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Assessing The Implications of Extension of Rubber Plantation on The Hydrology of Humid Tropical River Basin

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ABSTRACT: The impacts of land cover change on the hydrologic cycle from local to regional scales are not fully understood with regard to humid tropical river basins of Kerala, India. This study provides an approach to identify the effects of land cover changes on streamflowof a river basin in the humid tropical zone of Kerala, India using the Soil and Water Assessment Tool (SWAT).The SWAT model was calibrated and validated for two river gauging stations for a period of 18 years (1987 – 2004).The model performed well for predicting the streamflow in Meenachil river basin under changing landcover conditions. The study carried for temporal variation of the surface runoff and evapotranspiration showed that more water is lost by evapotranspiration from the rubber plantation than that from the mixed crop cultivated landscapes. This supports the popular saying of the local people that rubber plantations act as "water pumps".

Key words: Humid tropics, Meenachil river, Rubber plantation, SWAT2012, Hydrology, Land use change impact

INTRODUCTION

Land use affects land cover and changes in land cover affect land use. A change in either, however, is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply a degradation of the land. However, many shifting land use patterns, driven by a variety of social causes, result in land cover changes that affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere (*Riebsame et al.,* 1994).

One of the challenges in the water management sector is to understand and describe the effects of land cover change and climate change on the streamflow. Hydrologic effects of land coverand climate changes have been thoroughly described by *Calder (*1993). The major changes in land cover that effect hydrology are changes to forest cover, the intensification of agriculture, the drainage of wetlands, road construction and urbanisation. The most consequent influence of land cover on the hydrology of the catchment is manifested by changes in streamflow and evapotranspiration. *Guardiola-Claramonte* et al. (2010) suggest greater annual catchment water losses through evapotranspiration from rubber dominated landscapes compared to the traditional vegetation cover.

Rubber plantation is a tree crop with high water use. Rubber is a tree crop that may have important implications for local to regional scale hydrology because of its high water use for leaf flushing (*Fox et al.,* 2012). Flushing leaves imply that the tree must have access to sufficient reserves of water for the following leaf expansion (*Williams* et al. 2008; *Elliott et al.,* 2006). *Guardiola-Claramonte* et al. (2008) used extensive field observations of root zone soil moisture to show that significant deep root water uptake takes place during the leaf flushing of rubber trees. While leaf shedding reduces transpiration (*Priyadarshan et al.,* 2004), simultaneous root water uptake increases stem water potential that is needed for subsequent leaf flushing. The water is extracted from the soil column, but is not released to the atmosphere until new foliage is grown.

In the present study, hydrological modelling has been integrated with Geographical Information System (GIS) to simulate streamflow in the Meenachil river basin of Kerala, India, where rubber

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plantation has acquired domination in cultivation. The impact of changes in the land cover on the water availability in the basin has been modelled using the Soil and Water Assessment Tool (SWAT)(*Arnold* et al, 1995), which is a river basin or watershed scale model developed by the USDA Agricultural Research Services (ARS).

The Meenachil river basin in Kerala, India is selected for the study. The basin encompasses approximately 1272 km^2 of drainage area, extending from Vagamon in the east at an elevation of 1195 m above the mean sea level to the Vembanad coastal wetland on the southwest coast of India. It lies between 09º26'24" and 09º51'00" N latitude and 76º 22'12" and 76º55'12" E longitude. The mean annual rainfall in the basin is 3510 mm. The rainfall in the basin is mainly confined to south-west monsoon (June – August) and north-east (October – December) period and only 10 percent is available during the summer months (January – May). The major environmental issues in the study area are frequent floods and droughts, high rate of sedimentation and debris flow, salinity intrusion into rivers and ground water aquifers, lack of flushing and concentration of pollutants, especially in the lower stretches of rivers, river bank erosion and land degradation (*James*, 1997, *Vincy et al.*, 2010). The land-water system of the area is adversely affected by the rapid growth of population and changes brought about to the land cover.The water quality of Meenachil river as per CCME (Canadian Council of Ministers of the Environment) water quality index is poor (Report of Environmental Monitoring Programme on Water Quality, 2010). There are no storage reservoirs in the basin and therefore, there is shortage of water for drinking, industrial purposes and also growing food crops in the downstream reaches of the basin. The drinking water supply to urban areas in and around Kottayam town depends on the river flows. Suitable locations are not available for water impoundment. The available land and water resources are to be effectively utilized to improve the livelihood and socio-economic conditions of the people living in the basin.

The need for hydrological investigations in the Meenachil river basin has been recognized with an aim to suggest improved basin management programmes for the conservation of soil and water resources. The lack of understanding of hydrological processes and non availability of decision support tools for application in the area significantly hindered the planning activities in the area.

Fig. 1 shows the drainage map of the Meenachil river basin with the locations of raingauge and streamflow stations. The streamflow data of Peroorand Cheripad stations have been used in the present study; the areas of the sub-basins covered by these stations are 768 and 147 km^2 respectively.Physiographically, Kerala State is having a unique topography with highland (areas with altitude > 76m), midland (areas with altitude > 7.6 m and < 76m) and lowland (areas with altitude < 7.6m) areas. Almost all the river basins, except three, starts from the Western ghats (highland area) in the eastern part and flows towards west and drains to the lowland area. In between the highland and lowland lies the midland. Meenachil river basin starts from the highland and flows through the midland and lowland regions and finally drains to Vembanad lake. The present study area Cheripad lies in the highland and Peroor lies in the midland regions.

