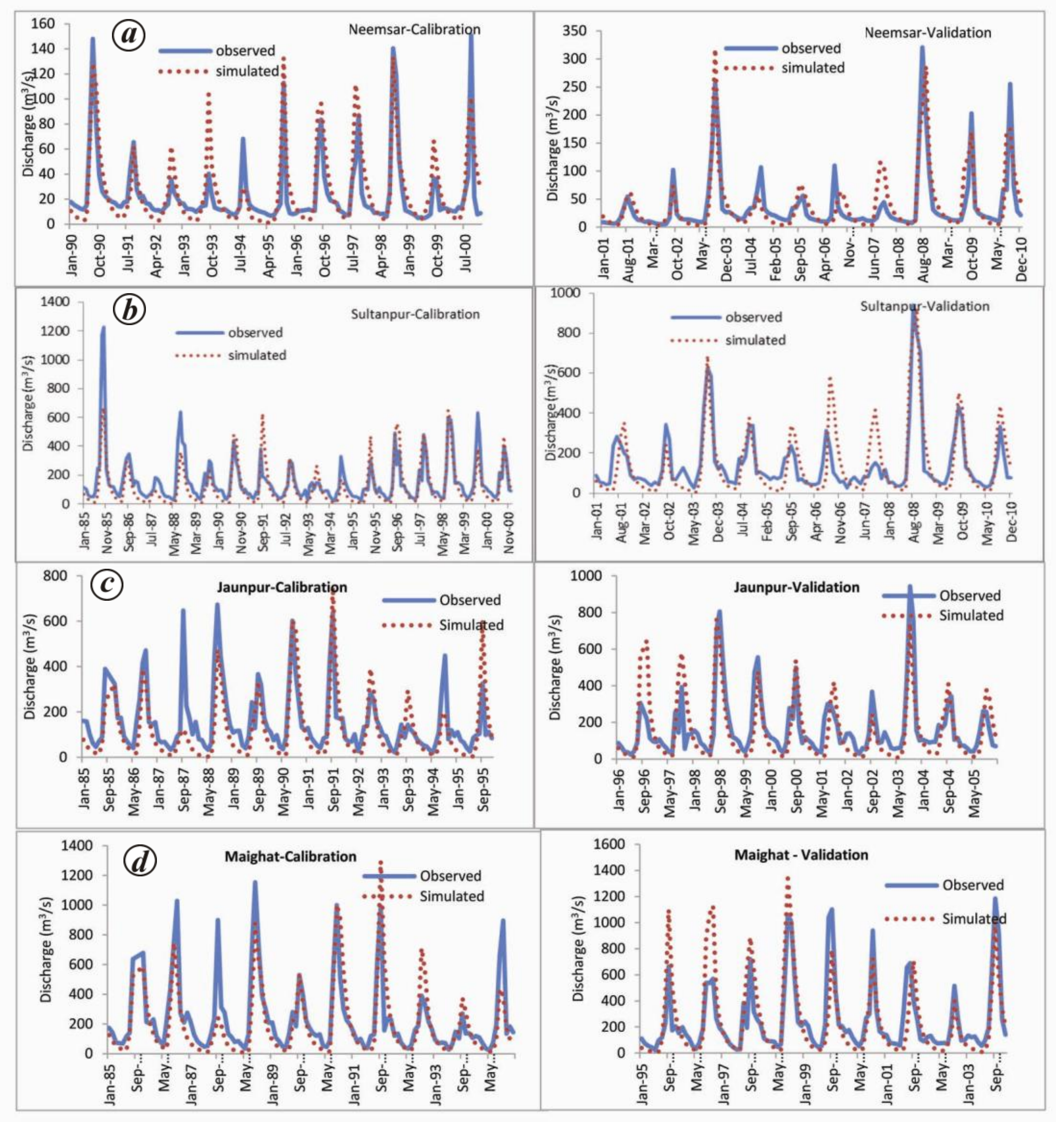

Figure 3. Observed and simulated monthly flow hydrograph at the (***a***) Neemsar; (***b***) Sultanpur; (***c***) Jaunpur; (***d***) Maighat gauging stations.

