CHANGES IN EVAPOTRANSPIRATION, RUNOFF AND BASEFLOW WITH LULC CHANGE IN EASTERN INDIAN RIVER BASINS DURING 1985-2005 USING VARIABLE INFILTRATION CAPACITY APPROACH

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ABSTRACT

Modification of land use land cover (LULC) modifies the catchment hydrology by altering the hydrological parameters as evapotranspiration (ET), runoff and baseflow and subsequently influences the local scale hydrological cycle. The current study focuses on the study of changes in hydrological parameters with reference to changes in LULC during 1985, 1995 and 2005, and possible changes by 2025 in four River basins as Subarnarekha, Brahmani, Baitarani, Mahanadi and Nagavali River of Eastern India. For analysis, the framework of the Variable Infiltration Capacity (VIC) macroscale hydrologic model is used to estimate the relative consequences LULC change. This region experienced the total increase of built-up, cropland and water body by 1401km^2 during 1985 – 1995 and 373km^2 during 1995–2005 with corresponding loss of forest and scrubland cover by 1343km^2 and 384km^2. With these major LULC modifications, the model simulation showed a decrease in ET with 0.03% during 1985-1995; with a slight increase with 0.01% during 1995-2005. Conversely, runoff and baseflow showed an overall increase with 0.03% and <0.01% respectively during 1985–1995; and decrease with <0.01% and 0.03% during 1995–2005. In response to the predicted LULC in 2025, with total increase of 1813km^2 in built-up, cropland and water body with loss of forest and scrubland cover by 1752km^2, the VIC model simulation estimated reduction of ET with 0.09% with an increase of runoff and baseflow by 0.05% and 0.08% respectively. Among the vegetation parameters, leaf area index (LAI) appeared the most sensitive to alter the water balance. LULC alterations via deforestation, urbanization, cropland expansions led to reduced canopy cover for interception and transpiration that in turn contributed to overall decrease in ET and increase in runoff and baseflow. This study reiterates changes in the hydrology due to LULC changes, thereby providing useful inputs for integrated water resources management in the principle of sustained ecology.

INTRODUCTION

River basins are subjected to Land Use Land Cover (LULC) changes that influence the water and energy balances, and regulate the corresponding change in hydrological cycle. The major components in hydrological cycle such as precipitation, surface and sub-surface water flow and storage, evapotranspiration can be modeled mostly knowing the variables such as spatial distribution of the land surface features or LULC, topography, precipitation, temperature and soil property. Reduction in forest or natural vegetation reduces the canopy inception and evapotranspiration, sediment holding capacity and alters the energy flux (Koster *et al.*, 2004; Seneviratne *et al.*, 2010; Schilling *et al.*, 2008). The conversions of forest cover to cropland and built-up increases the surface runoff, allow higher sediment loss, etc. (Calder, 1992). The alteration of LULC changes (LULCC) changes the leaf area index, rooting depth, albedo and surface roughness, and modifies the radiation, momentum and water dynamics between the atmosphere and land system (Pielke, 2005). In tropical regions, changes due to intense deforestation may lead to more warm and dry climate, whereas more cold in higher latitudes of Northern hemisphere (DeFries *et al.*, 2002; Lawrence *et al.*, 2010). Study of LULC changes (LULCC) give insights to the response of natural system due to disturbances created by human activities has significant utility especially in era of huge food and clean water demand.

Various hydrological models such as ArcView Soil and Water Assessment Tool (AVSWAT) (Arnold *et al.*, 1998), MIKE-SHE (Abbott *et al.*, 1986), Precipitation Runoff Modeling System (PRMS) (Markstrom *et al.*, 2015), and Variable Infiltration Capacity (VIC) (Liang *et al.*, 1994) are used to quantify the impact of LULC changes on the hydrological parameters. Moreover, the spatially distributed inputs of LULC and associated parameters such as Leaf Area Index (LAI), albedo, radiation, precipitation and temperature are important to capture the spatial heterogeneity of landscapes in hydrological models (Collischonn *et al.*, 2008; Tang *et al.*, 2009). Various hydrological studies have been carried out employing the VIC model that performs significantly to simulate the hydrological components at large spatial extents (Mishra *et al.*, 2008; Aggarwal *et al.*, 2012; Mun˜oz-Arriola et al., 2009; Tang et al. 2010).

In India, the impact of LULC on hydrological components has been studied by various researchers, where increase in runoff was observed due to deforestation and urbanization by Garg *et al.* (2012) in the Asan river watershed of Dehradun city, in Mahanadi River basin by Mishra et al. (2008). Patidar and Behera (2016) and Babar and Ramesh

(2015) observed decrease in evapotranspiration due to deforestation in the Ganga river basin and Nethravathi river basins respectively. The Mahanadi and its adjoining river basins that supported huge population are undergoing drastic LULC changes, experiences extreme and recurrent climate events as cyclone, flood and drought, that creates large gaps between supply and demand between food and water (Dadhwal *et al.*, 2010; Bhagwat and Maity, 2013; Behera *et al.*, 2017). Hence, the study of past and possible future LULC changes and associated impact on hydrological parameters in relation to the existing climate scenario in this region is valuable to society as well as scientific community, land resources managers, policy makers etc. The current study focuses on quantification of changes in hydrological parameters in relation to the LULC changes and to predict the future possible changes by employing the predicted LULC changes.