MATERIALS & METHODS

The study presents the application of SWAT2012model for the Meenachil river basin to examine the influence of land coverchange on the water balance components. SWAT represents the hydrologic cycle based on the general water balance equation (SWAT Theoretical Documentation v2005). Among the process-based (semi-)distributed models, SWAT is often used for modelling the impacts of land management practices on the hydrological cycle in large and complex watersheds (*Jayakrishnan et al.*, 2005; *Mulungu and Munishi*, 2007; *Setegn et al.*, 2008; *Mekonnen et al.*, 2009; *Githui et al.*, 2009; *Tibebe and Bewket*, 2010; *Kingston and Taylor*, 2010; *White et al.*, 2011). This model requires data on terrain, land use, soil, weather and man-made structures like reservoirs for assessment of water resources availability at the desired locations of the drainage basin. The interface used for the model application is ArcGIS 10. Thematic map layers for terrain, land use, soil and climatic information on the river basin are to be prepared prior to the execution of SWAT model.

The Survey of India (Government of India) topographic sheets (58C/9, 58C/10, 58C/13 and 58C/14) on a scale of 1:50,000 for the study area have been taken as the base map. The contours were digitised from these topographic sheets for the preparation of DEM, which are used for automatic watershed delineation in SWAT.

Land cover maps were prepared from the satellite images taken from different sources. Land cover maps for the year 1973 and 1990 were prepared from the Landsat imageries downloaded from the USGS web site (http://landsat.usgs.gov). Land cover maps for the year 1999, 2005 and 2009 were prepared from the IRS satellite images procured from the National

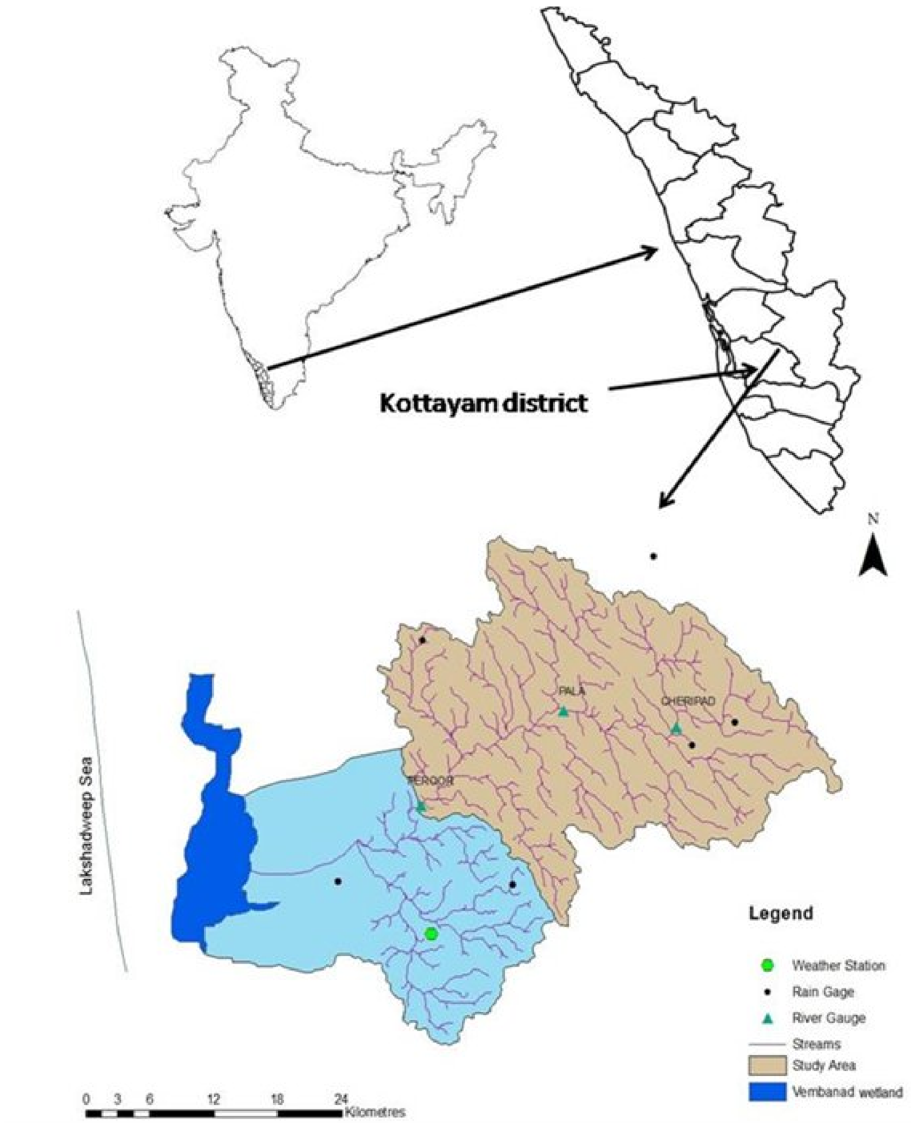

Fig. 1. Drainage map of Meenachil river basin

Remote Sensing Centre, Hyderabad of Indian Space Research Organisation.