Simulation results of both rice and wheat agree with the observed values, though in some years overestimation and underestimation of both rice and wheat yield were observed. Possible model error for this could be different management practices, e.g. tillage operations, crop rotations, different quantity of water applications and changing of planting dates, etc. Similar results for SWAT crop yield calibration were reported earlier[34–36]. The results showed that long-term average simulated yield of both rice and wheat was satisfactorily modelled by SWAT (Table 4).

The average annual canal water availability to Gomti River basin from Sharda and Sahayak canal system during 2004–2007 period was 475 mm/year (ref. 40). The simulated mean allocation of canal water for the basin (for irrigating rice, sugarcane and pulses) during 1985–2010 ranged from 350 to 455 mm with a mean value of 403 mm/year. The approximate similar values of observed and simulated canal water availability also show a satisfactory performance of model simulations of crop yields.

Annual water yield and evapotranspiration

Calibrated and validated SWAT model was used to compute the annual water yield and ET for the entire Gomti River basin for the 1985 to 2010 period. Average annual water yield for the entire basin was found to be 8440.41 MCM (million cubic meters) and ET was 24,431 MCM, approximately three times that of water yield. Dutta *et al.*[2] also reported that the average annual water yield of Gomti basin due to rainfall was 7390 MCM. Our computed water yield values are about 15% more than those reported by Dutta *et al.*[2], because we have also considered contribution of shallow groundwater besides that of rainfall.

Table 3. Model calibration and validation performance statistics for monthly streamflows at four gauging stations

	Calibration			Validation		
Gauge station	NSE	RSR	|PBIAS|	NSE	RSR	|PBIAS|
Neemsar	0.66	0.58	8.2	0.68	0.56	3.1
Sultanpur	0.65	0.59	18.0	0.56	0.66	5.2
Jaunpur	0.51	0.68	24.3	0.56	0.65	9.5
Maighat	0.65	0.59	16.3	0.58	0.64	2.5

Table 4. Rice and wheat calibration and validation performance statistics

	Lucknow	Barabanki	Sultanpur	Jaunpur
Rice calibration				
Reported mean yield (t/ha)	1.68	2.01	2.05	2.13
Simulated mean yield (t/ha)	1.75	1.98	1.91	2.18
T value	0.06	0.72	0.12	0.60
PBIAS	–10.5	1.4	7.5	–1.9
Rice validation				
Reported mean yield (t/ha)	1.96	2.18	2.14	1.8
Simulated mean yield (t/ha)	1.72	1.98	2.07	2.21
T value	0.64	0.12	0.58	0.09
PBIAS	2.2	9.5	3.7	–18
Wheat calibration				
Reported mean yield (t/ha)	2.34	2.59	2.51	2.40
Simulated mean yield (t/ha)	2.37	2.08	2.39	2.31
T value	0.19	0.63	0.64	0.70
PBIAS	–13.7	0.76	4.5	3.6
Wheat validation				
Reported mean yield (t/ha)	2.51	2.93	2.70	2.50
Simulated mean yield (t/ha)	2.42	2.14	2.48	2.33
T value	0.41	0.19	0.14	0.55
PBIAS	–5.9	14.2	8.3	6.9

The spatial distribution of annual average water yield per unit area, ET and rainfall, at sub-basin scale in the Gomti River basin are shown in Figure 4. It shows a general decreasing trend in water yield (mm/year) from u/s to d/s areas representing the sub-basin 18–21. Eastern section of m/s sub-basins showed the highest water yield followed by the eastern section of u/s sub-basin (sub-basin 2). This decreasing trend in water yield could be due to annual rainfall and canal irrigation distribution in the basin. Average annual rainfall distribution (Figure 4 *c*) showed that water yield of eastern part of u/s and m/s sections of the basin has a comparatively higher rainfall. Poor canal distribution at d/s sub-basin along with comparatively lower rainfall may have resulted in lower water yield in d/s sub-basins. Similarly, higher rainfall and irrigation contributed to greater water yield in m/s basins. Average annual ET was also generally decreasing from u/s to d/s (Figure 4 *b*). Eastern segments of u/s and m/s sub-basins were found to have higher ET compared to the western segments. It may be attributed to higher rainfall and dense canal irrigation system. The linear regression analysis between annual water yield and rainfall for the entire basin over the 1985–2010 period showed a significantly positive correlation of 0.94 ($P < 0.01$), indicating that rainfall is the main determinant of water yield in Gomti River basin. Similar results have been reported earlier[41–43].