STUDY AREA

The study is carried out in Mahanadi (144,395.04 km^2), and three adjoining river basins as Brahmani-Baitarani (53,088.52 km^2), Subarnarekha (26,521.45 km^2) and Nagavali (41,975.77 km^2) (named as MRB hereafter) situated in eastern India, flowing eastward to Bay of Bengal. (Fig. 1i). These rain-fed river basins with dry sub-humid to moist sub-humid climate, situated in the elevation range of mean sea level (msl) to 1500 m (above msl) (Fig. 1ii), and shared by five Indian states as Odisha, Chhattisgarh, Madhya Pradesh, Maharashtra and Jharkhand. The annual average rainfall of this region is 1360 mm; mean temperature varies between 4°C to 12°C in winter to a maximum of 42°C to 45.5°C in May. The main soil types in the study basin are Loamy, Clayey, clay and loamy skeletal. The study area is cropland and forest dominated landscape, where numbers of dams, irrigation projects, and barrages were constructed for irrigation and flood control, contains the largest dam of Asia as Hirakud Dam (746 km^2).

DATA AND METHODOLOGY

LULC Modeling

We have studied the changes in hydrologic response due to LULCC at decadal scale for past three decades and predicted the changes in 2025. The ISRO-IGBP Land Use Land Cover Change Dynamics Modeling Platform (ILUCC-DMP) is a macroscale LULC model, developed with the concept of Dynamic Conversion of Land Use and its Efficiency (Dyna-CLUE) model. This model consists of a combination of three modeling techniques of regression: Logistic Regression, Linear Regression, and Neural Regression. The ILUCC-DMP model takes the LULC maps and drivers as the spatial and demands as non-spatial inputs for future scenario prediction (Behera et al., 2017). The spatial allocation of demanded area depends on the location suitability, demand condition which is constraint by the defined decision rules in form of location specific land use types. The location specific land use type decision rules include the migration order (preferred land cover) and the class inertia (rigidity of conversion). For accounting the effect of neighborhood, window size 3x3 and 5x5 kernels matrix were available. The LULC maps were generated at 1:50,000 scale using Landsat MSS (1, 2 and 3; 60 m) for the year 1985 and TM (4 and 5; 30 m) for the years 1995 and 2005 which were accessed from Earth Explorer data portal (https://earthexplorer.usgs.gov/). The LULC modeling was carried out at a spatial resolution of 250 m (Behera *et al.*, 2017). For LULC modeling, numbers of driver data were used as climate, edaphic, topographic, anthropogenic and distance to road, built-up, water body and forest. The IMD (Indian Meteorological Department) daily climate data (temperature and precipitation) (Resolution: 1° and 0.5° for temperature and precipitation respectively); NBSS & LUP (Indian National Bureau of Soil Survey and land Use Planning) soil map (soil depth) were collected. Shuttle Radar Topographic Mission (SRTM) derived digital elevation model (DEM) was downloaded to be used as elevation and to derive the slope and aspect raster. Anthropogenic variables (socioeconomic (numbers of households, population, working population, literacy, sex ratio, drinking water facility, medical facility, total road length) were collected from various sources as local data office, Census India web portal, etc. Distances to drivers were generated from the primary data mapped in the LULC maps as built-up, cropland, water body and forest. To verify the model performance, the LULC of 2005 was simulated using the LULC of 1985 and 1995, and compared with the actual LULC of 2005. With satisfied accuracy, the LULC of 2025 was predicted.

Hydrological Modeling

To simulate the corresponding changes in hydrological parameters, the VIC model was used. It is a macro-scale level semi-distributed hydrological model developed at the University of Washington, USA (Liang *et al.*, 1994). The VIC model uses empirical approximations to simulate hydrological processes of evapotranspiration, infiltration and runoff, but possesses a physically-based component to represent the exchanges of latent and sensible heats with the atmosphere. The Penman-Monteith equation (1948) is used in VIC for estimating the evapotranspiration, which is the sum of weighted evaporation and transpiration from the vegetation cover, and evaporation from the bare soil cover according to their occurrence in a grid cell. The VIC model was run with a grid cell of 0.25° appending the area of each LULC in the grids (Bhattacharya *et al.*, 2013). The VIC simulates non-uniformly distributed runoff in each grid cell using a stand-alone routing model that solves the linearized de saint-venant equation (Lohmann *et al.*, 1996, 1998). The vegetation parameterization of the VIC model typically includes fractional coverage of each LULC within the grid cell, monthly LAI and albedo, flag for presence/absence of canopy, displacement height, roughness length and stomatal and architectural resistances. MODIS leaf area index (LAI) and albedo data (500 m resolution) were used to derive the monthly LAI and albedo of each LULC. The values of rest of the parameters were derived from the LDAS 8th database and MM5 terrain dataset (ldas.gsfc.nasa.gov/LDAS8th/MAPPED.VEG/web.veg.monthly.table.html). The daily climate data from India Meteorological Department (IMD) was used as meteorological forcing of maximum temperature, minimum temperature and precipitation for the year 1976 to 2005 were used in the VIC model for hydrological simulation. The soil parameters, viz., soil layer depths (d_1 and d_2), infiltration curve parameter (b_i), sub-surface flow parameters (Ds and W_s) were calibrated and validated with the daily discharge data for the gauging sites. The methodology flowchart is given in Fig. S1. The VIC simulated runoff is routed for three river sites as Bamnidhi (Lon: 82°42'24.064"E, Lat: 21°54'7.923"N), Tilga (84°24'56"E, 22°37'22"N) and Gomlai (84°54'24"E, 21°5'0"N) gauging stations for the years 1996 to 2000 for calibrating the soil parameters and 2001 to 2005 for validation at monthly time steps. The simulated streamflow is compared with the observed streamflow provided by the Central Water Commission (CWC), India. The Nash–Sutcliffe efficiency E_f, relative error E_r, and coefficient of determination (r^2) were used to test the efficiency of the VIC model (Nash and Sutcliffe, 1970). The efficiency (E_f) and the relative error (E_r) were calculated using the given formula:

$$E_f = 1 - \frac{\sum_{i=1}^{N} (Q_{\text{mod},i} - Q_{\text{obs},i})^2}{\sum_{i=1}^{N} (Q_{\text{mod},i} - \overline{Q_{\text{obs},i}})^2} \qquad E_r = (\overline{Q_{\text{mod}}} - \overline{Q_{\text{obs}}}) / \overline{Q_{\text{obs}}}$$

where, $Q_{\text{mod},i}$ = monthly modeled streamflow for month ; Q_{obs} = monthly observed streamflow for month ; N = number of months; and $\overline{Q}_{\text{mod}}$ and $\overline{Q}_{\text{obs}}$ are the mean of the monthly modeled and observed stream flows respectively. When E_f = 1.0, the model perfectly predicts the observations.

RESULTS AND DISCUSSION

LULC change and prediction

13 LULC classes were visually identified and mapped in 1985, 1995 and 2005 in the study area as aquaculture (AQ), barren land (BL), built up (BU), crop land (CL), deciduous broad leaved forest (DBF), fallow land (FL), grass land (GL), Mangrove (MG), mixed forest (MF), plantation (PL), salt pane (SP), shrub land (SL), water body (WB) and waste land (WL) (Fig. S2). Cropland was observed as the dominant land cover (nearly 56%) in all three years (Fig. S2), followed by DBF (~26 %). Least area were occupied by MG, BL and SP occupied small fractions of basin area in these three years (less than 1%). MF and SL occupancy were observed nearly 4% and 5% of the total geographic area, respectively. We observed overall decreases in the forest classes for the study periods and increases in BU and CL classes for the basin (See Fig. S2e; Table 1). Among the forest classes, the maximum decrease was observed in DBF with 1.09% followed by MF (2.54%) during 1985 to 1995, although, this rate was decreased to 0.37% during 1995-2005 for both the classes. Similar trends were also observed for SL, lost by 1.75% and 0.57% during 1985-1995 and 1995-2005 respectively. In contrary, fallow land was decreased by 2.80% during 1985-1995; but increased by 0.14% during 1995-2005. Conversely, the maximum increase in area was observed for CL with an overall increase of 0.48%, followed by BU with an area of 9.97% during 1985-1995. However, during 1995-2005, the rate of cropland and BU expansion reduced to 0.02% and 6.11% (See Fig. S2e; Table 1). During 1985-1995, WB increased by 4.55%; whereas, during 1995-2005, this increment reduced to 0.38%.

Predicting the LULC of 2005, we observed satisfactory level of modeling accuracy showing an overall accuracy of 98% with a Kappa value of 0.97 (Behera et al., 2017). The predicted change in land use by the model during 2005 to 2025 followed the pattern as observed during 1985 to 2005, where deforestation and increase in BU and CL areas were majors. About 0.54% change in the dominant land use as CL and 14.38% in BU area are predicted during 2005 to 2025. Whereas, maximum decreases were predicted in DBF and MF as 1.50% and 3.06% respectively during 2005 to 2025 (See Fig. S2e; Table 1).

The overall LULCC in the study area denotes reverse trend for forest and scrubland vs cropland and built-up classes, where forest and scrubland were decreasing, on contrary croplands and built-up were increasingThe construction of dam and reservoirs also causes major conversions as: forest and cropland to water body, forest to croplands and built-up, croplands and scrublands to built-up etc. . Similar changes in LULC were also reported is past studies (Dadhwal et al., 2010; Bhagwat and Maity, 2013; Behera et al., 2017). These changes were mainly caused to fulfill the local and regional food demand for escalating population along with sufficient water availability from canal irrigation led to extensive agricultural practices at the cost of deforestation.