The land cover of 1967 was mapped, classified and calculated accurately from the topographic sheets of Survey of India and it was compared with those prepared from satellite images. All the satellite images were first geo-referenced with the map of 1967 prepared from the topographic sheets. Visual interpretation method was adopted to prepare the land cover maps from satellite images. Ground observation of land cover was made at several places and the map for the year 2009 revised accordingly. Certain corrections were also made for land cover of other years based on the survey carried out in representative areas. Land cover maps were then converted to grid files in ArcGIS 10 to use with SWAT.

Land cover change observed from the land cover maps are tabulated in Table 1. Since the images obtained for different years were of different resolution the area delineated for different land uses varies to some extent. It is observed that there are some minor discrepancies with regard to the area under rocks identified using Landsat and IRS sources. The trend with regard to area under plantations, crops and water bodies has been verified using ground truth and other available sources of information.As there is an increasing trend in the rubber plantation area and a decreasing trend in the mixed crop area, land use update files has been created considering the variation between the available year-span. Since the gap from 1973 to 1990 is high to properly interpolate the land cover variation, simulation of the model was done for the period 1990 to 2004. The land cover map for the year 1990 (Fig. 2) was used with the SWAT model. The SWAT land cover was appropriately selected from the inbuilt SWAT database for each land cover in the map and reclassified. SWAT allows a maximum of ten files for updating the land use. A spatial linear interpolation was applied for updating the land use. Table 2 gives the percentage area variation made on creating the land use update file. Seven land use update files were created.

Soil data and soil map required for the SWAT model were collected from the Soil Survey Organisation of Kerala State. The soil map was digitized and converted to grid file using ArcGIS 10 for using in the model. The major soils of the study area are Muthur, Arpookara, Kooropada, Lakkattoor, Koduman, Nellappara and Mavady series (Fig.3), the details of which are given in Table 3. The texture

Table 1. Land cover change detection in Meenachil river basin

	Area in percentage for the years			
Land Cover	1990	1999	2005	2009
Grass	2.83	2.87	2.18	2.71
Rock	2.90	2.38	2.06	2.58
Rubber Plantation	27.81	46.89	64.18	85.95
Tea Plantation	3.33	3.15	1.63	0.04
Mixed Crop	52.47	32.34	16.62	0.27
Cleared Area	2.71	4.24	3.56	2.43
Paddy Field	5.82	5.65	4.66	2.13
Builtup Area	1.60	2.00	4.69	3.42
Water Bodies	0.53	0.48	0.42	0.47

Table 2. Year wise percentage area conversion

Year	percentage mixed crop area converted to rubber plantation
1992	5
1994	10
1996	15
1998	20
2000	26
2002	32
2004	38