The temporal variations in annual water yield and ET per unit area for u/s, m/s and d/s sub-basins are shown in Figure 5. The temporal variations in ET (cv = 7%) were much lower than those in water yield (cv = 37%). The water yield increased over time in u/s and m/s sub-basins and over entire basin but it decreased in d/s sub-basins. In each period, the highest water yield was found in m/s, followed by u/s and lowest in d/s sub-basins. Similar temporal patterns were observed in ET in u/s and m/s sub-basins even though the range of variations in ET was lower than that in water yield. For each period, the ET was highest in u/s sub-basins and lowest in d/s sub-basins. The ET in u/s sub-basins was 19.7% higher than

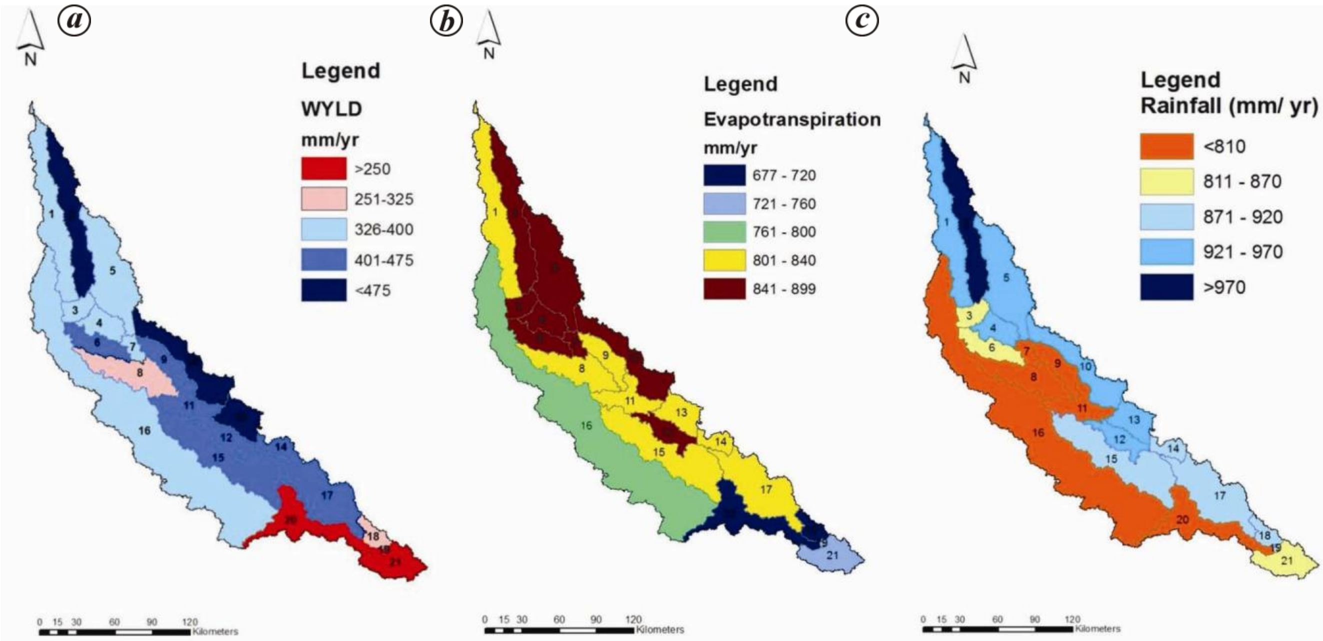

Figure 4. Long term average of (***a***) annual water yield, (***b***) evapotranspiration and (***c***) rainfall in different sub-basins in Gomti River basin. The numerals in the map refer to sub-basins.