Impact of LULC change on hydrological water balance

To assess the impact of LULCC on hydrological parameters, we used a delta approach in which the model simulations were performed for each LULC scenario by keeping climate data (of the year 2005) invariant (Mao and Cherkauer, 2009; Wagner *et al.*, 2013). Thus the simulations highlight the effects of LULCC on ET, baseflow and surface runoff with the climate scenario of 2005. Due to the easy and accurate measurement of streamflow than evapotranspiration and baseflow, the gauging stations (Bamnidhi, Tilga and Gomlai) measured streamflow data during 1996 to 2005 was used for model calibration and validation. In calibration, we got maximum and minimum r^2 of 0.90 (Gomlai) and 0.62 (Bamnidhi) with highest efficiency (E_f) of 0.86 and error (E_r) of -0.02 at Gomlai (Table 2). The validated streamflow also showed good agreement with the highest r^2 values of 0.92 with E_f of 0.92 and E_r of -0.22 at Gomlai. These results reveal that the efficiency of the VIC model is well accepted in the current study.

An overall decrease was observed in ET in past three decades in MRB (Table 3). During 1985-1995, 0.03% decrease in ET was observed, whereas slight increase (0.01%) was observed during 1995-2005. The reverse changes were observed in runoff and baseflow showed an overall increase (0.03% and 0.01%) within the years 1985-1995. However, during 1995-2005, slight increase in ET was observed with corresponding decrease in runoff and baseflow (< 0.01% and 0.02%) (Fig. 2). The overall change of these hydrological parameters during 1985-2005 was predicted, where expected decrease in ET would be varying from 0.09% with increase in runoff and baseflow by 0.05% and 0.08% respectively. The decrease in ET during 1985-1995 could be attributed to higher deforestation rate with a loss of nearly 771 km^2 DBF and 286 km^2 MF. However, a slight increase in ET with a decrease in runoff and baseflow during 1995-2005 could be attributed to a lower deforestation rate with higher rate of plantation in the basin, where the increase in ET cancelled out the decrease in ET at the basin scale considerably. The same compensation effects were also observed for runoff and baseflow. The higher deforestation during 1985-1995 led to less canopy evaporation since the canopy cover reduced with a decrease in LAI leading to decreased interception and transpiration. The conversion of forest to crop, shrub and plantation led to decrease in surface roughness which ultimately resulted in increasing runoff due to decreased basin storage. Additionally, the absence of deep rooting system due to deforestation and conversion of untilled land or other perennial cover crops to annual row crops led to less consumption of groundwater that increased the baseflow. Due to these, the predicted deforestation and increase in cropland built-up in 2025 will reduce the ET and increase the runoff and baseflow. Past studies have reported increased baseflow due to deforestation which leaded to decrease in both interception and dry season transpiration (Zhang and Schilling, 2006; Favreau *et al.*, 2009). Schilling (2005) observed an increase in baseflow due to increased intensity of row crops in Iwoa. Mishra (2008) and Dadhwal *et al.* (2010) also observed an increase of streamflow with 4.53% at Mundali outlet of the Mahanadi River basin as a result of decreasing ET. Bhattacharya *et al.* (2013) observed higher runoff in cropland area for Chambal River basin in India using the VIC model. The results of the study suggest that the small scale LULC changes may not extensively impact hydrological components at the basin scale, particularly when the compensation effects are prominent.

Table 4 shows the seasonal change of monthly ET, runoff and baseflow at basin-scale during 1985-2025 respectively. It can also observed that the loss of monthly ET was lowest and highest during April (driest) and July (wettest) respectively, which were December and July for runoff, and February and September for baseflow. Such yearly variation could be attributed to be influenced by the amount of precipitation. The seasonal change in hydrological components are summarized from Fig. 3 showing more prominent change in ET and runoff in pre-monsoon season (Jan, Feb, Mar, and Apr) than the monsoon and post-monsoon seasons. During the crop growing season (monsoon to post-monsoon), the LAI is higher leading to more canopy transpiration in contrast to low LAI in dry season resulting in low canopy evaporation causing lower ET and vice versa. The lower values of baseflows in dry season due to exploitation deep store of water by forests with deep roots and human use. With sufficient water availability, the LULCC impact got suppressed for both the ET and runoff in monsoon and post monsoon due to over expression of climate variables, such as, precipitation, leading to smooth curve. With the future predicted LULC scenario, the high deforestation rates were predicted during 2005-2025; and hence, the decrease in evaporation and in overall ET with an increased trend of runoff and baseflow. Decadal changes in hydrological components revealed that the higher changes in relative % difference are prominent during pre-monsoon rather than monsoon and post monsoon seasons. The impact of deforestation rate on seasonal change in evaporation during 1985-1995 was higher as compared to 1995-2005 during monsoon season.

It can be surmised from the above analysis that, change in runoff and ET would be less significant; however, these values could be significant because of the large basin area. Conversely, from this analysis, it can be understood that the recurrent high magnitude flood events occurring in the basin recently may not be much influenced by the LULC change at the basin-scale. However, the occurrence of these flood extremes could be attributed to the rainfall extremes by which rainfalls with high intensities occur within a short span of time. Moreover, due to the encroachment of the river floodplains by constructing buildings and other establishments and obstruction of natural stream lines, the runoff generated from different land uses could not be effectively drained out, causing flood havoc. Furthermore, an increase in baseflow would help in groundwater recharge.