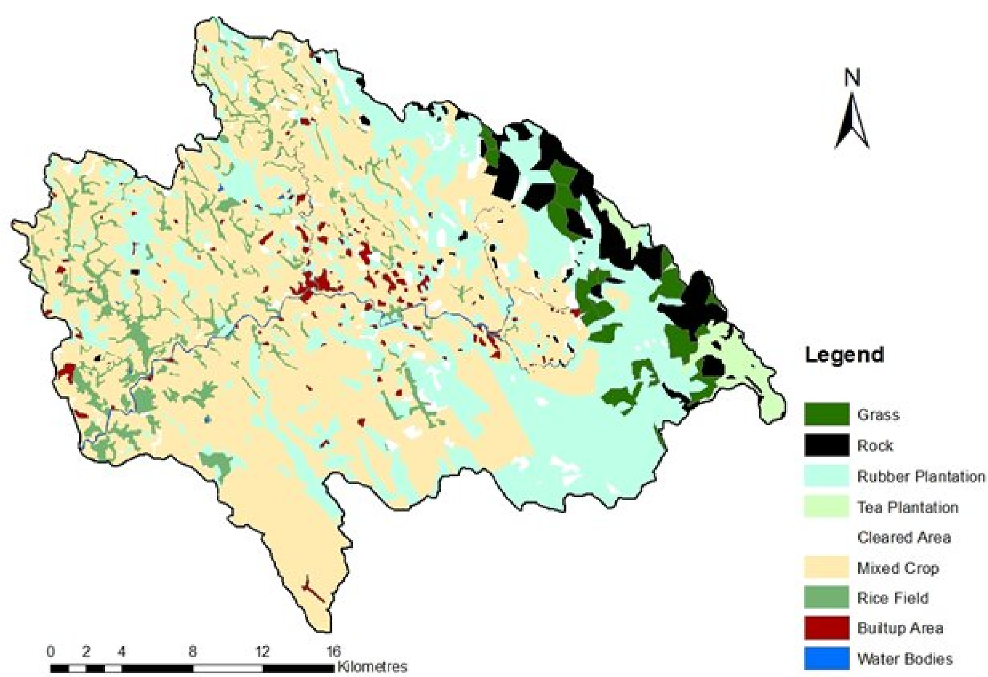

Fig. 2. Land covermap ofMeenachil river basin – 1990

Table 3. Details of major soils of Meenachil river basin

Major Soils	Drainage type	Texture
Muthur	Very deep, Imperfectly drained, hydromorphic soils	Silty clay to clay texture
Arpookara	Very deep, well drained laterite soils	Gravelly clay loam to gravelly clay
Kooropada	Deep, well drained soils underlain by hard laterite	Gravelly clay loam
Lakkattoor	Very deep, well drained soils developed from gneissic rocks	Gravelly loam to gravelly clay loam
Koduman	Very deep, well drained hill soils developed from gneissic material	Sandy clay loam to gravelly clay texture
Nellappara	Moderately deep to deep, well drained soils developed from gneissic rocks	Sandy clay loam to clay loam

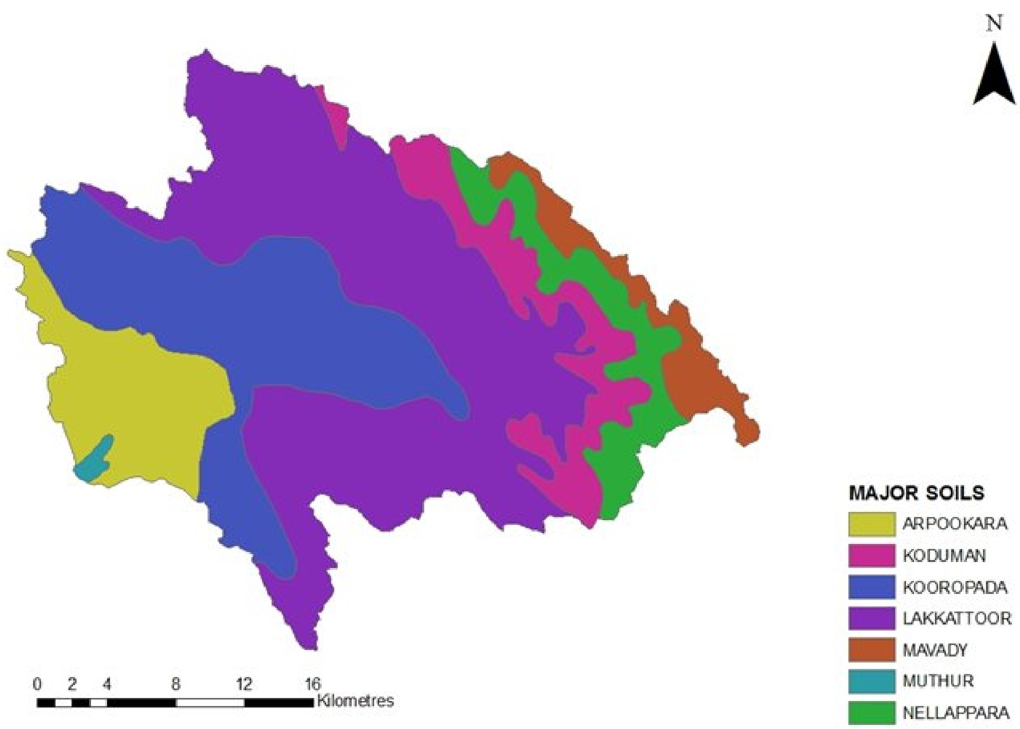

Fig. 3. Major soils of Meenachil river basin

classification is done on USDA classification system based on grain size. The soil hydraulic properties required to run SWAT were computed using the 'Soil Hydraulic Properties Calculator Work Table (U.S.) / ' from the web site www.pedosphere.ca/resources/texture.

The required climate data are precipitation, maximum and minimum air temperature, wind speed, relative humidity and solar radiation. Daily rainfall data from four raingauge stations – Erattupetta, Teekoy estate, Kozha and Kottayam (Fig 1) – were used for the model simulations. Rainfall data for each sub basin is taken from the nearest gauging station. For other climatic parameters, namely, maximum and minimum temperatures, relative humidity, wind speed and solar radiation, daily data from Rubber Research Institute (RRI) Puthupally station were used. The observed data were available for 30 years (1979-2008).

Daily streamflow data from Peroor and Cheripad were collected from the Hydrology Division of the Water Resources Department of Kerala State. These data are available for a period of 26 years (1979-2004). For modelling purpose, the longer the time period selected for simulation and the more high quality measured data that are available as input for both calibration and validation periods, the more reliable are the simulations. In addition, simulations of data averaged over longer time periods, such as annual or monthly mean streamflows, are more reliable than simulations of daily data (*Santhi et al.*, 2001; *Green et al.*, 2006). Here in this study the main focus is to find out the seasonal effects of rubber plantation on streamflow and hence for modelling purpose monthly average values were used.Monthly average values were computed from the observed daily data for the calibration and validation of SWAT model.