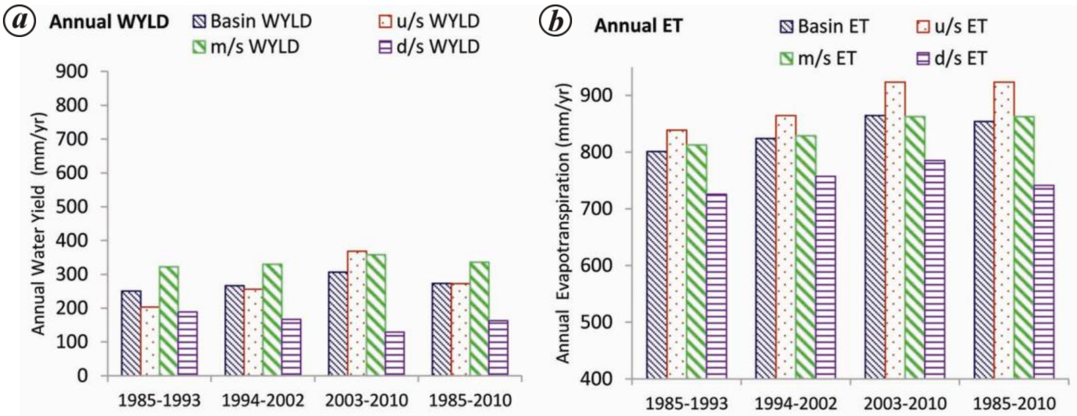

Figure 5. Average annual (***a***) water yield (WYLD) and (***b***) evapotranspiration (ET) averaged over the basin, sub-basins in u/s (upstream), m/s (midstream), d/s (downstream) during 1985–1983, 1994–2002, 2003–2010 and 1985–2010 (long term).

those in d/s sub-basins. In contrast to water yield, the ET also showed increasing trend in d/s/sub-basins. This implies that, the d/s sub-basins are drying over time on account of both decrease in water yield and increase in ET. Hence, water managers and planners need to give more attention to the d/s area of the basin.

Seasonal water yield and evapotranspiration

The temporal variations in water yield and ET per unit area for u/s, m/s and d/s sub-basins during monsoon and non-monsoon seasons are shown in Figure 6. The water yield was generally higher in m/s followed by u/s and lower in d/s sub-basin during different time periods. Similar to the annual pattern, the water yield during both monsoon and non-monsoon seasons increased with time in u/s and m/s sub-basins but decreased in d/s sub-basin. The water yield during monsoon season was higher than that in the non-monsoon season. Similar pattern was observed in u/s and m/s ET during both monsoon and non-monsoon seasons but in d/s ET remained constant over time. The magnitude of ET in respective sub-basins was significantly higher in monsoon season than that in non-monsoon season. During monsoon season, the annual average ET varied little among u/s, m/s and d/s sub-basins, though the u/s sub-basin ET was generally higher. The ET was generally higher in u/s followed by m/s and lower in d/s sub-basin.