The assessment of the hydrologic effects of LULC change is a vital prerequisite for water resources development and management. Implementation of physical and distributed model VIC requires a detailed description of vegetation and soil parameters, but can precisely identify the modifications in hydrological regime due to LULC changes. Nevertheless, the assessment of hydrologic impacts of LULC change is a challenging task mainly due to the fact that the observed or simulated changes in hydrological components are combined impact of climate variability, LULC change and human interventions (such as regulation of river flow through dams and barrages). Although the procedure which was adopted in this study to simulate hydrological responses from the study area is reasonable in order to identify the impacts of LULC change, an analysis can be performed in future studies to assess the relative contributions of LULC change and climate variability to changing hydrological responses.

CONCLUSIONS

The impact of LULCC on the hydrological components of evapotranspiration, runoff and baseflow at basin-scale computed by the VIC macro-scale model clearly brought out the significant impact of anthropogenic activities and dictates the model ability to successfully accommodate all components of the environmental and landscape variables. The overall annual ET was decreased by 11.30%, compensated by an increase in annual Runoff by 5.85% and 9.20%, and annual base flow by 18.51% and 29.58%, respectively; is well corroborated with the conversion of forest to plantation, forest to cropland in the river basins. Cropland and built-up area expansion by means of deforestation costs the decrease in the overall ET with increase in runoff and baseflow. This study has provided the valuable insights in the perspective of the subsequent changes in hydrological components as a result of LULCC for future prediction, which can be useful in developing management policies to conserve the forests in more intelligent and scientific way. For calibration and validation, the gauging sites were selected in the upstream areas of the rivers which were showing good agreement with the simulated streamflow. However, the downstream gauging sites might bias the estimation due to the dam management policies which were not included in the present study, which could be scope of a future study by including the lake module in the VIC framework. The LULC have clear impact on the watershed hydrology altering the runoff and streamflow discharges, especially in the studied basins, where monsoon flood and water inundation is regular events in past decades. However, a number of man-made structures as reservoirs and dams reduced such events. Deforestation, cropland expansion and urbanization are prominent and will continue in the upcoming decades. This study is providing insights to the future hydrological scenarios, which will offer the planners to take prior actions for sustainable water use.

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Table 1 LULC change area statistics (in %) (-) Sign indicates loss

LULC types	Change duration		
	1985-1995	1995-2005	2005-2025
Aquaculture	13.89	142.68	66.83
Barren land	-4.90	-6.69	-12.09
Built-up	9.97	6.11	14.38
Cropland	0.48	0.02	0.54
Deciduous Broad leaved Forest	-1.09	-0.37	-1.50
Fallow land	-2.80	0.14	-2.82
Mixed Forest	-2.54	-0.37	-3.05
Mangrove	-9.95	-1.51	-13.27
Plantation	0.47	2.46	2.74
Saltpan	0.00	4.55	4.35
Scrubland	-1.75	-0.57	-2.36
Waterbody	4.55	0.38	4.41
Waste land	10.16	-5.21	2.28

Table 2 Statistical parameters of calibration and validation at three gauging sites

	a) Calibration (2005)			*b) Validation*		
	Gomlai	Tilga	Bamnidhi	Gomlai	Tilga	Bamnidhi
r^2	0.90	0.88	0.62	0.92	0.76	0.77
Ef	0.86	0.83	0.40	0.92	0.59	0.79
Er	-0.02	-0.13	-0.15	-0.22	0.04	-0.21

Table 3 Decadal change in hydrologic variables (in mm) due to LULCC

Year	ET	Runoff	Baseflow
LULC 1985	746.21	179.45	444.40
LULC 1995	746.00	179.52	444.46
LULC 2005	746.07	179.51	444.36
LULC 2025	745.42	179.60	444.73
Change Duration		Change in %	
1985-1995	-0.03	0.03	0.01
1995-2005	0.01	0.00	-0.02
2005-2005	-0.09	0.05	0.08