DEM generated for the study area was input for the automatic watershed delineation in SWAT. The entire study area was delineated to 17 sub basins, by the SWAT software. Landcover map prepared for the year 1990 and the soil map for the river basin were then loaded to SWAT for the HRU (hydrologic response units) creation. A total of 234 HRUs were created. For the next step the climate data were loaded and the input files written by SWAT for further execution. To incorporate the dynamic changes in land use of the study area, the land use update files were added in the model. The SWAT model was then used for simulation for a period of 14 years from 1987 to 2000, with 1987 - 1989 taken as warm-up period, in which the model was allowed to initialise and then approach reasonable starting values for model state variables. The simulated monthly streamflow values from the two points, Peroor and Cheripad, were compared with the observed values to evaluate the model performance.

Santhi et al., (2001) and *Coffey et al.*, (2004) recommended using the correlation coefficient (R^2) together with the Nash-Sutcliffe model efficiency coefficient (N_{SE}) (*Nash and Sutcliffe*, 1970) as a method to evaluate and analyse simulated monthly data. The R^2value is a measure of the strength of the linear correlation between the predicted and observed values. The N_{SE} value, which is a measure of the predictive power of the model, is defined as :

$$N_{SE} = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} (Q_o^t - \overline{Q_o})^2} \qquad (2)$$

where,
N_{SE}= Nash-Sutcliffe coefficient,
Q_o= observed discharge,
Q_m= modeled discharge,
$\overline{Q_o}$= mean observed discharge,
Q_t= discharge at time t.

A value of 1 for N_{SE} indicates a perfect match between simulated and observed data values. A value of 1 for the R^2 also indicates a perfect linear correlation between simulated and observed data values.

In order to avoid certain problems associated with R^2an index of agreement (*d*) (*Willmott*, 1982), is presented (equation 3). This statistic reflects the degree to which the observed variable is accurately estimated by the predicted variable. *d* is not a measure of correlation in the formal sense but rather a measure of the degree to which a model's predictions are error free. It varies between 0 (complete disagreement between predicted and observed values) and 1 (perfect agreement). It is a dimensionless statistics and its value should be evaluated based on (a) the phenomenon studied, (b) measurement accuracy and (c) the model employed.

$$d = 1 - \frac{\sum_{t=1}^{T} (Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T} \left(\left|Q_m^t - \overline{Q_o}\right| + \left|Q_o^t - \overline{Q_o}\right|\right)^2} \qquad (3)$$

Moriasi et al.(2007) suggested a general performance ratings for recommended statistics for a monthly time step (Table 4).

In the above table the N_{SE} given is the Nash-Sutcliffe model efficiency coefficient and it is computed as per equation 2. RSR is the (root mean square error) RMSE-observations standard deviation ratio. RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation 4.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]} \quad (4)$$

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. PBIAS is calculated with equation 5 :

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)*(100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right] \quad (5)$$

where

PBIAS is the deviation of data being evaluated, expressed as a percentage

Y_i^{obs} is the observed value, Y_i^{sim} is the simulated value and $Y^{mean}$is the mean of observed values.

Guidance for identifying input parameters for manual calibration provided by *Feyereisen et al.*, (2007) based on the study conducted by *Van Liew et al.*, (2007) has been followed in this study for manually calibrating the streamflow from the two gauging sites in the Meenachil river basin. The model was calibrated with SWAT 2012 starting from the upstream gauging station Cheripad. Looking to the uncalibrated model result, the two parameters,baseflow recession constant (alpha_bf) and groundwater "revap" coefficient (gw_revap), were adjusted for the entire area. Thereafter, the model was calibrated for the observed streamflow values for Peroor gauging station after adjusting the parameter, deep aquifer percolation fraction (rchrg_dp). Since the river basin lies in the highland and midland regions, the rchrg_dp for midland region was varied to arrive at best value for predicting accurate streamflow. Table 5 gives the final fitted parameter valuesfor Meenachil river basin.

Comparison between the observed and calibrated streamflow values for eleven years of simulation indicated that there is a good agreement between the observed and simulated streamflows with higher values of Nash-Sutcliffe efficiency and lower values of *RSR*, as rated by Table 4. The calibrated model

Table 4. Performance Ratings of Recommended Statistics for Monthly Time Step for Streamflow

Performance Rating	RSR	N_{SE}	PBIAS (%) Streamflow
Very good	0.00 ≤ RSR ≤ 0.50	0.75 NSE ≤ 1.00	PBIAS < ±10
Good	0.50 < RSR ≤ 0.60	0.65 NSE ≤ 0.75	±10 ≤ PBIAS < ±15
Satisfactory	0.60 < RSR ≤ 0.70	0.50 NSE ≤ 0.65	±15 ≤ PBIAS < ±25
Unsatisfactory	RSR > 0.70	NSE 0.50	PBIAS ≥ ±25

Table 5. SWAT adjusted flow parameters and fitted values after calibration

No.	Sensitive Parameters	Lower and Upper Bound	Final Fitted Value	Parameter description
1	alpha_bf 0- 1	0.80		Baseflow alpha factor (days)
2	gw-revap	0.02 -0.20.19		Ground water revap coefficient
3	rchrg_dp	0.0 – 1.00.98		Deep aquifer percolation fraction (For subbasins in midland region)

predictive performance statistics for the two streamflow sites on monthly streamflows are summarized in Table 6. The calibrated model was then validated for the period from 2001 to 2004. The simulation indicates a good agreement. Table 7 gives the performance statistics for the validation period. Figs.4and5give the time series of observed and simulated monthly streamflows at Cheripad and Peroor stations respectively, for the entire period (1990-2004). The peak flows are underestimated by the model. However as per the statistics (Table 4) the SWAT model is rated very good for Meenachil river basin in predicting the monthly flow values.