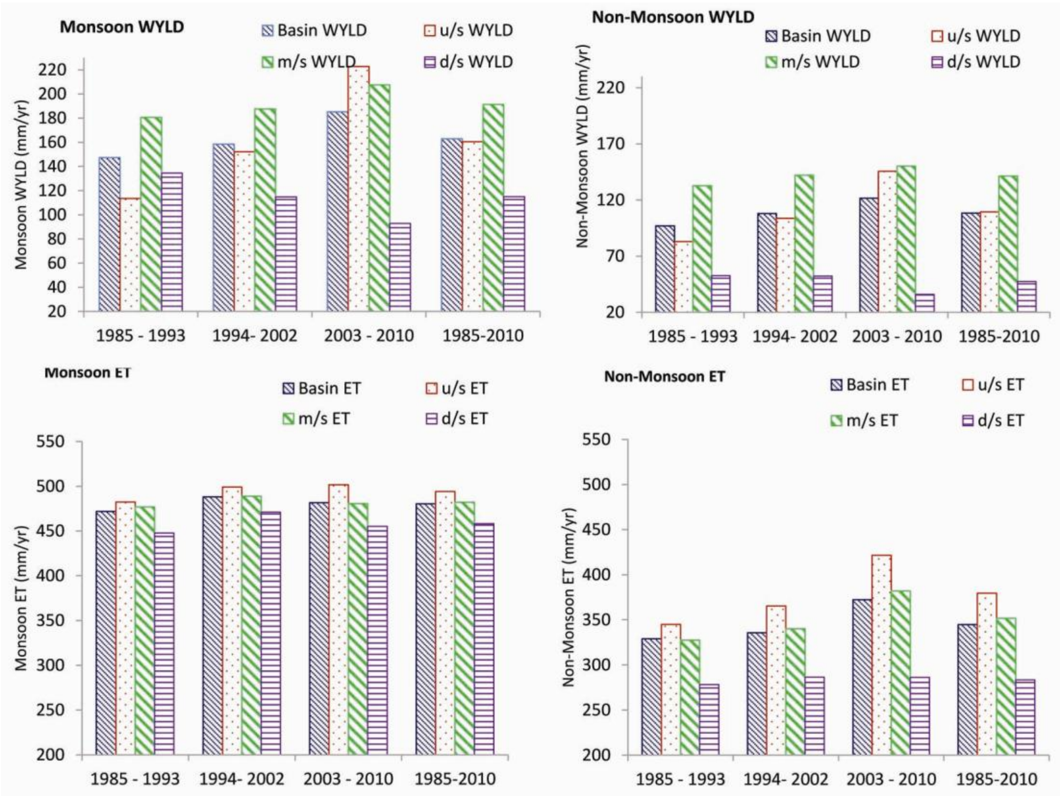

Figure 6. Total monsoonal and nonmonsoonal evapotranspiration (ET) and water yield (WYLD) averaged over the basin, sub-basins in u/s (upstream), m/s (midstream), d/s (downstream) during 1985–1983, 1994–2002, 2003–2010 and 1985–2010 (long term).

Table 5. Summarized results of Mann–Kendall test with Sen's slope estimator of mean temperature of different districts of the Gomti River basin (1972–2007)

District (sub-basin)	Sen's slope of mean annual temperature °C/year
Pilibhit (u/s)	0.022**
Shahjahanpur (u/s)	0.024**
Kheri (u/s)	0.023**
Sitapur (u/s)	0.020**
Hardoi (u/s)	0.020**
Unnao (m/s)	0.021**
Lucknow (m/s)	0.020**
Pratapgarh (m/s)	0.016**
Bara Banki (m/s)	0.021**
Faizabad (m/s)	0.017**
Sultanpur (d/s)	0.018**
Jaunpur (d/s)	0.016**
Varanasi (d/s)	0.011

**Significant at 0.05 level based on Mann–Kendal test.

The temporal patterns in water yield during monsoon season can be attributed to the temporal pattern of rainfall during monsoon season (Figure 7) which account for 80% of annual rainfall. The rainfall increased over time in u/s and m/s sub-basins, but decreased in d/s during monsoon season, thus resulting in similar pattern in seasonal water yield. The temporal pattern of ET during monsoon and non-monsoon seasons was not related to the respective seasonal rainfall patterns. The temporal pattern during non-monsoon season may be attributed to the increase in temperature. Table 5 shows the Sen's slope values for temperatures trends for different districts over the 1972–2007 period. It was found that the average temperature of the entire basin significantly increased from 1972 to 2007 and the rate of increase was more in u/s districts compared to d/s districts (Table 5).

It is thus clear that water yield at d/s decreased both during monsoon and non-monsoon seasons from 1985 to 2010.

Conclusions

In this study the semi-distributed SWAT model was successfully applied to quantify the ET and water yield (an index of surface water availability) for the entire Gomti River basin and its sub-basins over the 25-year period. Calibration and validation at four hydrological stations indicated good to satisfactory performance of the SWAT model in modelling streamflow in the Gomti River basin. The ET and water yield simulations were improved by simulating crop yields at HRU level – a major sink of the water in the basin.