Table 4 Monthly changes in (i) ET, (ii) runoff and (ii) baseflow due to LULC

	Value in mm				Change in %		
	1985	1995	2005	2025	1985-1995	1995-2005	2005-2025
Jan	37.07	37.17	37.19	37.36	0.27	0.05	0.45
Feb	45.32	45.34	45.37	45.49	0.06	0.06	0.27
Mar	26.31	26.40	26.41	26.43	0.35	0.04	0.06
Apr	18.30	18.35	18.35	18.35	0.24	-0.01	0.05
May	31.99	31.99	31.99	31.98	0.02	0.01	-0.04
Jun	47.09	47.05	47.03	46.99	-0.10	-0.03	-0.08
Jul	113.36	113.25	113.24	113.07	-0.10	-0.01	-0.15
Aug	112.93	112.87	112.87	112.72	-0.06	0.01	-0.13
Sep	104.59	104.53	104.53	104.40	-0.06	0.00	-0.13
Oct	92.36	92.29	92.30	92.14	-0.08	0.01	-0.18
Nov	69.91	69.83	69.84	69.61	-0.12	0.02	-0.33
Dec	46.97	46.93	46.95	46.88	-0.08	0.04	-0.15
(ii)							
Jan	2.03	2.03	2.03	2.03	0.02	-0.02	-0.01
Feb	0.71	0.71	0.71	0.71	0.02	-0.01	0.05
Mar	0.93	0.93	0.93	0.93	-0.05	-0.05	0.00
Apr	0.74	0.74	0.74	0.74	-0.08	-0.10	0.00
May	1.48	1.48	1.48	1.48	-0.02	-0.05	0.00
Jun	12.45	12.45	12.45	12.45	-0.05	-0.02	0.01
Jul	52.30	52.30	52.28	52.29	0.00	-0.04	0.01
Aug	34.06	34.08	34.08	34.10	0.06	0.02	0.05
Sep	47.10	47.13	47.14	47.18	0.07	0.01	0.09
Oct	25.23	25.24	25.25	25.27	0.05	0.02	0.09
Nov	1.97	1.97	1.97	1.97	0.05	0.03	0.04
Dec	0.45	0.45	0.45	0.45	0.05	0.00	0.36
(iii)							
Jan	0.00	0.00	0.00	0.00	0.00	0.31	0.06
Feb	0.01	0.01	0.01	0.01	0.01	0.03	-0.34
Mar	0.00	0.00	0.00	0.00	-0.55	0.00	0.00
Apr	0.00	0.00	0.00	0.00	-4.81	0.76	-0.50
May	0.00	0.00	0.00	0.00	-1.21	-0.47	-0.20
Jun	0.77	0.77	0.77	0.78	-0.41	-0.11	1.04
Jul	84.09	84.01	83.98	84.01	-0.09	-0.04	0.04
Aug	148.78	148.77	148.76	148.83	0.00	-0.01	0.05
Sep	127.17	127.26	127.24	127.37	0.07	-0.02	0.11
Oct	68.26	68.30	68.28	68.37	0.06	-0.03	0.13
Nov	15.04	15.05	15.04	15.07	0.09	-0.03	0.14
Dec	0.28	0.29	0.29	0.29	0.25	-0.01	0.42

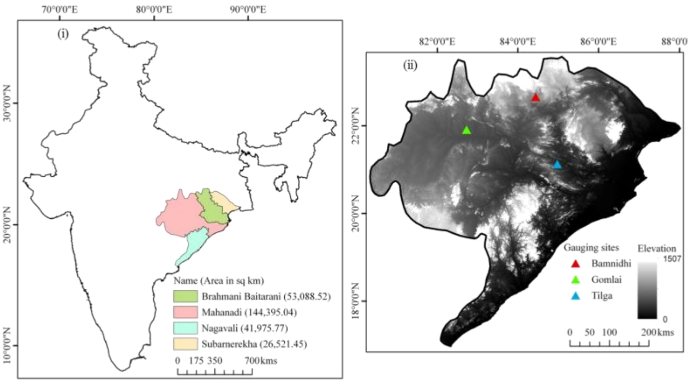

Figure 1. (i) Study area with (ii) altitude map and the location of the discharge locations Gomlai, Bamnidhi and Tilga