The calibrated model was then executed without the land use update files to see the changes in water balance components. The results from the two different executions of the SWAT model ie., with the land use change and without the land use change, were compared and plotted for surface runoff, evapotranspiration and total water yield. Temporal variation of surface runoff (fig. 6) and water yield (fig. 8) shows a conspicuous decreasing trend whereas evapotranspiration shows a conspicuous increasing trend (fig. 7). Analysing the spatial variations in each sub basin, it is found that a 50% increase in area under rubber plantation can reduce water yield by 9.6%, surface runoff by 12.8% and increase evapotranspiration by 3.3% in the Meenachil river basin.

Table 6. Model performance statistics (1990-2000)

Station	NSE	R^2	RSR	d	PBIAS(%)
Cheripad	0.87	0.89	0.36	0.96	-1.40
Peroor	0.83	0.87	0.42	0.94	-2.80

Table 7. Model performance statistics (2001-2004)

Station	NSE	R2	RSR	d	PBIAS(%)
Cheripad	0.79	0.84	0.46	0.92	1.90
Peroor	0.71	0.76	0.49	0.89	-9.10

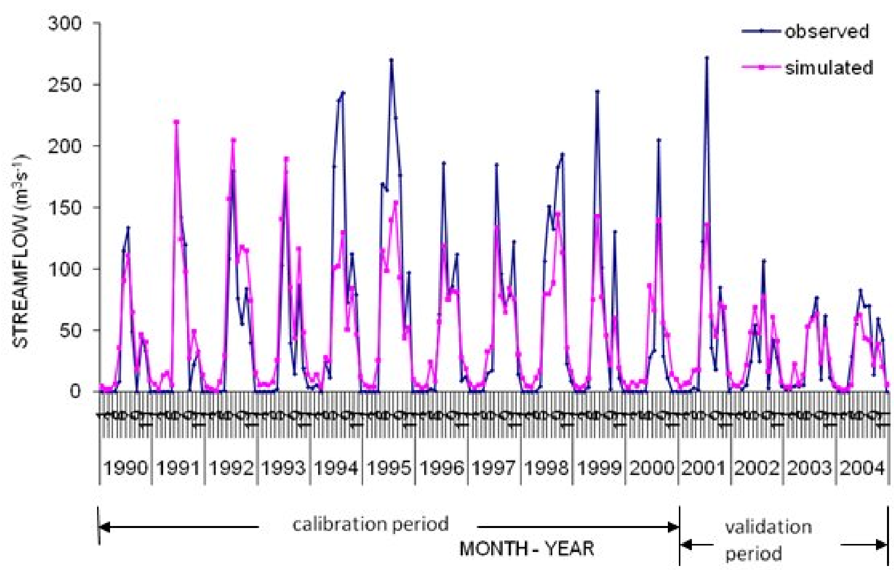