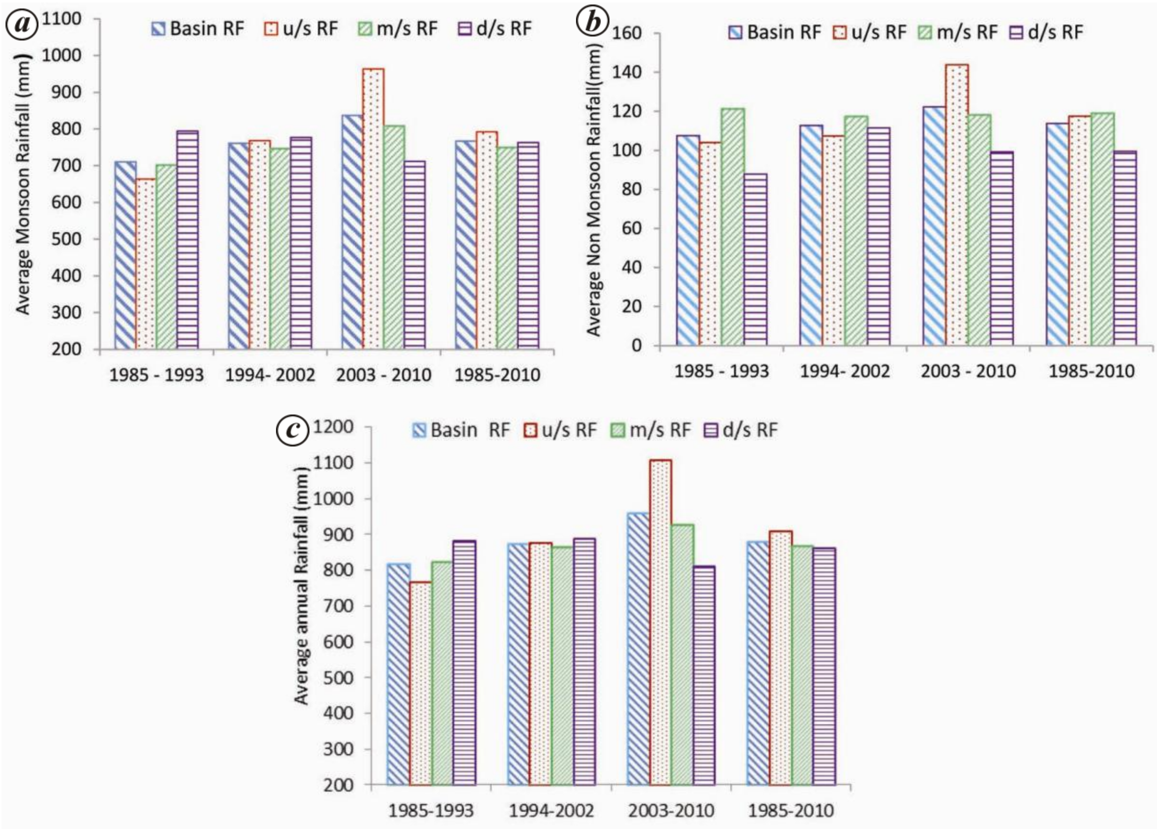

Figure 7. Average (***a***) monsoonal, (***b***) nonmonsoonal and (***c***) annual rainfall averaged over the basin, sub-basins in u/s (upstream), m/s (midstream) and d/s (downstream).

Overall, the water yield decreased from u/s to d/s areas of the basin which is primarily attributed to the annual rainfall distribution across the basin and, to a certain extent, the distribution of canal irrigation system. Lower annual rainfall and poor canal distribution in d/s sub-basin covering the districts of Jaunpur and Varanasi are responsible for lower water yield.

Over time, the water yield is increasing in u/s and m/s sub-basins but decreasing in d/s sub-basin. In contrast, ET is increasing in d/s sub-basin. It may be concluded that though at basin scale water yield is increasing over time, mainly due to increase in rainfall, the d/s sub-basin covering districts of Jaunpur and Varanasi is drying up. Therefore, there is a need for better understanding of the relationships of supply of surface water resources from the existing canal network and the long standing cropping pattern in vogue. We propose a viable change in the cropping pattern of the d/s area of the basin by shifting it to cultivating less water-intensive crops. These results may be of great importance in developing the restoration plan of the Gomti River basin.

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ACKNOWLEDGEMENT. We thank the CWC, Government of India for providing streamflow data and the Department of Agriculture, Uttar Pradesh, for providing crop production data.

Received 8 October 2014; revised accepted 28 January 2015