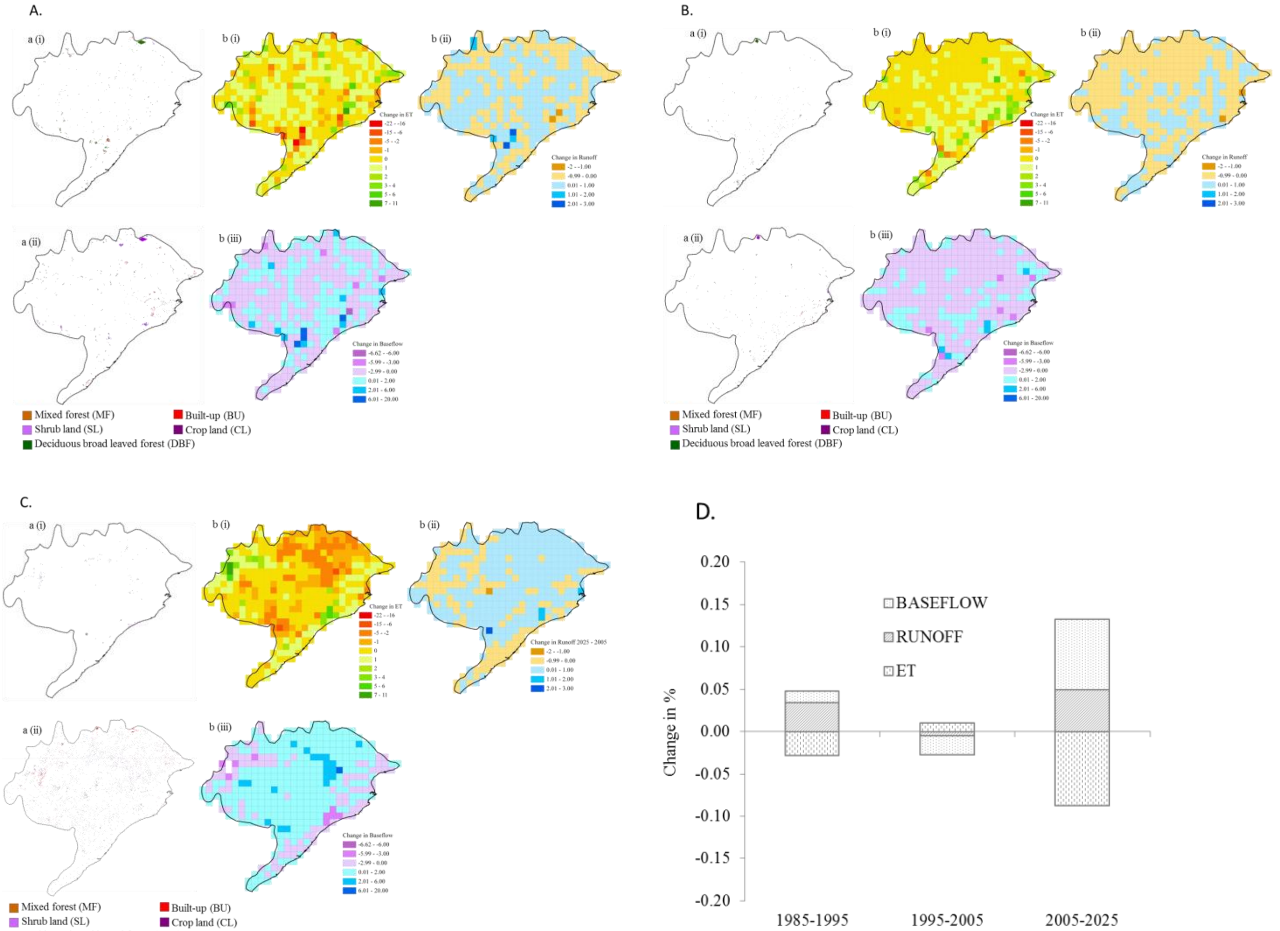

Figure 2. a: LULCC (i) loss and (ii) gain ; b: change in hydrological variables (i) Evapotranspiration (Mean -0.2; S.D. 2.08) (ii) Runoff (Mean 0.06; S.D. 0.31) and (iii) Baseflow (Mean 0.06; S.D. 1.64) during (A) 1985-1995 and (B) 1995-2005 and (C) 2005-2025 * unit in mm and (D) graphical form

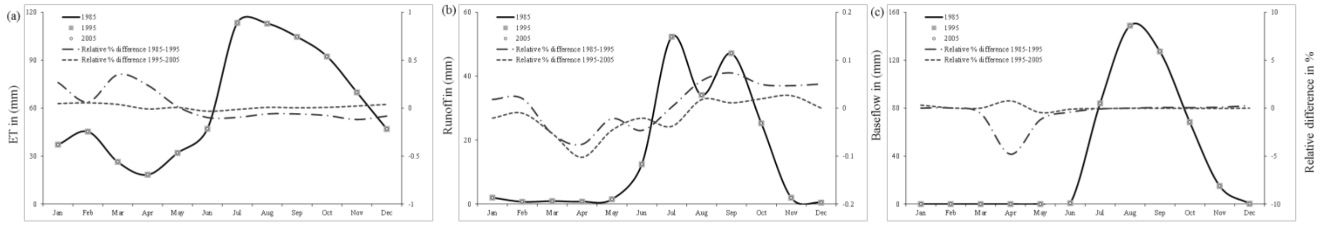

Figure 3. LULCC effect on monthly (a) ET, (b) runoff and (c) baseflow during 1985, 1995 and 2005