Fig. 4. Observed and simulated streamflow at Peroor

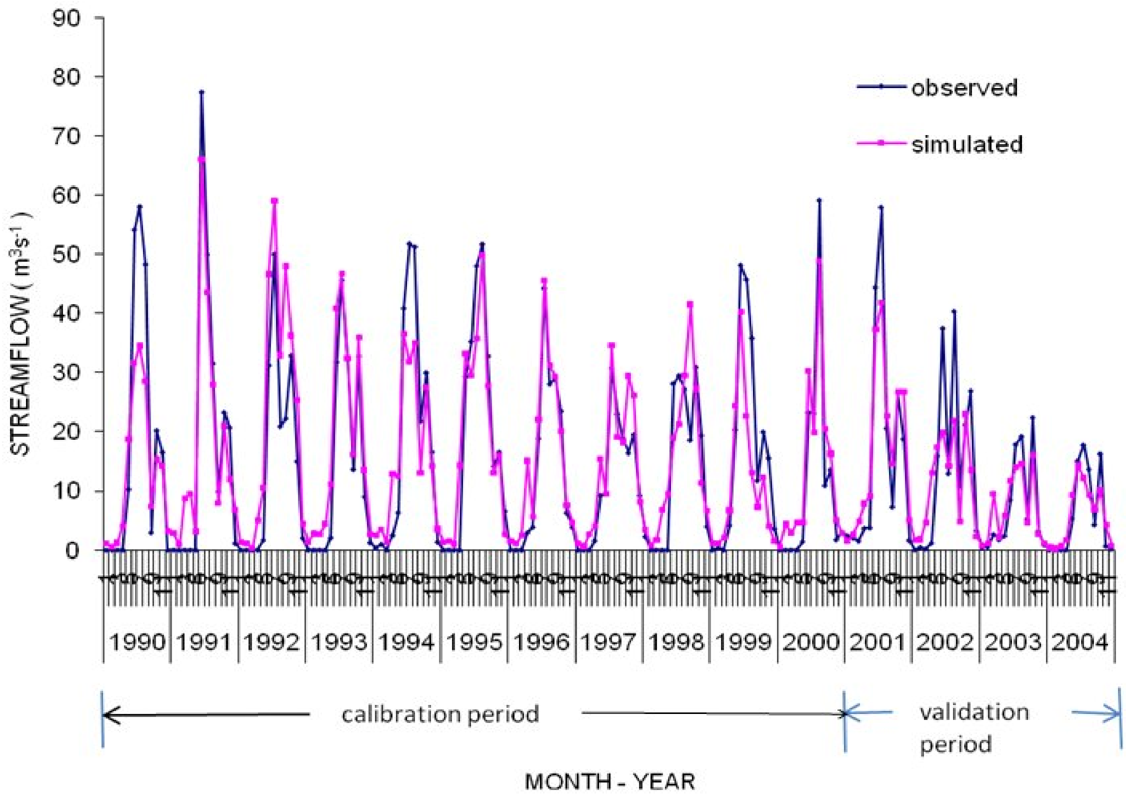

Fig. 5. Observed and simulated streamflow at Cheripad

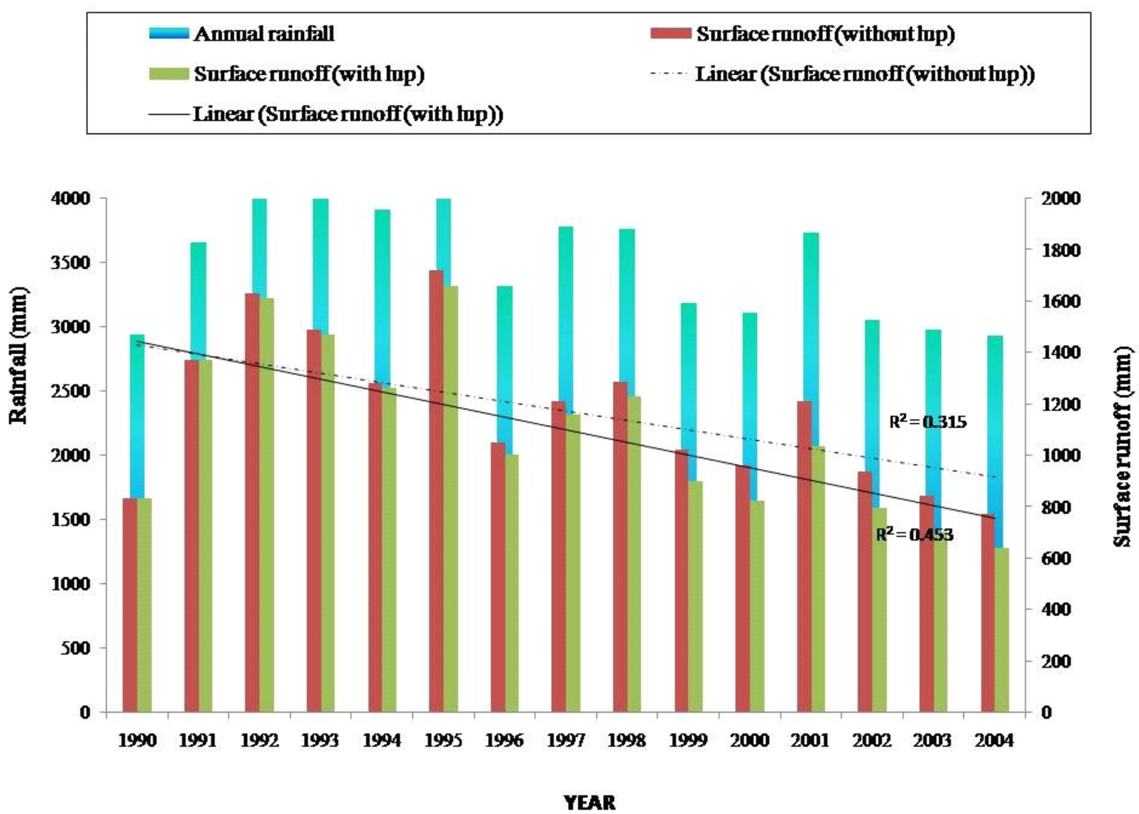

Fig. 6. Temporal variation of surface runoff

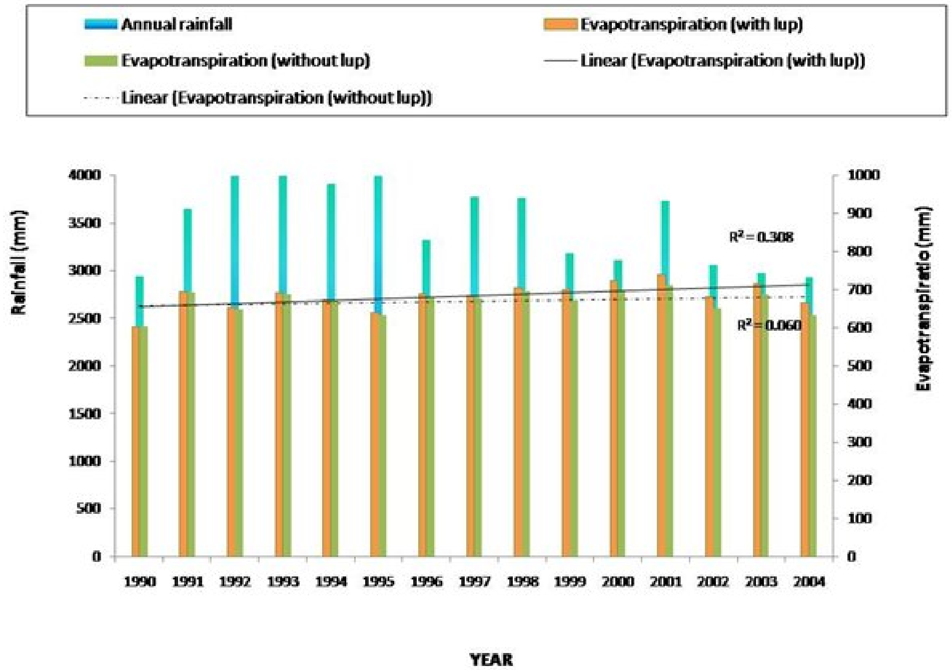

Fig. 7. Temporal variation of evapotranspiration

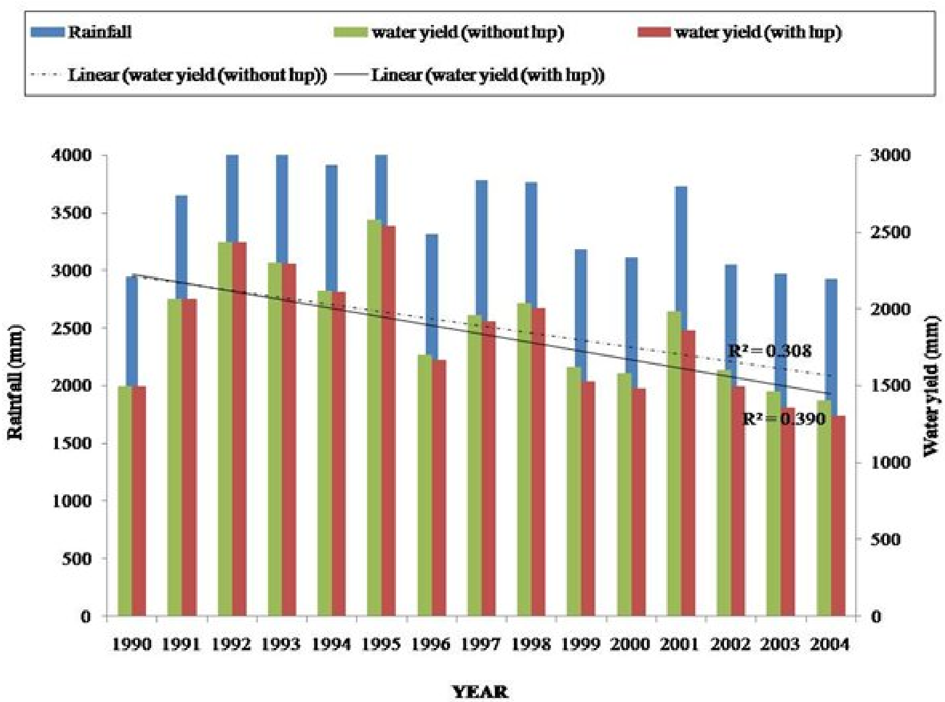

Fig. 8. Temporal variation of water yield

CONCLUSIONS

SWAT 2012 has been applied to assess the impact of land cover changes on the streamflow in the Meenachil river basin of Kerala, India, which lies in the humid tropical zone. The study implies that the SWAT modelis applicable for the Meenachil river basin. As the percentage area under rubber plantation increases, the surface runoff decreases in the river basin. More water is lost by evapotranspiration from the rubber plantation than from the mixed crop cultivated area.

It can be concluded that:

- The SWAT model helped in understanding the modifications to the hydrologic characteristics of Meenachil river basin due to land use changes.

- A 50% increase in area under rubber plantation reduce water yield by 9.6%, surface runoff by 12.8% and increase evapotranspiration by 3.3%.

- The following mixed crop pattern with locally adopted crops is suggested for the study area situated in the wet humid tropic zone of Kerala :

  - Upper canopy layer : tree crops such as coconut or arecanut
  - Mid canopy layer : coffee, nutmeg, cloves or cocoa
  - Lower layer : pineapple and tubers like tapioca, turmeric, ginger or fodder grass

The suggested mixed cropping system has the advantage of efficient use of sunlight and also appropriate utilisation of soil moisture and nutrients from different layers of soil. This suggestion is based on the recommendations of Central Plantation Crops Research Institute, Kerala (1979).

- The results of study are expected to help in future developmental planning within the river basin and similar other basins in the thickly populated Kerala State situated on south-west India, and coming under the humid tropical zone.

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