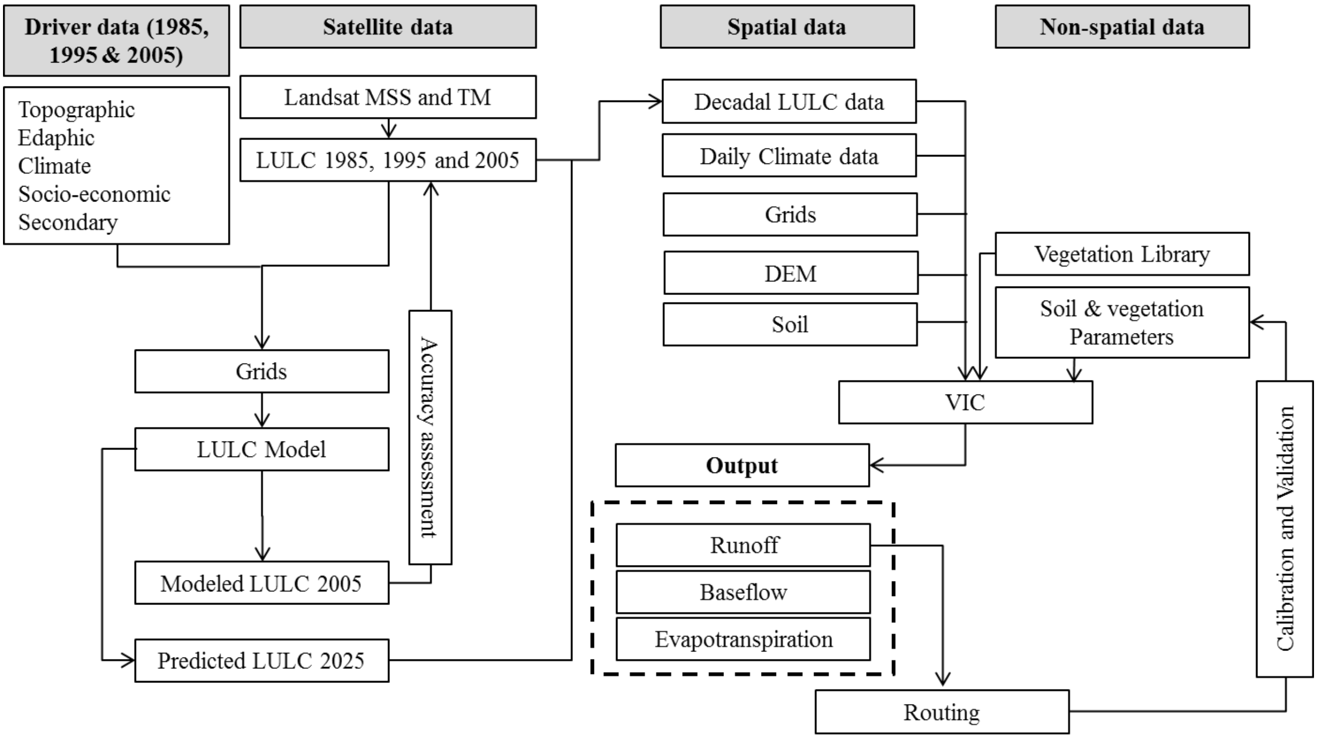

Figure S1. Methodology flowchart

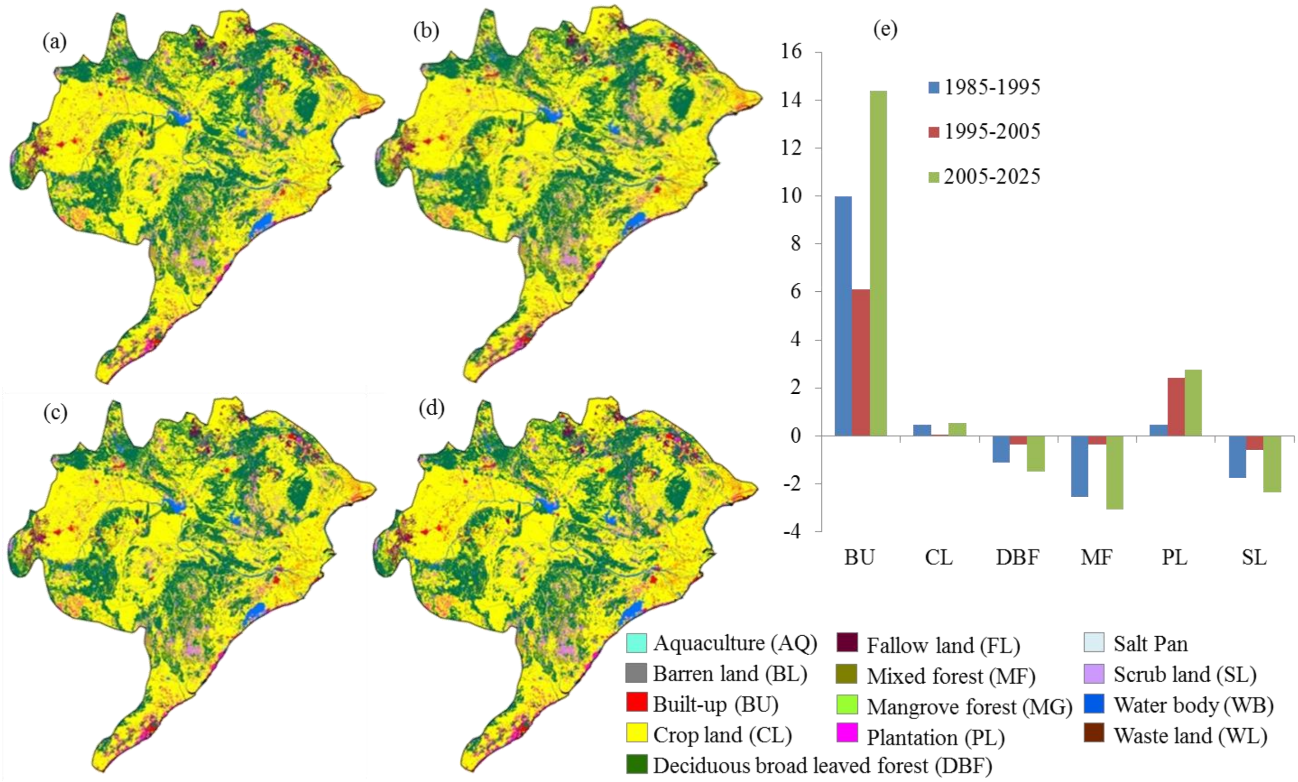

Figure S2. LULC maps of MRB for (a) 1985 (b) 1995 (c) 2005 (d) Predicted 2025 and (e) LULC change area statistics (Adapted from Behera et al., 2017)